Designing Biodiversity Into Flat Solar Systems

A developed solution for biodiversity challenges integrated into Sunbeam products

Graduation report

This report presents research and the design process of Beau Dessens' master thesis, developed at TU Delft in collaboration with Sunbeam.

Master thesis Integrated Product Design
July 2025
By Beau Dessens

A developed solution for biodiversity challenges integrated into Sunbeam products

Master thesis Integrated Product Design

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Abstract

As rooftop solar deployment keeps accelerating in the Netherlands, a new question arises: Can these functional rooftop surfaces also contribute to restoring and supporting local biodiversity, especially in a context of persistent agricultural pollution, and increasingly limited available space? This thesis explores how the solar mounting systems of Sunbeam, a Dutch solar mounting system manufacturer based in Amersfoort, can play a role in this dual-purpose challenge.

The report begins with a breakdown of market opportunities for biodiversity integration within Sunbeam's product range (Section A). This is followed by a deeper exploration of relevant biodiversity needs and species groups (Section B), identifying where ecological priorities align with rooftop types and technical realities. By combining these insights, the research narrows down a landscape of possibilities to identify the most viable, feasible, and desirable opportunities for intervention.

Through various design methods, prototyping and expert consulting, this thesis builds and evaluates conceptual directions for biodiversity-supportive solar infrastructure. The outcomes demonstrate the potential of rooftops as both energy producers and ecological stepping stones when product context, ecological function, and user needs are effectively combined into a mutualistic bond.

Results are presented in Section E, presenting the final product within its potential habitats. This section demonstrates how modular adaptability enables successful deployment across diverse environments, achieving targeted biodiversity enhancements while accounting for site-specific constraints and opportunities.

Abbreviations

PV = Photovoltaic. Refers to solar panel technology, or solar panels in general.

ABP = Additional Biodiversity Product. A supplementary feature that could be integrated into the Sunbeam structure to enhance its ecological value.

Contents

Introduction

This report has been prepared as part of the graduation project of Beau Dessens. It focuses on identifying strategic areas where biodiversity restoration can be integrated into Sunbeam products while fulfilling stakeholder needs. The project focuses on creating solutions that support both ecological and economic sustainability. The further project brief can be found in Appendix A.

With this central vision in mind, many of the insights gained throughout this process extend beyond the scope of Sunbeams' product development framework. They may also contribute to the broader dialogue on integrating biodiversity and/or the solar industry within the broader market context.

In the context of climate and biodiversity crises, the urban rooftop is no longer just an unused space; it is a design opportunity. Across the Netherlands, solar panels are being rapidly deployed on both residential and industrial rooftops to meet national climate goals. However, this movement often overlooks a critical question: can solar infrastructure also contribute to ecological regeneration?

This thesis focuses on exploring opportunities for biodiversity-positive solar mounting systems. The project was carried out in collaboration with Sunbeam, a Dutch company based in Amersfoort that manufactures mounting systems for rooftop PV installations. Sunbeam operates in various rooftop contexts, offering unique constraints and ecological possibilities.

Previous research has extensively examined rooftop solar's technical and economic performance, but relatively little attention has been paid to its potential dual function as ecological infrastructure.

However, growing regulatory pressure, such as species protection laws and EU regulations, signals an emerging niche. This project investigates how Sunbeam can respond to this shift through product innovation and understanding stakeholder needs and spatial typologies.

General Structure

Section A explores the current product offerings, stakeholder landscape, and market context.

Section B identifies pain points and current building solutions for biodiversity.

Section C focuses on identifying and comparing a variety of opportunities and analysing their technical feasibility, viability and desirability.

Section D dives into the final chosen opportunity and the development of the linked concept.

Section E presents the final product, including visualisations of the product in its surroundings and applicability, while indicating its unique selling points.

For a better general overview and to create a visual hierarchy in this report, various font styles have been used, which are described below.

As seen here, key takeaways and advised design directions are indicated by vertical-coloured lines in bold font. These guiding principles form the foundation for developing the final optimised product.

Additional background information and/or argumentation, coming from literature research, expert interviews and/or design methodology is indicated with this light-coloured italic text to create a visual hierarchy.

Design requirements are indicated with a light cursive font, as they will be annotated in various places in the report, and this way, they can be easily identified.

Further quotes or paraphrasing from experts are illustrated in a slightly larger cursive font.

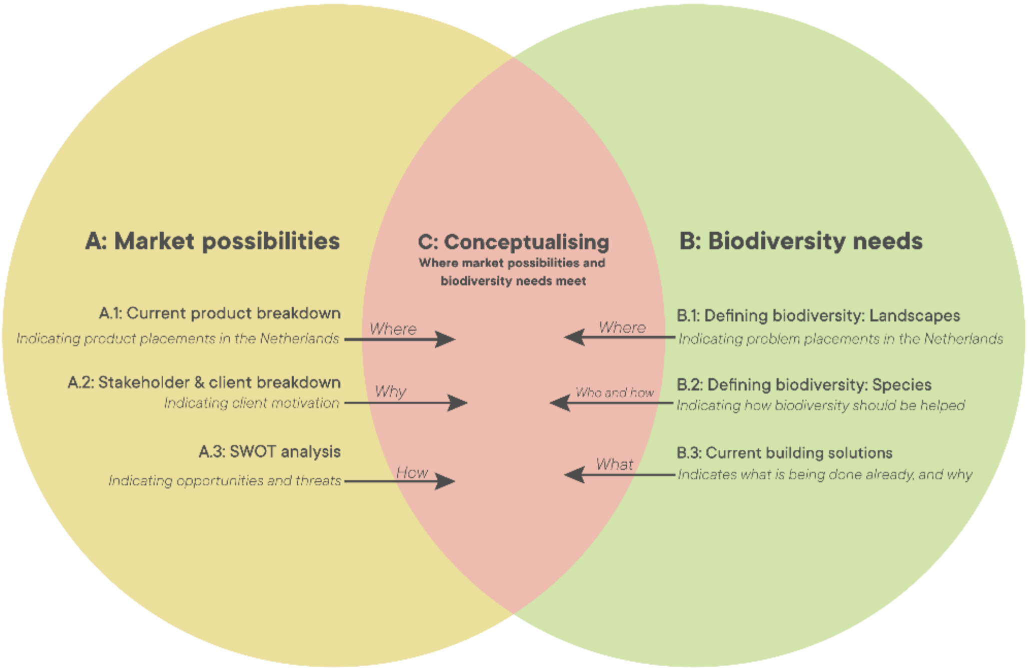


Figure I.1: Venn diagram of Section A and B, mapping the research methodology

Section A and Section B together form the research section of this report.

While methods like "How Might We" (*Van Boeijen et al., 2014)* are often used in early design phases to generate open-ended ideas, the research in Section A and Section B create a clear view on what are interesting further interesting points to combine the field of green and energy roofs. This gives us a clear starting point for designing this emerging combination. The conceptualisation phase began early in the project, with initial ideas taking shape during and just after this research phase.

The first two sections provide answers to a variety of questions, shortly illustrated below.

Where is potential impact given? Chapter A.1 indicates the landscapes Sunbeam products can be found in, and B.1 indicates what landscapes in the Netherlands have what type of biodiversity problems.

What is desired by potential stakeholders, and why? Chapter A.2 gives an answer to what motivations of clients could be and how the final client can be reached, and B.3 gives current market solutions to create biodiverse building solutions.

How should this problem be tackled, and for whom? A.3 gives the opportunities coming from Sunbeams' core strengths and weaknesses, and B.2 gives a list of potential species that could be helped in the earlier indicated places. B.3 combines these knowledges eventually in its key takeaway.

Section C, **Section D** and **Section E** together form the total design process of the final product.

These insights from the research are combined to see how a potential ABP can be applied best to Sunbeams' current product in further conceptualisation and development. More specific opportunities get identified through various design methods in **section C**, and the initial best concept gets further developed in **section D**, eventually leading to the final product shown in **section E.** This total process could be viewed as a triple diamond, with continually converging and diverging steps. These methods were adapted to combine contextual, ecological, and technical variables and to highlight where the most promising biodiversity gains could be achieved. It gives us answers to a variety of questions on how to implement a potential ABP with the most effect.

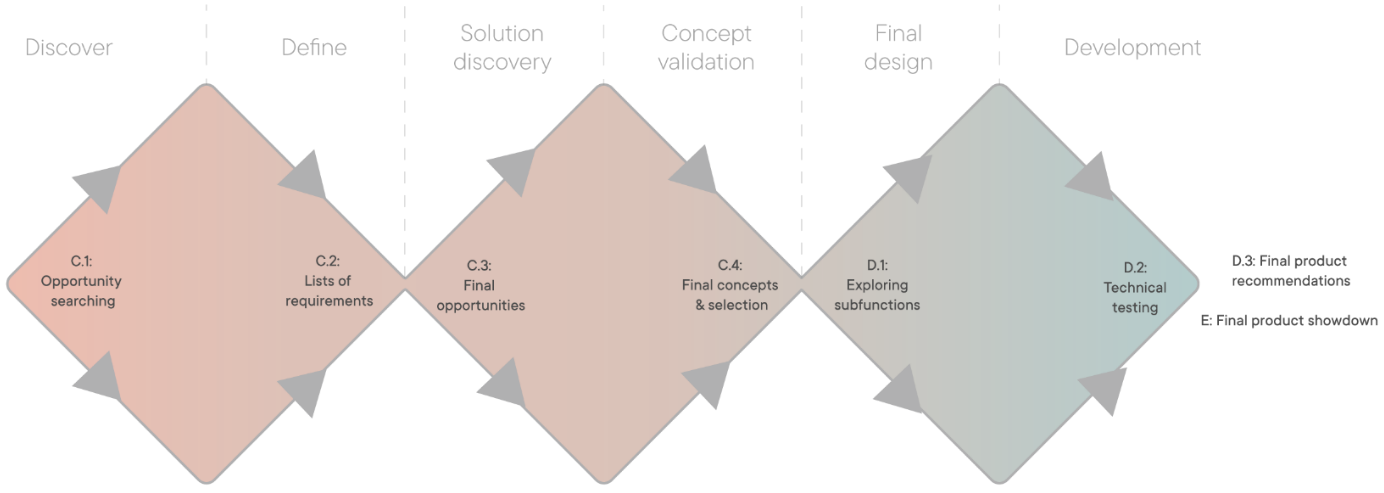


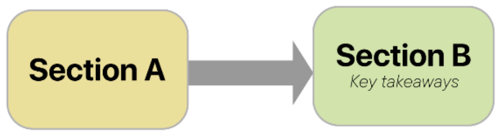
Figure I.2: Triple diamond figure (Moradi, 2023), mapping the design process in Section C, D and E

Suggested reading order: Research

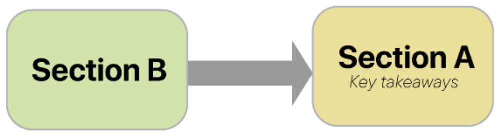
Given this report's interdisciplinary nature and potential readers' diverse backgrounds, a linear, cover-to-cover reading is not necessarily recommended. Some sections may not be relevant to every reader's expertise or interest. To support a more effective and understanding reading experience, a reading guide is provided below, suggesting an optimal order based on the specific background and interests of the reader.

For Section A and Section B, the reader should start with the section that he/she is less familiar with. For ecologists, it is wise to start reading Section A so that a clear image of the solar industry is set. However, people working in the solar energy sector should start with Section B: Biodiversity needs. After, the most important key findings in the familiar section should still be scanned over so that the reader still understands how these fields are exactly coming together.

Reading order ecological background

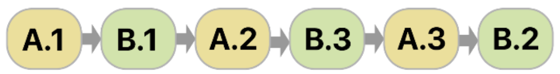


Reading order solar energy background



Finally, an intertwined reading approach is recommended for readers new to both fields. This involves beginning with Chapter A.1, then moving to B.1, followed by A.2, B.3, and concluding with A.3 and B.2. This alternating structure helps to draw clearer connections between the two domains, making the key insights and proposed design directions more accessible and easier to grasp.

General reading order

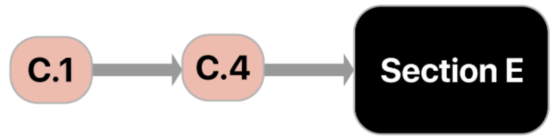


Suggested reading order: Design process

Regarding the sections about the design, it depends on how deep and how technical the reader wants to dive into the design process.

If the reader is mainly interested in the final result and its potential impact, the reader can scan through C.1 and C.4 to get a general understanding of what direction is chosen, and then look at the final product showcase illustrated in **Section E**.

Reading order to understand impact

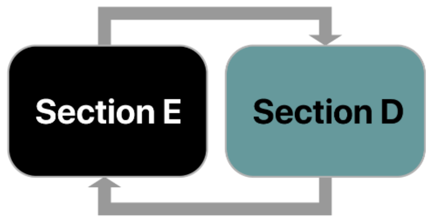


If the reader (generally designers) is interested in seeing the whole design process, Section C, Section D and **Section E** can be read by following the standard page numbering of this report.

Complete reading order design phases

If the reader is interested in the final product and technical validation of this product, **Section E** can be scanned first to get a general understanding of the product's vision, then Section D can be explored wherever interested, while coupling these insights back to **Section E.**

Technical reading order



Section A: Market possibilities

Sunbeam is a solar mounting systems supplier located in Amersfoort, the Netherlands. It is currently on the market with three different products, which will be briefly introduced below.

This section is the first of two to explore how Sunbeam can best contribute to restoring and sustaining biodiversity in the Netherlands. Identifying these opportunities depends not only on the purpose of the new ABP itself, but also on client demands, stakeholder involvement, and Sunbeam's current market position.

A.1: Current product breakdown
This chapter looks into Sunbeam's current products and where they are (potentially) located.

A.2: Stakeholder & client breakdown
Various stakeholders are involved when a product is implemented into Sunbeam's systems. Limitations or opportunities might occur when still trying to keep all the stakeholders' needs intact.

A.3 SWOT analysis
To solidify the clarity of the market position of Sunbeam, a SWOT analysis is done, summarising opportunities and threats for Sunbeam to implement in future biodiversity products.

SWOT is an acronym for Strengths and Weaknesses, representing internal factors of the company, and Opportunities and Threats, representing external factors (Van Boeijen et al., 2014, p.73).

Sunbeam's stance at the Solar Solutions fair, 2023

A.1: Current product breakdown

This chapter begins with a brief overview of Sunbeam's product portfolio, followed by an analysis of where these products are typically applied. This serves as a starting point for understanding Sunbeam's potential impact and the added value it could offer for biodiversity.

Product portfolio

Sunbeams' portfolio consists of three products: **Supra**, **Nova**, and **Luna**.

The Nova and Supra systems, developed for flat rooftops, allow different panel orientations to suit various needs. Since the best efficiency is typically reached at a 12-13° tilt, Sunbeam offers the option to position panels facing south (to capture the most sunlight throughout the day) or in an east-west orientation, as seen in the images on this page.

The east-west orientation is commonly used in larger solar fields because it helps spread energy production and avoid sharp peaks during the brightest hours. This approach gives the client more flexibility in how and where the frames can be installed.

All systems on this page display the solar panels in a landscape orientation. All Sunbeam systems can also be installed in portrait mode. Choosing portrait orientation can be beneficial when working with narrower roof spaces, optimising wind resistance, or maximising the number of rows on a given surface.

Placement of products

As shown below in the left diagram of Figure A.1.1, most solar energy produced using Sunbeam products comes from the Nova[1] system, which accounts for 90% of the total output. This is mainly due to Nova has been on the market the longest.

As expected in future instalments by Sunbeam in 2025, their outputs will become more diversified, as seen in the right diagram. The Supra and Nova Systems are illustrated in Figure A.1.1 in a south orientation.

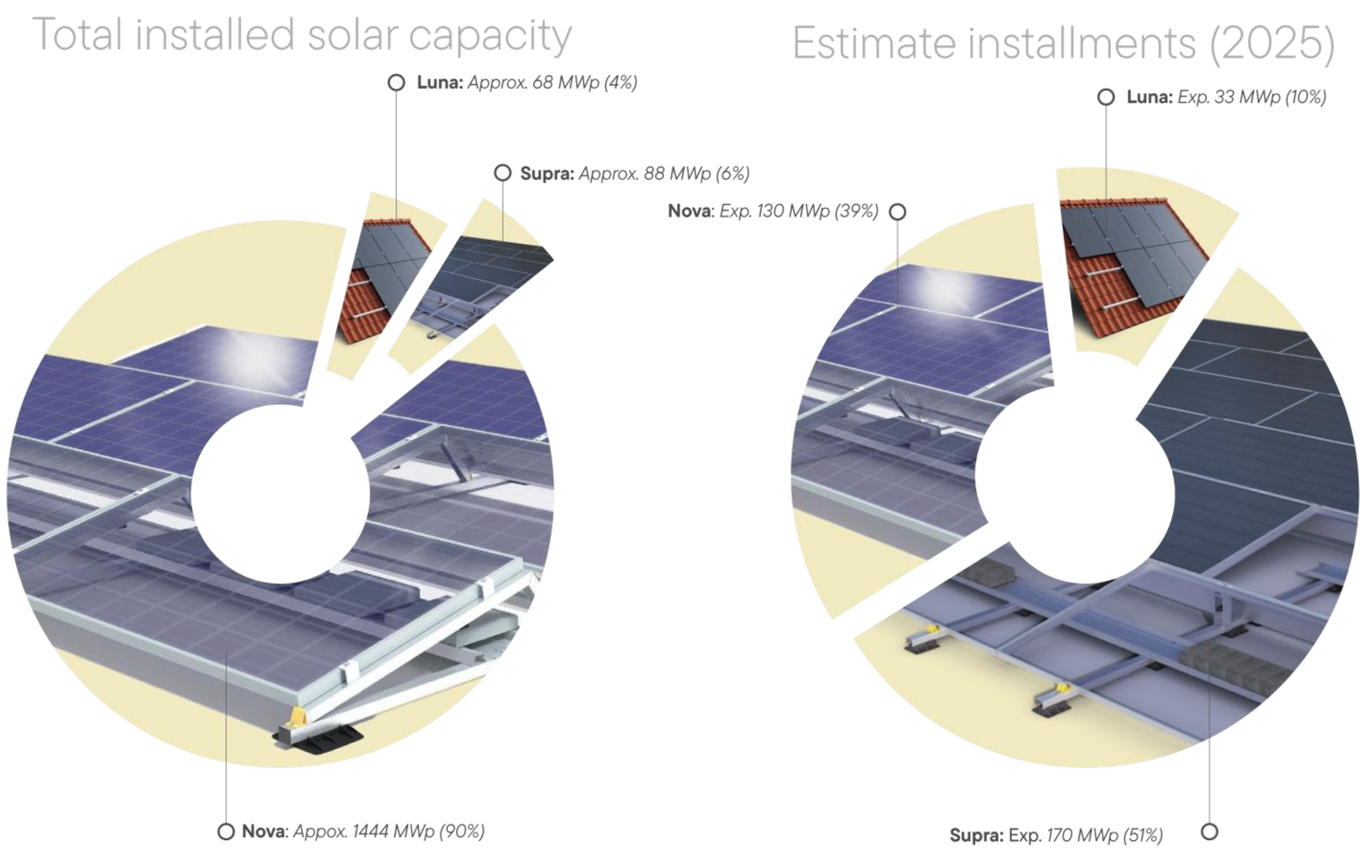


Figure A.1.1: Instalments of Sunbeam products

Besides solar mounting systems, Sunbeam also offers a variety of accessories, such as cable clips, anchoring systems, and wind deflectors.

As both Supra[2] and Nova offer flexibility in various panel sizes, a modular approach remains preferred due to its flexibility in various project types. As can be seen, Supra product sales are expected to increase. For Luna[3], future product ideas with more integrated and pre-assembled designs are more favourable. It is increasingly tied to steel rooftops, where the product offers unique selling points. This focus aligns with the trend in the Netherlands of replacing fibre cement roofs with steel, making Luna particularly well-positioned for this growing segment.

[1] https://sunbeam.solar/producten/nova/
[2] https://sunbeam.solar/producten/supra/
[3] https://sunbeam.solar/producten/luna/

The future of the solar industry: A quick review

Solar panels can be found in various locations, and future estimations show growth in infrastructure. In this report, the different ground areas are mentioned as typologies, a term which will be used throughout the report.

The division of total potential PV surface area in the Netherlands is estimated and visualised in Figure A.1.2 below; this estimation is based on the 2050 scenario outlined in the TKI Urban Energy report (van Hooff et al., 2021).

Sunbeam products are currently found (almost) exclusively in residential and utility buildings. However, given the projected growth of solar installations in infrastructure and landscape settings, it is advisable that future concept development also considers these emerging categories.

Important to mention is a significant development in the solar industry is the future of the net-metering scheme (“salderingsregeling”). Its potential phase-out may make large-scale landscape installations less attractive, as these are harder to integrate into the existing power grid (Rijksoverheid, 2025). This would make large solar fields less attractive, but this depends on how innovations develop. Much will depend on how new technologies evolve. Innovations like energy sharing between buildings or affordable on-site energy storage could offset these drawbacks and make larger solar systems again more viable and efficient in the long term.

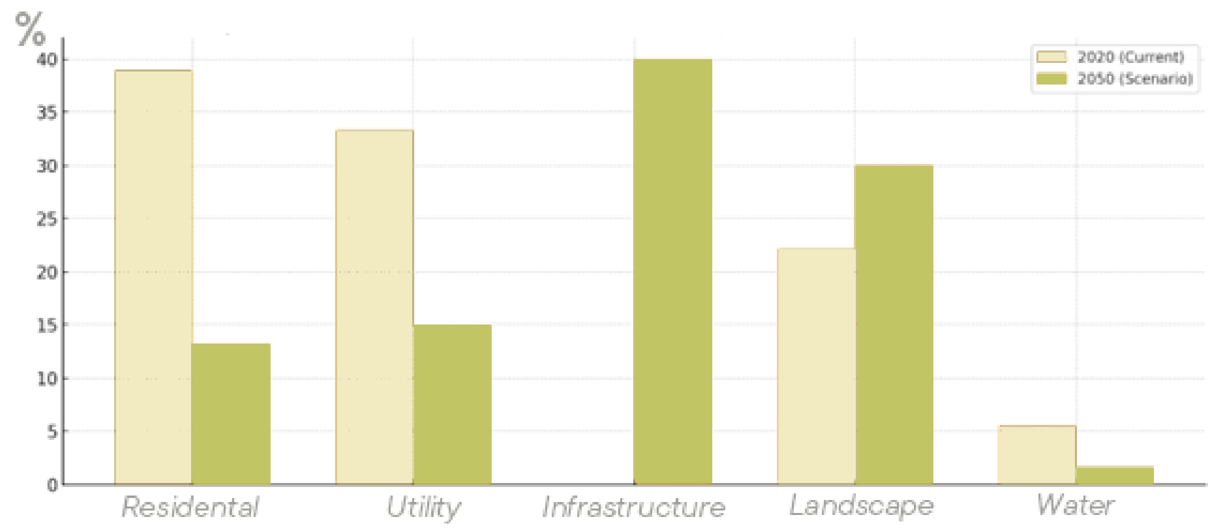


Figure A.1.2: Solar panel placement in the Netherlands as dated in 2020 and scenario of 2050

On this page, locations of Sunbeam products are translated into so-called 'Typologies', a term which will also be used in this report to indicate specific opportunities. These typologies were developed in collaboration with Sunbeam employees through joint discussions.

Sunbeam mounting systems can be found anywhere throughout the Netherlands. For further development and investigation of potential ABPs, a clear overview of these locations is essential for evaluating how the local (microclimate) and broader environmental (macroclimate) factors may influence the performance and ecological impact of the solar mounting system. Discussions were held with various Sunbeam employees to support this and to identify relevant typologies. These typologies are listed in Figure A.1.3, and are ranked on:

Surface area (Y-axis): The total available surface area for (potential) PV placement.

Build density (X-axis): The relative building density in the area where the buildings are generally located.

Roof height ("Z-axis"): The height range in which rooftops in this typology generally occur.

Appendix B provides real-world examples of the typologies.

It is important to note that some projects may deviate from the defined typologies and cannot be fully classified.

Agriculture

Rooftops in the agriculture sector (barns, stables, etc). It consists mainly of tilted, fibre cement roofs, but some flat rooftops also occur.

C&I (Commercial & Industrial)

Over-coupling cluster for larger flat rooftops of depots, warehouses, distribution centres, and light-industrial facilities.

Flats

Flats are the general cluster for rooftops higher than 9m, primarily found in more built dense areas, and commonly owned by housing associations or private landlords.

Municipality

Municipality buildings owned by local authorities could be a bunch of different types of buildings, like schools, hospitals, police/fire departments or swimming pools.

Dense houses

General houses in medium to high-density neighbourhoods that are owned by private residents, social housing associations, or landlords.

Spacious houses

General houses in less built dense areas, owned mainly by private homeowners.

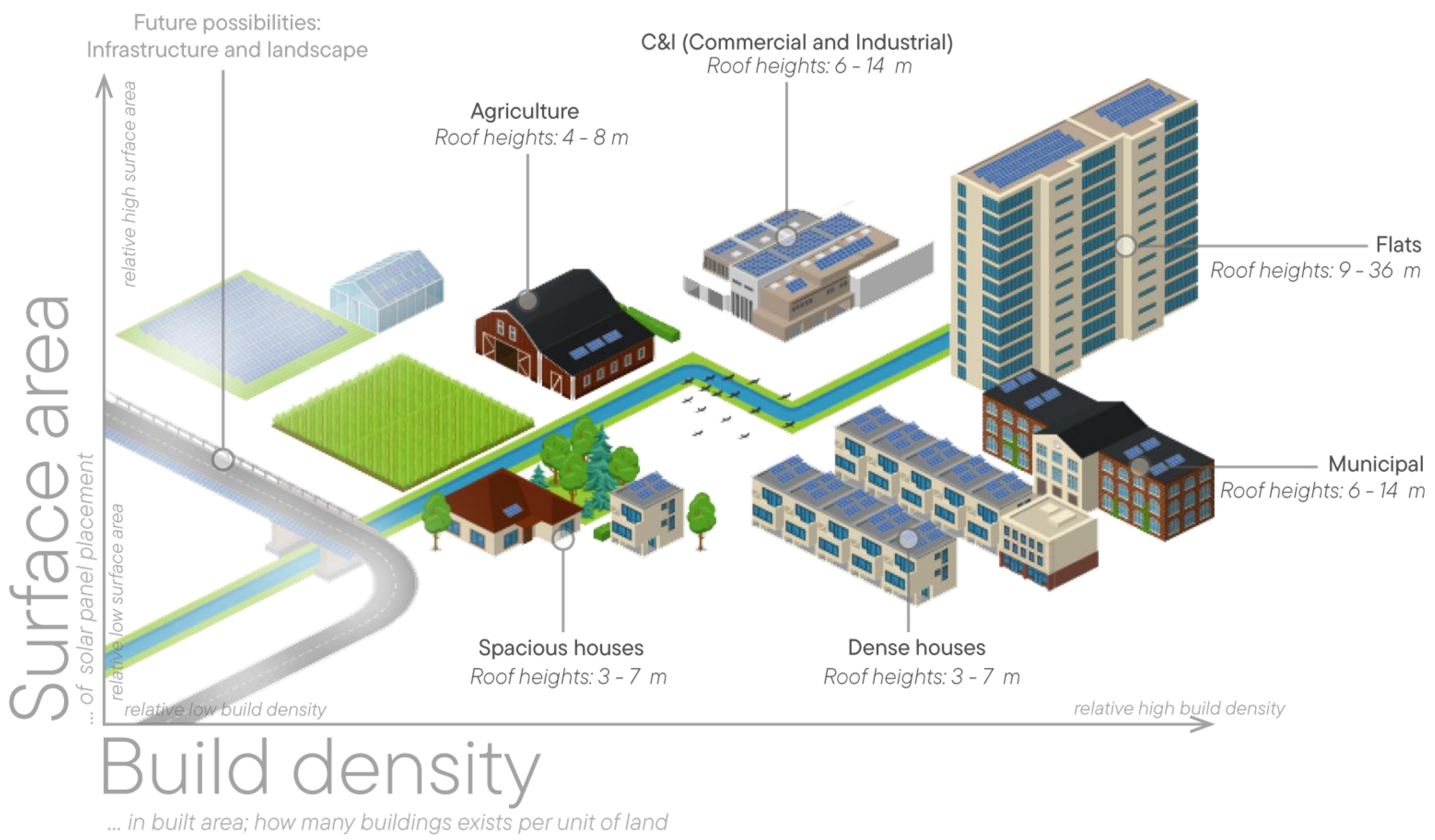


Figure A.1.3: Typologies: The current placements of Sunbeam products

The earlier identified typologies are linked to the Sunbeams product portfolio on this page. This shows in what type of environment you can generally expect what systems.

The three Sunbeam products described all have different fittings with the described typologies, just as other types of PVs. Smaller panels are generally more suitable for smaller roof surfaces, while larger panels are preferred in solar fields due to lower installation and material costs per Wp. (Ramasamy et al., 2023). This analysis shows the main difference between the Nova and Supra systems, as can be seen in Table A.1.1

It should be noted that a future increase of PV applications within the agricultural sector is to be expected, partly due to anticipated legal obligations and policy developments.

The typologies shown in Figure A.1.3 represent a broad range of built environments where Sunbeam products may be applied. Some categories, such as agricultural buildings and flats, are relatively uniform in form and use; others, like municipal buildings, can contain various forms. These can range from schools and libraries to community centres and sports facilities, each with different rooftop structures, surface areas, and regulatory requirements. This variation makes the municipal category particularly complex but versatile in terms of the integration of the solar mounting systems.

The C&I (Commercial & Industrial) category typically involves buildings with similar roof structures: often large, flat, and uniform in design. The surrounding environments and functional contexts may vary, however. A logistics warehouse on the outskirts of a city presents different spatial and ecological conditions than a commercial retail building in a dense urban zone, for example.

Typology \ Product	Nova	Supra	Luna
Agricultural	Potentially found on large scale structures, storage sheds	Potentially found on larger scale structures, storage sheds	Currently mostly found on fibre cement barn roofs, potential is more indicated on steel roofs
C&I	Well suited	Great	Potentially found on steel tilted roofs
Flats	Well suited	Well suited	Not applicable
Municipal	Great	Potential fittings, if larger areas.	Tiled rooftops more rare in general
Residential houses	Great for occasional fitting on smaller flat roof/shed	Not quite suitable for smaller areas	Mostly found on tiled roofs, currently not Sunbeams expertise however

Product fitting: Current common fit – Potential fit – Rare fit – Not relevant

Table A.1.1: (potential) Product fitting of Sunbeam products in different typologies

This analysis indicates that most of Sunbeams' bigger projects are on larger, flat rooftop areas. Relatively smaller projects can be found mainly in the residential and municipal sectors.

A.2: Stakeholder & client breakdown

This chapter analyses Sunbeam's current sales and logistic processes, and explores how these can be leveraged to introduce a product aimed at helping complex biodiversity problems in the Netherlands.

This assessment is based on internal input from Sunbeam employees and insights from previous company reports.

Stakeholder analysis

Stakeholders and sales streams of current Sunbeam products have been summarised below.

Stakeholder list

This stakeholder list is based on a previous report directed by Sunbeam (Eeftink, 2024, p. 89). The following section defines the stakeholder and outlines their current position within the PV market, and introduces the potential impact on ABPs.

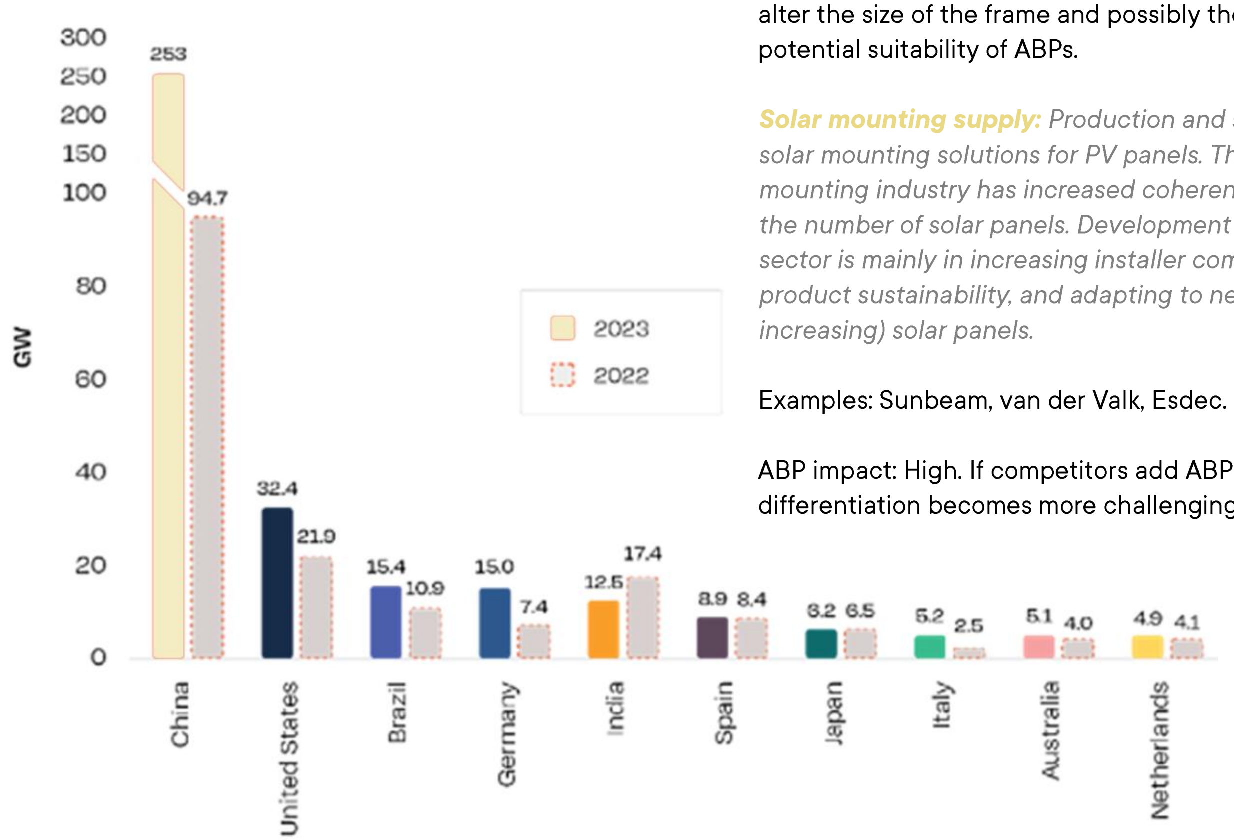


Figure A.2.1: PV production fluctuations by SolarPower Europe

PV producer (EU/China): *Most PV panels are produced in China, since they produce 80% of the total amount, as shown below in Figure A.2.1 (SolarPower Europe, 2024). The most current trend is a general size increase in panels, which decreases the cost-capacity ratio per product. (This is also the opportunity that the Supra mounting system utilises.)*

Examples: TW solar, JA solar.

ABP impact: Low-moderate. Mass production adjustments regarding the size of the panels would alter the size of the frame and possibly the potential suitability of ABPs.

Solar mounting supply: *Production and supply of solar mounting solutions for PV panels. The solar mounting industry has increased coherently with the number of solar panels. Development in this sector is mainly in increasing installer comfort and product sustainability, and adapting to new (size-increasing) solar panels.*

Examples: Sunbeam, van der Valk, Esdec.

ABP impact: High. If competitors add ABPs as well, differentiation becomes more challenging.

Warehouse: *Sales and logistics institutes are responsible for bringing together panels, mounting, and tools for installers. Since this market is quite saturated, bigger companies are taking over smaller ones and starting to handle more parts of the supply chain, from making products to working directly with installers.*

ABP Impact: Moderate-high. Potential warehouses adding ABPs to their product portfolio make it more accessible for the final client to install products, especially in the residential sector.

Installer group/individual ('ZZP'): *Are responsible for planning, delivering, and installing solar panels, mainly for residential and small business clients. Companies are expanding into energy consultancy, while individuals face practical issues like larger panel sizes and mounting challenges. The sector is dealing with a shortage of skilled workers and no clear certification policy, pushing installers to specialise, outsource, and use support tools to improve efficiency.*

Examples: Atama, SolarNRG.

ABP Impact: Moderate: While installer groups serve as key influencers in the client decision-making process, the risk of sales friction remains limited if the ABP delivers clear, tangible benefits to the end client. A sufficient and easy assembly also makes it more favourable for installers to recommend a particular product.

Project developer: *A company/person responsible for establishing, coordinating, planning, delivering, and installing solar panels (fields) for bigger solar projects.*

Examples: NOVAR, PowerField.

ABP impact: Moderate. Like installer groups, project developers can influence decision-making, particularly from the construction project side. Their involvement early in the design and tender phases means their support (or resistance) can significantly affect the inclusion of ABPs in project specifications.

Service/maintenance providers: *Applicable for residential and/or utility clients, a company that provides service and maintenance activities for solar panel owners. This gets outsourced more and more since the market is increasing.*

ABP Impact: Low. As long as the ABP meets the requirement of not interfering with maintenance access or procedures, the impact on maintenance operations is expected to be minimal.

Residential clients: *Customers of solar panel installation from the private market.*

Examples/ABP impact: Personas are described below in Figure A.2.3, under Client personas.

Utility clients: *Customers of solar panel installation projects for Utility buildings, from the public and/or business market.*

Examples/ABP impact: Personas are further described in the upper part of Figure A.2.3, under Client personas

Stakeholder sales streams

The clustering of stakeholders is derived from a previous report (Eeftink, 2024, p. 90) and has been summarised here to clarify the possible pathways a product follows before reaching the end client and where potential ABPs could be added. The big ABP arrows indicate where potential opportunities for biodiversity solutions can be introduced within the chain to reach the end client. When added, an ABP would be stored in Sunbeams' storage and/or general warehouses. In the sales streams, you can see that Sunbeam rarely sells immediately to its end client, whether to Utility or Residential clients. The sales mostly go via project developer or installers (individual (ZZP) or installer groups). ABPs could also be installed later, for example, during PV maintenance.

Note on Figure A.2.2: The illustrated flows represent the most common sales pathways, but do not exclude other possibilities. An example is that solar mounting companies may occasionally sell directly to clients. As can be seen, most project developers focus on larger solar fields and or utility (size) buildings. Project developers manage their own storage and installer crews.

As shown, *project developers* typically focus on larger solar fields or utility-scale buildings. They often manage their own storage facilities and installation teams.

An *installer group* is quite similar to a project developer, but focuses more on smaller projects from residential clients. Since their projects are smaller, warehouses are used occasionally to source their materials.

In contrast, individual installers (freelancers) depend entirely on warehouses to obtain mounting systems and other installation components.

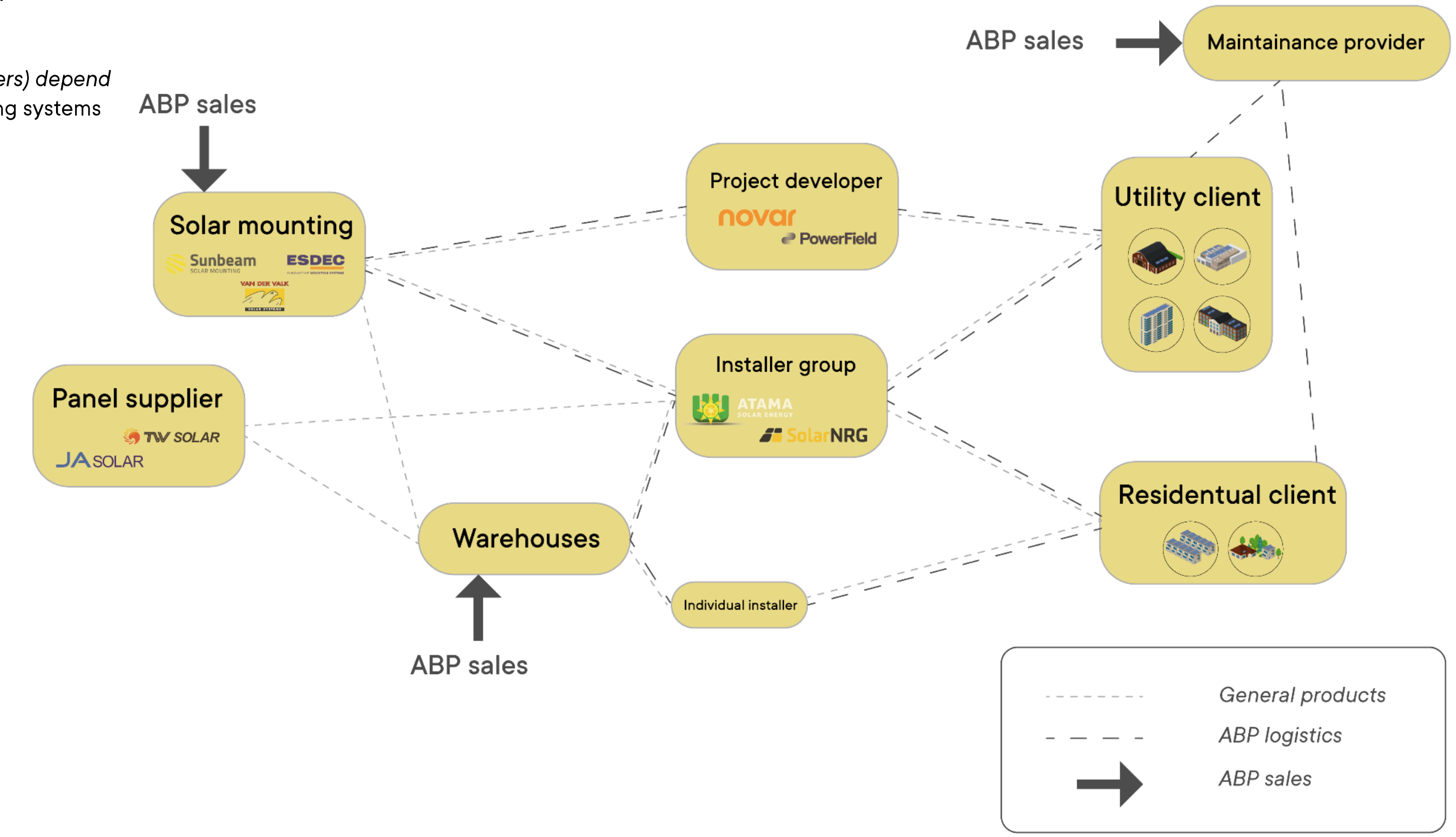


Figure A.2.2: Sales streams of solar mounting products

This analysis shows that a potential ABP should benefit both the end client and biodiversity while addressing the needs of in-between stakeholders.

A way to make the ABP more tangible for the final client is by adding the product to various sales streams.

The client: Motivation

As outlined above, there are various pathways through which Sunbeam's products reach the end client. Ultimately, it is the end client who drives demand, even if that demand is influenced by other stakeholders along the way. This part of the report will try to understand the final client better and their motivation behind applying for an ABP. Desktop research and current interviews with Sunbeams employees indicate that the final client can be grouped into four personas, as shown in Figure A.2.3 on the next page. Each persona could represent a different motivation for engaging with biodiversity and potential interest in ABPs, which is briefly explained below the figure. The X-axis represents whether their motivation is intrinsic or extrinsic, while the Y-axis shows the type of building or environment they influence.

There can be quite a list of external factors that Influence extrinsic motivation. A complete list of regulations can be found in Appendix G.

The overview on the next page captures the core motivations behind why an ABP could be a valuable solution, as well as the key influences coming from the sales streams described above. Potential typologies have also been linked with the potential motivations.

Several targeted questions were included in the customer satisfaction survey to provide a more concrete basis and move beyond estimation.

The personas' names, occupations, and visual representations are illustrative and not based on real individuals. The motivations and characteristics described are drawn from patterns observed in interviews with Sunbeam employees and the customer satisfaction research. Most clients will fall somewhere between these personas rather than matching one exactly. For example, an intrinsically motivated client does not necessarily have to be a homeowner; the persona reflects one possible profile within that motivational cluster.

The client: Customer satisfaction report

In week 17 of 2025, a customer satisfaction survey was conducted, which included several questions about the potential integration of ABPs into Sunbeams' offerings. The results provide insight into the options most compatible with Sunbeam's current market. While a stated interest does not guarantee actual purchase behaviour, the findings indicate whether ABPs could be commercially viable within Sunbeam's existing client base.

Customer satisfaction report: Questions

The questions of the Customer satisfaction report will be presented to the client as follows:

Question 1) I am open to adding a biodiversity feature/nature-inclusive addition to my solar panel project, such as for birds, bats, insects, or plants.
Answer 1) [Strongly agree – Agree – Neutral – Disagree – Strongly disagree]

Question 2) Can you explain your answer?
Answer 2) [Open question]

Question 3) Can you indicate to what extent the following factors influence your willingness to add such a feature to your solar panel project?
Sub question 3.1) Building regulations (such as the Environment and Planning Act)
Sub question 3.2) Potential additional subsidies (for example, SDE++)
Sub question 3.3) The importance of nature and biodiversity
Answer 3) [Very important – Important – Neutral – Not important – Not important at all]

Customer satisfaction report: Results

General conclusions that can be retrieved from the outcomes can be found below.

Results Question 1 (n=132):
55% of all clients indicated that they strongly agree or agree with the statement. 11% indicated to strongly disagree or to disagree.

Results Question 2 (n=132):
Various answers are given, with the main reoccurring outcomes below:

Clients who agreed with the statement often referred to the increasing number of small-scale biodiversity initiatives already being implemented; ranging from individuals adding nesting boxes themselves to competitors integrating full green roof systems beneath solar panels. In contrast, clients who disagreed expressed concerns about potential negative impacts, such as contamination on and around solar panels. They also emphasised that ease of installation remains a critical factor and should not be compromised.

Results Question 3 (n=73):

When asked about the importance of building regulations, 63% of respondents rated them as important or very important. In contrast, 10% considered them not important at all, while the remaining respondents were either neutral or uncertain.

For potential additional subsidies, 64% of participants indicated that they were important or very important, while 12% saw them as not important at all. The rest expressed no strong opinion or were unsure.

Finally, in relation to the importance of nature and biodiversity, a strong majority of 86% rated it as important or very important. Only 3% considered it not important at all, with the remaining respondents either neutral or undecided.

> **The customer satisfaction report indicated that more than half of current clients show openness to adding ABPs into their products in the future. The reasons behind this interest vary, but many respondents pointed to a belief in the importance of biodiversity itself.**

> **A variety of concerns should be kept in mind. Addressing these practical issues effectively could help expand the group willing to adopt ABPs.**

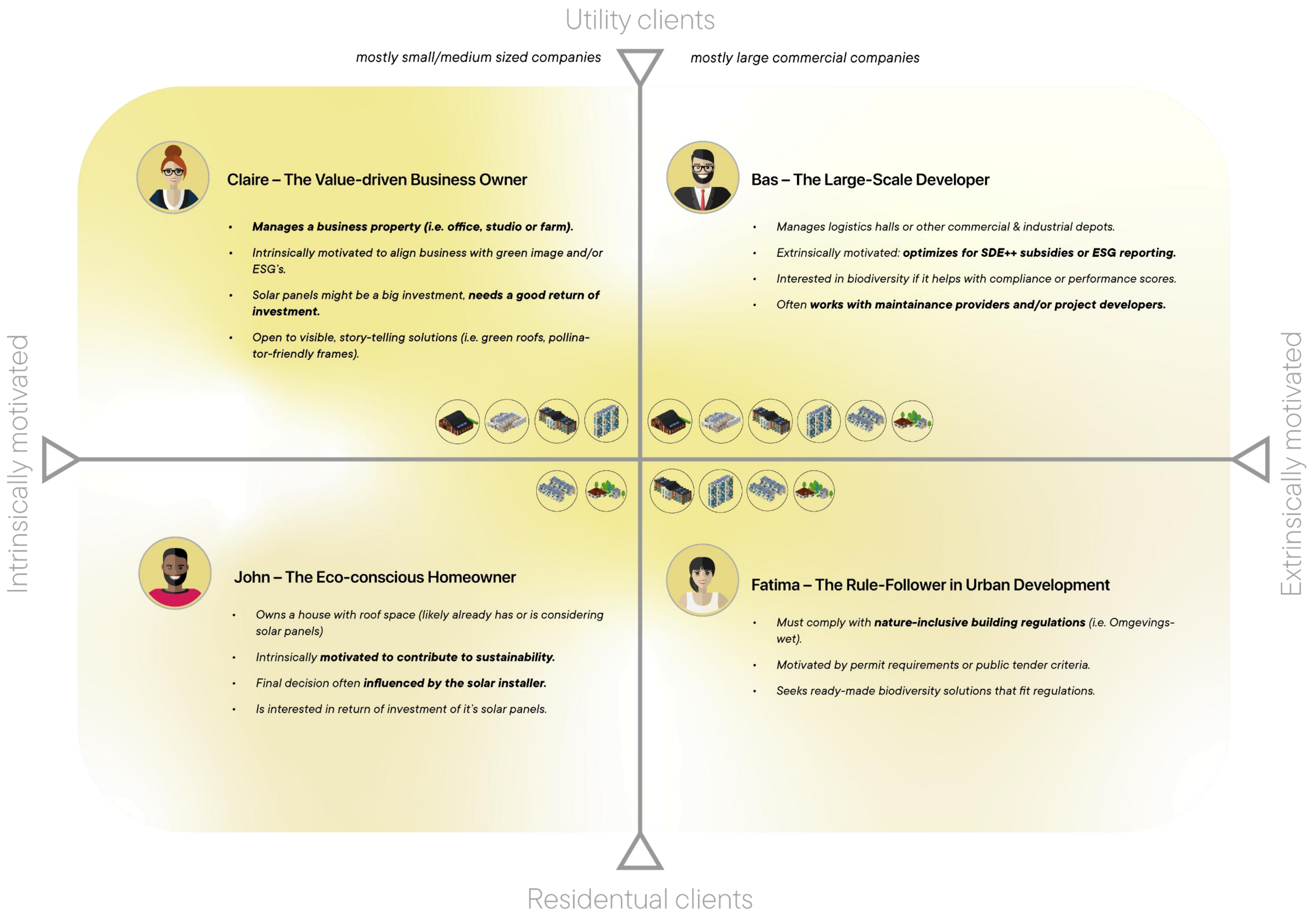


Figure A.2.3: Overview of client personas and their potential motivations for adopting ABPs, overlaid with a heatmap indicating the degree of alignment with Sunbeam's client base, based on insights from the customer satisfaction survey.

Motivations for potential ABPs vary.

Sunbeams utility clients appeared slightly more intrinsically motivated, whereas residential clients showed a broader mix of motivations.

A.3: SWOT analysis

After the product and stakeholder breakdowns were executed in Chapter A.1 and A.2, a general SWOT analysis was conducted in Figure A.3.1 with Sunbeam employees to see where further opportunities could generally lie to excel in their market.

SWOT is an acronym for Strengths and Weaknesses, representing internal factors of the company, and Opportunities and Threats, representing external factors (Van Boeijen et al., 2014, p.73).

This analysis aims to identify which opportunities can be used and which threats should be avoided in relation to ABPs. The strengths and weaknesses reflect Sunbeam's current internal capabilities, while the opportunities and threats are specifically focused on the potential impact of ABPs.

Remaining able to claim "climate neutral" is expected to become more difficult for Sunbeam and competitors. Under the EU's upcoming Green Claims Directive, from 2026 onwards, such claims, especially those based solely on carbon offsets, will be banned unless backed by scientifically sound, independently verified evidence. (Reuters, 2024) In other words, the compensation for carbon emissions will become more difficult. An ABP might have an opportunity to be of additional value here.

Further explanations can be found below:

*I: Sunbeam actively pursues climate-neutral certification and emphasises sustainability in its operations. At first glance, its motivation appears to exceed that of some competitors. However, this assumption is difficult to quantify and could be validated through further comparative research on sustainability reporting and targets across the industry.

*II: Sunbeam, of course, has Luna, but many competitors have way more experience in solar mounting structures for tiled rooftops.

*III: This is particularly the case with steel, which plays a significant role in Sunbeam's products. Reduction in the use of steel could strengthen the brand's environmental positioning and align with market demand for greener construction solutions. Using biodegradable or carbon-storing materials could help offset the carbon footprint of steel components, improving the product's overall potential Life Cycle Assessment.

Sunbeam should focus on a possible personal solution, which explores sustainable material alternatives.

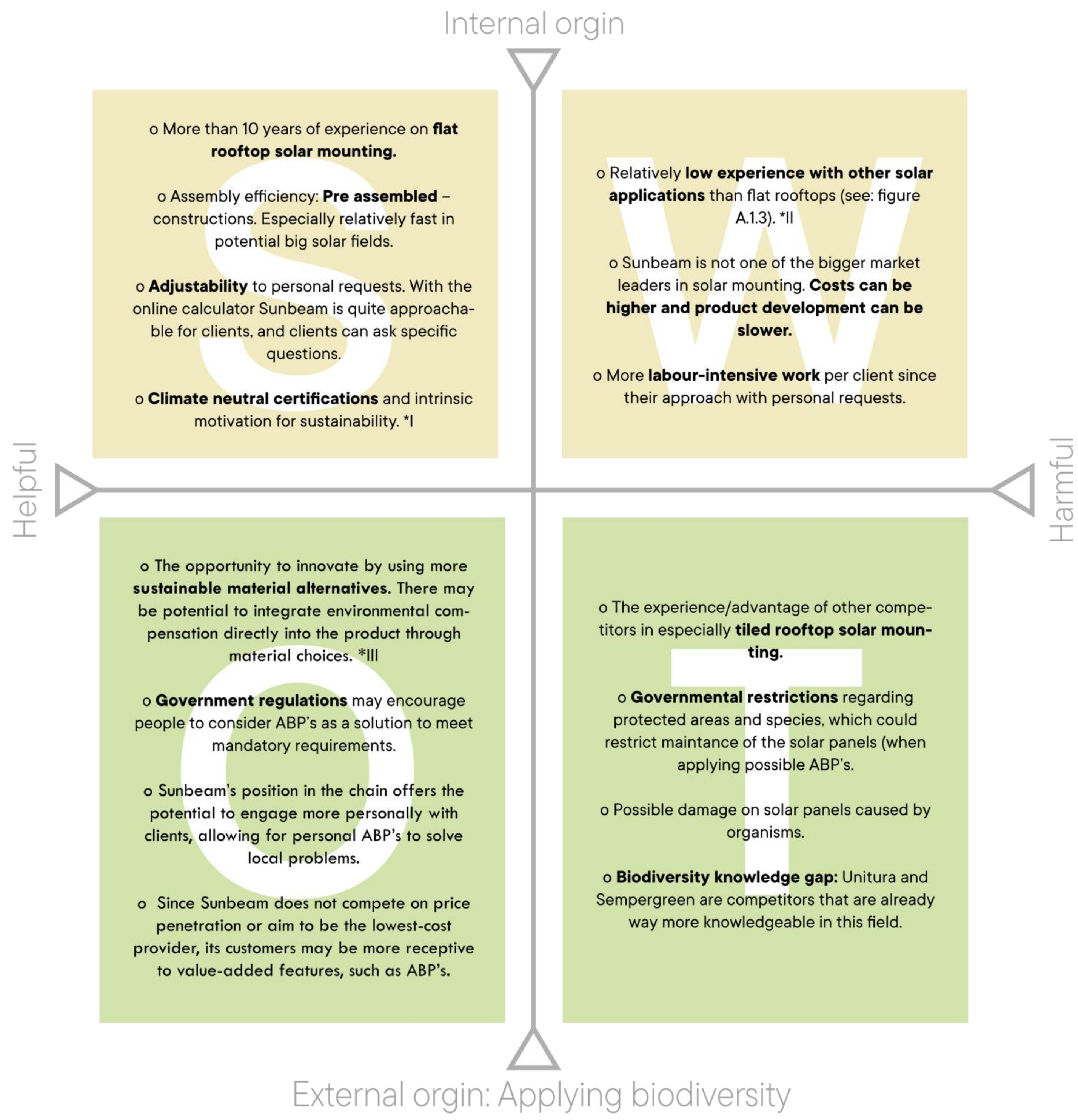


Figure A.3.1: SWOT analysis

Section B: Biodiversity needs

This section is the second of two that explore how Sunbeam can best contribute to restoring and sustaining biodiversity in the Netherlands. It provides a comprehensive analysis of the biodiversity opportunities that could be relevant in the Netherlands, and is also implementable for Sunbeam's product line. It starts with two chapters defining biodiversity in the Netherlands, and then criticises current building solutions regarding biodiversity.

B.1: Defining biodiversity: Landscapes

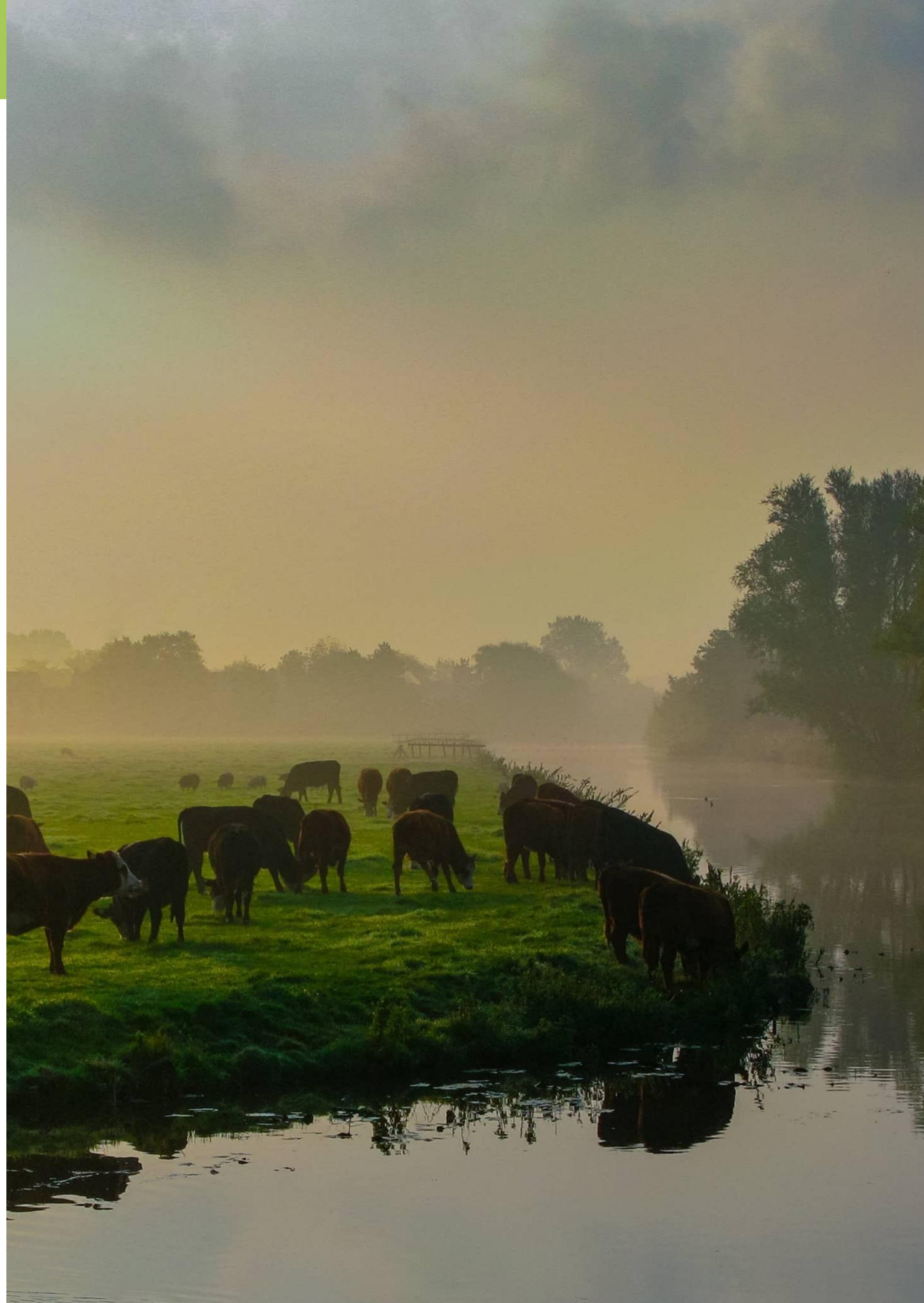
B.2: Defining biodiversity: Species

B.3: Current building solutions

Every chapter ends with key design considerations, showing what can be done and indicating the main takeaways for sections C, D, and E later in this report.

Various measurement tools and terms are used to measure and understand biodiversity. Some of the terminology is described below, and these measurement tools will be used throughout the following chapters:

- *LPI: Living Planet Index: A Measurement tool for biological diversity based on vertebrate species, and can provide insights into overall biodiversity health. The LPI is based on the geometric mean of population trends across multiple species.*
- *FBI: Farmland bird indicator: Geometric mean indicator used to monitor population trends of bird species that are dependent on agricultural landscapes*
- *RLI: Red List Index, Extinction risk trends, based on IUCN trends.*



A typical Dutch landscape, where biodiversity appears to thrive at first glance. *However, this section will critically examine the ecological coherence between native and domesticated species present in such environments.*

B.1: Defining biodiversity: Landscapes

This chapter begins by defining biodiversity and ecosystems and outlining their broader importance. It then maps the main biodiversity challenges in the Netherlands and the key contributing factors. The chapter concludes by identifying potential opportunities for Sunbeam, focusing on the relevant typologies indicated earlier in Figure A.1.3.

General definition and importance

In general, biodiversity is a term that refers to *the variety of life on earth, consisting of the diversity within species, between species and of ecosystems* (UNEP, 2022). A web of ecosystems naturally moderates biodiversity: the *dynamic complex of plant, animal, and microorganism communities and their non-living environment, interacting as a functional unit.*

The importance of biodiversity has been known and is scientifically founded for decades. Biodiversity plays a critical role in maintaining ecosystem stability and resilience; ecosystems with higher biodiversity are generally better able to adapt to and recover from environmental changes, disturbances, or shocks. Ecosystems can be highly complex, and various ways exist to explore and visualise them in detail.

The importance of biodiversity has been known to us for decades. Expert interviews (Appendix C) highlighted that the core value of biodiversity lies in its role as ecological insurance, contributing to services such as reduction and production of organisms. The influence of biodiversity goes further than its regulation, playing key roles in pollination, water purification, carbon storage, and climate regulation (Shin et al., 2022). This underscores the fact that preserving biodiversity is not only about directly protecting species, but also about maintaining the resilience and functionality of the full environment we live in.

Evaluating biodiversity

When evaluating biodiversity, choosing the correct and appropriate indicators reliably reflecting the overall status of species populations over time is essential. Two key mathematical measurements are the arithmetic mean and the geometric mean of species abundance. The geometric mean is particularly well suited for tracking overall biodiversity trends as it better captures proportional changes across multiple species and aligns with ecological growth patterns. (A. Van Strien et al., 2011).

When looking over a significant period, it can be seen that biodiversity has been declining drastically over the last decades. The LPI worldwide between 1970 and 2018 has declined by 69% (Ritchie, 2022). It is important to note that while the LPI indicates a significant average decline, it does not imply that 69% of all species have gone extinct. It reflects an average decrease in the relative abundance of species over the specified period. In this chapter, the overall status of various habitats is assessed using a range of Living Planet Index (LPI) values. These LPIs provide a general overview of biodiversity trends and help identify key areas of concern.

For this analysis and report, we represent the ecosystem further in the report using a food pyramid, as illustrated in Figure B.1.1 on the right. The food pyramid is a great way to illustrate the core function of an ecosystem: maintaining balance between production and biomass reduction (Barbier & Loreau, 2019). Species depend on one another through feeding relationships, which work as natural mechanisms. These natural mechanisms, such as predation and resource limitation, help regulate population sizes and keep an ecosystem in balance.

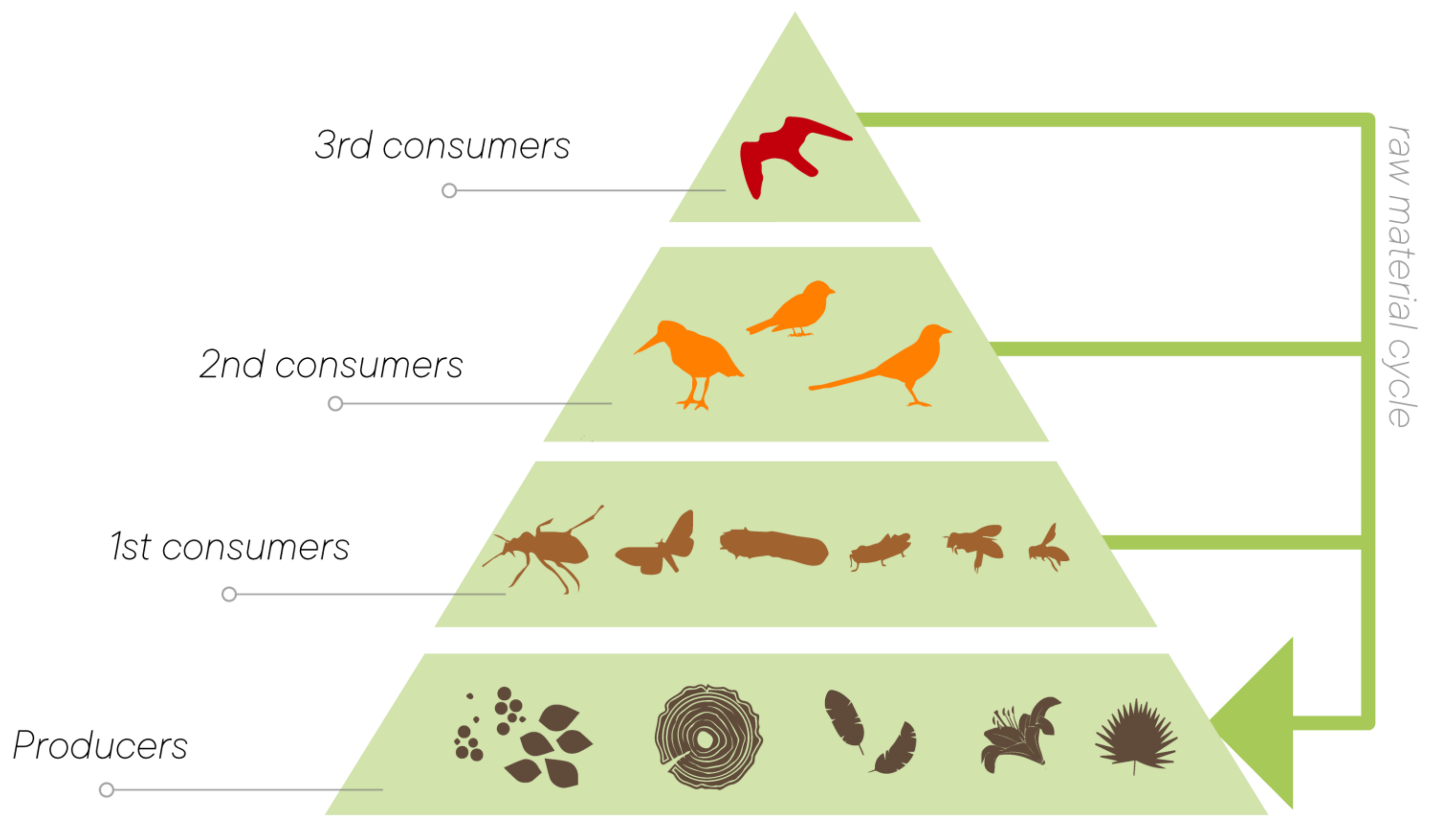


Figure B.1.1: Food pyramid: Visualising energy flow and feeding relationships within an ecosystem.

Mapping biodiversity problems in the Netherlands

In the Netherlands, various habitat types reveal critical tensions where natural ecosystems and human society intersect. This chapter analyses these biomes and identifies the key ecological pressures and disruptions specific to each. This will form the foundation for understanding how urban planning and other anthropogenic activities shape biodiversity and its fragile balance.

Landscapes of the Netherlands can be clustered into the three main categories, with subcategories visualised in Figure B.1.2 below. (CLO, 2018), (CBS, 2022), (Eurostat, 2018).

Recent research on the Living Planet Index (LPI) indicates a slight overall increase in the Netherlands between 1990 and 2014 (Van Strien et al., 2016). The slight overall increase is mainly because of the significant increase in water environments, since most of the biodiversity falls under this category. Regarding Sunbeams' typologies, fresh freshwater and marshlands are out of scope.

A detailed overview of these variations in habitat types is provided in Figure B.1.3 (Van Strien et al., 2016), (CLO, 2024), (CBS, 2024).

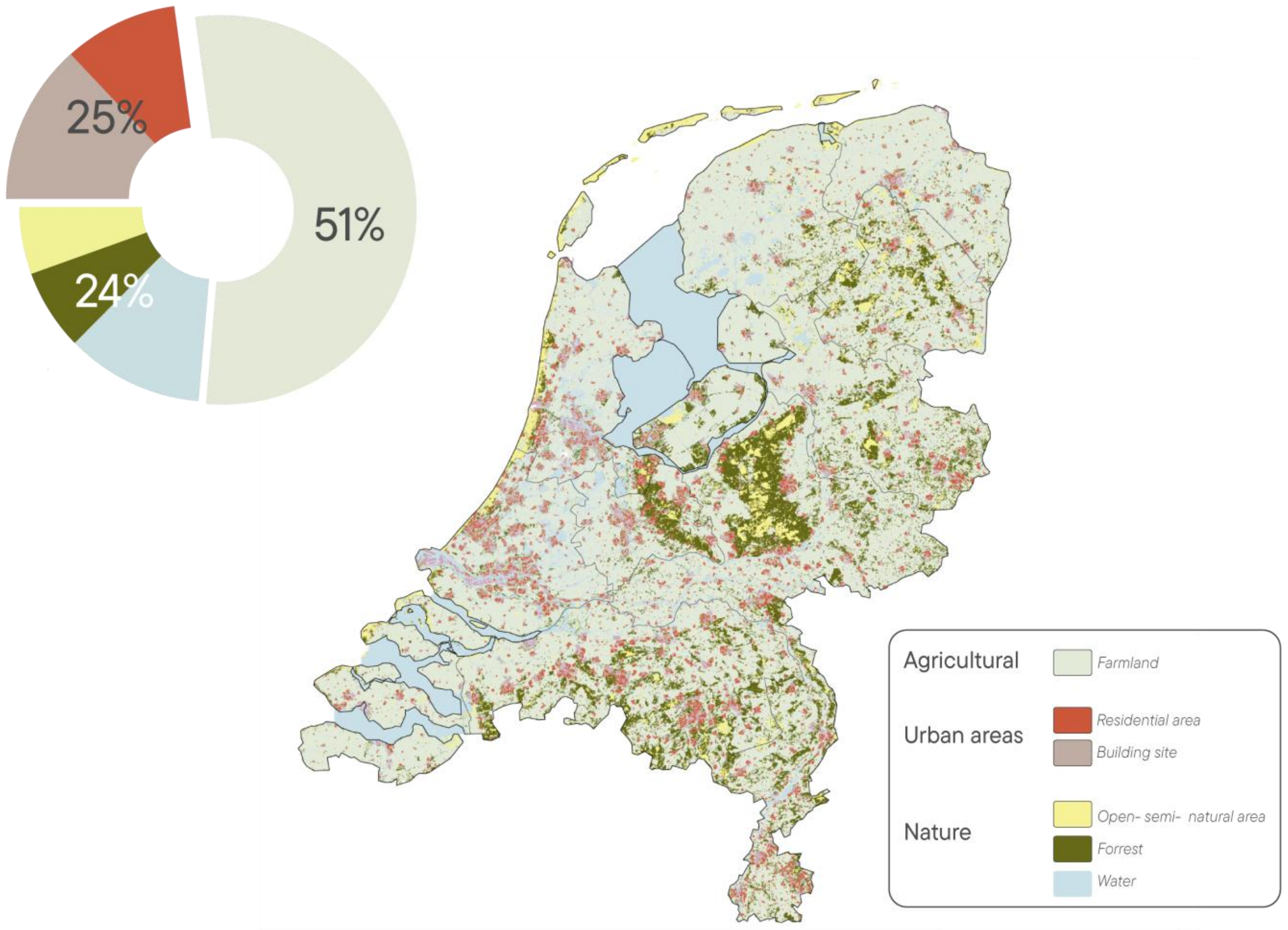


Figure B.1.2: Landscape ratio in the Netherlands

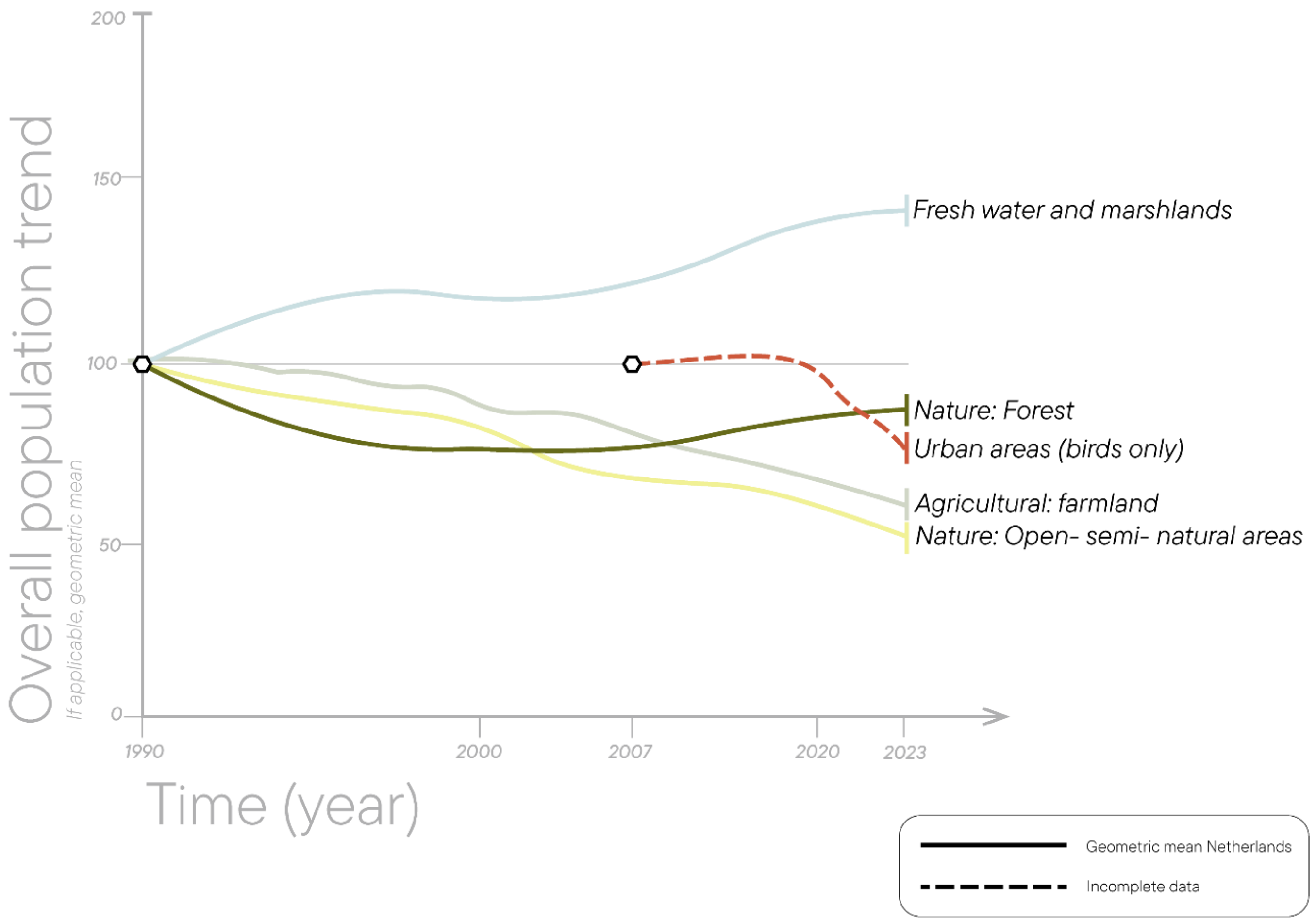


Figure B.1.3: General LPI trends in wild animals in different habitat types.

The reasons behind these regressions could be complex, with multiple contributing factors, and are further analysed by experts and further literature research in the following pages.

A more detailed overview of these variations in habitat types is provided in Figure B.1.3 above (Van Strien et al., 2016), (CLO, 2024), (CBS, 2024). Comprehensive data on organisms other than birds in urban areas is limited, and it is important to note that the available data uses 2007 as its baseline year.

This analysis shows the general decreases in LPI are most detrimental in natural open areas, urban areas and farmland.

Drivers behind landscape vulnerability in landscapes

In the following paragraphs, the three mentioned main challenged landscapes are described based on their current status and main challenging factors, as identified by experts and supported by additional desktop research. Each landscape section concludes with a key quote from the interviews.

The main challenging factors are described in more depth in Appendix D.

Agriculture: Farmlands

Agricultural areas are estimated to be 49-66% of the total area, located quite evenly throughout the land as seen in Figure B.1.4. Even if agricultural biodiversity is regressing, some efforts from governmental organisations have been made (CLO, 2024). These managements aim to separate agricultural land and nature areas, such as the Natura 2000 areas. Also, the nitrogen policy will push towards extensification (less intensive farming) in vulnerable areas. More about these specific regulations is listed in Appendix G.

However, despite these ongoing efforts and ambitions, farmland biodiversity has declined by 40%, indicating that significant steps remain to be taken. The main challenge remains overall nitrogen pollution.

Main challenging factor(s): Acidification by multiple toxins, invasive species and competition with built environments.

The nitrogen issue is about more than just particular species gaining a significant advantage; it also concerns the overall chemical balance. Plant species become imbalanced (low in calcium, high in nitrogen), which in turn affects insects, and consequently, Predatory birds are a great example, since for them it can lead to weakened eggshells. – Mathijs Verwij, ecologist at Kwinfra.

Urban areas

The Netherlands aims to construct 900.000 new homes by 2030, so this area will increase in size, leading to more clashes with nature. Increased attention must be given to integrating biodiversity into the built environment. Several proposals, such as those described in the OSKA report, highlight the growing ambition to embed nature-inclusive principles in future spatial developments (OSKA, 2023). The motivation for developing potential ABPs does not stem solely from declining LPI trends or biodiversity vulnerability. Building regulations can also play a significant role. The protected status of particular species can result in specific building requirements aimed at protecting their habitats

Main challenging factor(s): Competition (because of built environments), building regulations. *Data especially shows a significant drop in the LPI of birds (Figure B.1.3)*

"Bats and birds are increasingly losing suitable nesting and roosting sites due to modern construction techniques, such as the lack of accessible spaces like cavity walls for hibernation." – ecologist.

Nature areas

Research from Wageningen University indicates that the soil in natural areas can be degraded because of agricultural pesticides and other agricultural monocultures. Even though nature gets more space, specific species still thrive a lot since certain nutrients are in overload. As can be seen in the figure, it is mainly the open land areas that also show a declining trend, despite many areas being protected from competition (because of built environments).

Main challenging factor(s): Acidification by multiple toxins, Invasive species and altered water flows.

"The nitrogen issue in the open solar parks where I conducted research is particularly problematic; it leads to soil impoverishment." - Friso van der Zee, project manager at Wageningen Environmental Research. Biodiversity and policy.

Key design considerations in different landscapes

Key design considerations following the analysis are summarised below.

Structural reinforcement is required in agriculture and open nature areas

While this chapter illustrates that biodiversity is receiving increasing political attention in the Netherlands, many initiatives still fall short of solving the root causes of biodiversity loss, like ground pollution. These nutritional imbalances mostly affect agricultural and open natural areas. They are challenging problems to tackle, since they could require some fundamental changes, given the substantial economic weight behind the agricultural sector. Looking back at the Food Pyramid in B.1.1, disruptions at the base of the ecological system, as seen earlier, can cause problems throughout all trophic levels. **Since there are fundamental problems in these environments, fundamental solutions must happen.**

Increasing urban biodiversity by creating less competition

In contrast to the agricultural and open nature areas, urban areas have different problems regarding biodiversity. New building techniques tend to make it more demanding and more challenging for biodiversity to have a place, and this is something where a potential ABP could play a significant role, even on a more minor scale (Rogers, 2022). **This sector needs smaller, quick, implementable solutions that fit a variety of typologies to help avoid this competition for the environment.**

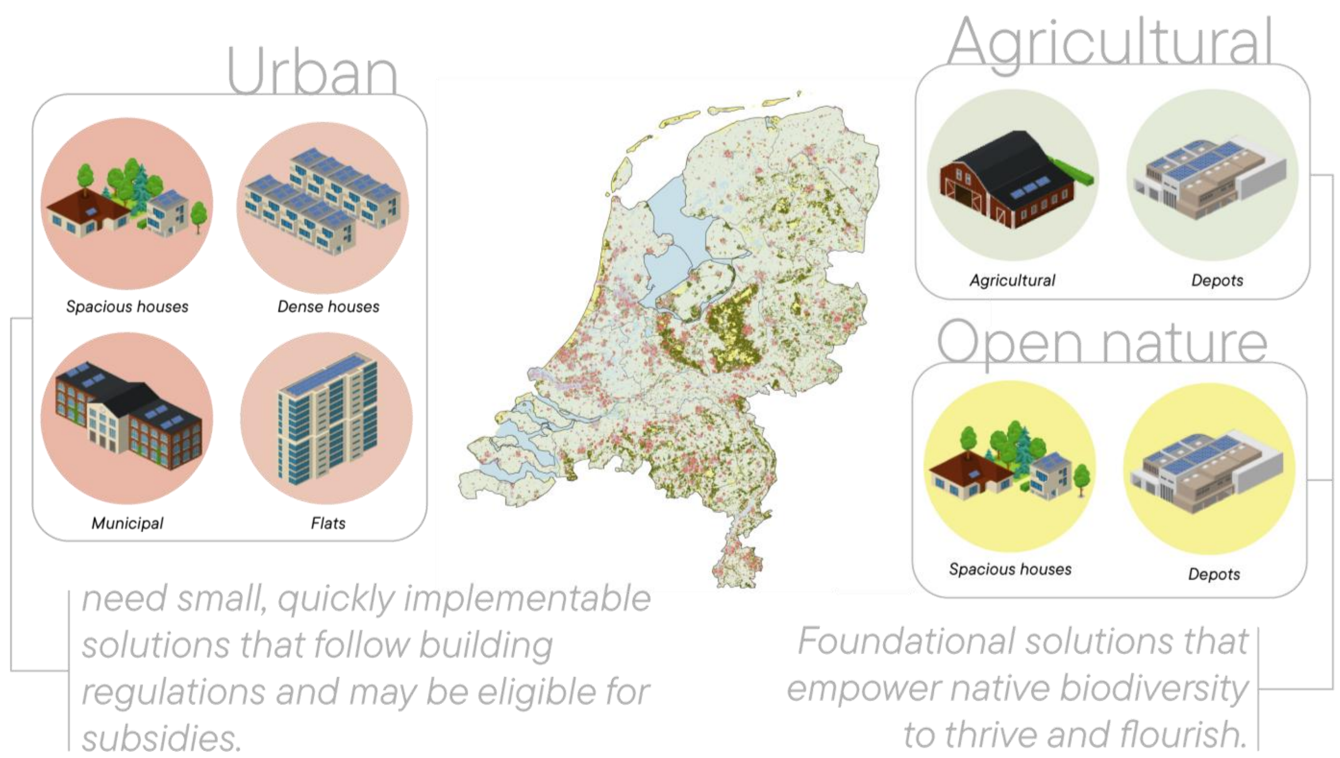


Figure B.1.4: Key design considerations linked to typologies of Sunbeam

Chapter B.2: Defining biodiversity: Species

While chapter B.1 focused on the diversity of habitats, a clearer view of biodiversity in the Netherlands also requires looking beyond habitat variety. This chapter adds species-level insights by highlighting LPI trends across various taxonomic groups. In addition, RLI trends are used to identify species with a critical conservation status and/or ecological importance.

While long-term sources show that biodiversity worldwide has been declining for decades, this analysis focuses on the period from 1990 to 2025 in the Netherlands, during which some species populations have stabilised compared to earlier losses. This makes it possible to identify today's most critical and urgent biodiversity pain points. To conclude this analysis, a list of noticeable species has been made to identify the most valuable current opportunities.

At the end of May 2025, a report similar to this chapter came out from Naturalis, showing some similar insights. Notably, this paper indicates that many species, even those in the Netherlands, remain undocumented. As such, the picture outlined in this chapter should be viewed as an indication rather than a complete overview; the status of many species remains unknown.

Species: LPI

The LPI is a valuable tool for analysing biodiversity trends, but it also has its limitations. The LPI primarily focuses on vertebrate species, making it challenging to find comparable data for plants and invertebrates. Alternative indicators that provide similar insights into biodiversity trends are used to include these groups in the analysis and enable a meaningful comparison. An overview of the sources used per taxonomic group, along with the reasoning behind the selected values, is provided in Appendix E. As this report focuses on terrestrial ecosystems, taxonomic groups such as fish will not be included in the scope of the research.

On the right in Figure B.2.1, the general trends of native, non-domesticated species can be seen. Most of the taxonomic groups could be expressed in geometric mean values. For some of the taxonomic groups, the data is incomplete. This is also further elaborated in Appendix E.

Closer inspection of subgroup data (particularly for mammals, birds, and invertebrates) reveals that many species have declined significantly over the past 35 years. Notable drops in the current years are mainly in insects, different landscape birds, and wild plants. More about these categories can be read on the next page.

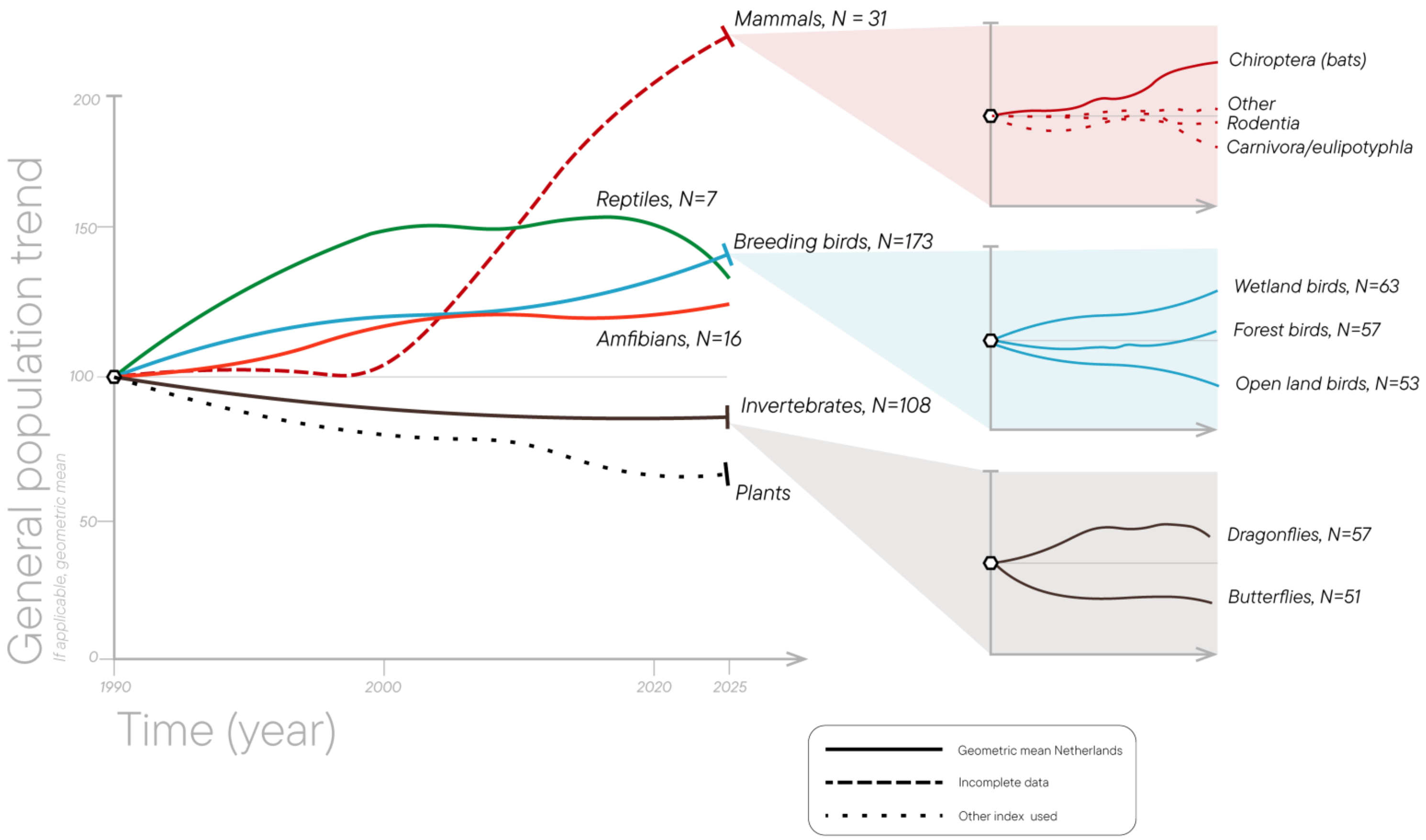


Figure B.2.1: Population trends per taxonomy group, number of species in each group indicated by N

This analysis shows the general decreases in LPI are most detrimental in Wild plants, invertebrates and open land birds.

Species: The Red List

When an organism faces significant decline, it is placed on the Red List, identifying threatened plants, animals, and fungi ("The IUCN Red List," n.d.).

A species can be threatened and/or protected: Threatened refers to its conservation status, which does not automatically grant legal protection. Laws like the Dutch Nature Conservation Act and EU regulations safeguard protected species. A species can be threatened but not protected, or vice versa. Protection measures are often focused on vulnerable species and considered valuable for nature conservation.

The Red List Index (RLI) analyses the Red List over time. The RLI tracks changes in extinction risk over time based on the different Red List categories. (least concern, threatened, vulnerable, endangered, extinct). An overview of the trends regarding species on the Red List can be seen in Figure B.2.2 below. This shows the trends in numbers of species on the red list and the degrees of threats ("CLO: Red List Indicator, 1995 - 2022," 2023). In general, there was a slight increase in endangered species between 1995 and 2005, and a modest decline followed post-2005. Notable information regarding taxonomic groups from this index is that breeding birds show a significant ongoing vulnerability in the Netherlands, since their number remains higher than in 1995. Other groups also show minimal recovery, emphasising the need for attention for species on the red list.

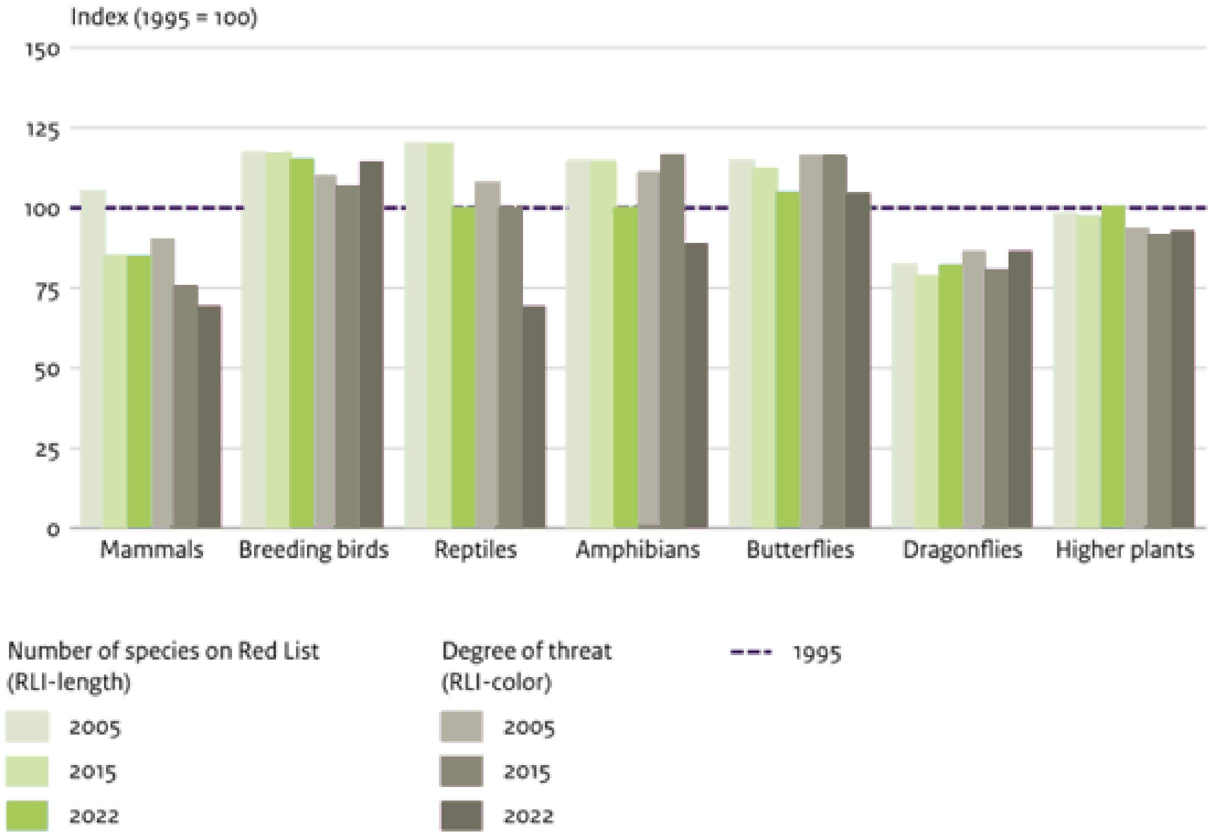


Figure B.2.2: RLI trends per taxonomy group (CLO, 2023)

Key design considerations for different species

Following the analysis, the primary focus in design should be on the regressions currently occurring the most significantly, following the following groups.

Insects

Standardised and sustained monitoring is still lacking for most insect groups at the global and national scale. This makes it harder to indicate specific species (WWF, 2023).

In general, flying insects show worldwide regression, called 'a death by a thousand cuts.' (Naturalis Biodiversity Centre, 2025, p. 84) Pesticides, monoculture and climate change can all be traced back to this gigantic worldwide loss. In Germany, a study indicates a 75% decline in flying insect biomass over the last 27 years. (Scheper et al., 2017). **Foundational solutions that restore habitat, regulate temperature, and balance chemical conditions are essential to support the recovery of insect populations.**

Birds (open land)

While wetland and forest bird populations have generally shown an upward trend in recent years, open land bird species have experienced a significant decline over the past 35 years. This regression is particularly seen among migratory birds and is primarily driven by competition for suitable nesting habitats, rather than by interspecific competition. **The more favourable and accessible the nesting environment, the more likely these species are to reproduce successfully.**

Wild plants

A decline in flora is generally found most in farmland flora, by 35% (CBS: Decline in farmland flora and fauna as of 1900, 2020), especially with the regression of specific native Dutch species. **If new environments can be created, this can affect the whole ecosystem.**

Notable species for potential Sunbeam ABPs

The following overview presents notable species that could potentially (could) inhabit the locations of Sunbeam products (typologies indicated in Figure A.1.3).

Species were selected based on general insights of declines in LPI trends, their status on the Red List Index, or their ecological significance as indicated by consulted experts.

These notable species can further be used as an outline for conceptualisations in section C. These species could be clustered based on their potential opportunities in Sunbeams typologies for future conceptual development to structure the approach.

To ensure clarity, each species is listed by its English, Dutch and scientific name.

Bats

All bat species are legally protected in the Netherlands. While the LPI indicates an overall increase in bat populations, bats still impose significant restrictions on construction and renovation projects in urban areas, likely due to their strict legal protection. Bats in urban environments are primarily found in building structures such as roof surfaces, cavity walls, and fascia boards of buildings. The work is technically not permitted if a building with such bat presence requires renovation.

Earlier studies indicate that bat populations in the Netherlands have steadily increased in recent decades. Experts note that because all bat species are legally protected, current mitigation measures, such as mandatory roost surveys and construction restrictions, stem primarily from stringent building regulations to prevent habitat disruption. In addition, bats hold an important position in the food pyramid, as shown in Figure B.1.1, functioning as one of the dominant species within the group of secondary consumers. For this reason, bats remain a relevant and promising candidate for biodiversity enhancement within Section C. Some notable species are described below. Bats tend to look for spaces with quite specific microclimates, and need a variety of humidity levels. Bats are species with many requirements for their habitat; they tend to look for specific microclimates, especially in old buildings. Potential solutions need to include microclimate regulation, since research indicates that bats currently tend not to hide close to PV systems, as PVs can alter the temperature and humidity conditions on rooftops, making certain areas less suitable for bats to use as shelter (Snijder & van der Voorst, 2024).

Notable bat species

- Pond bat (*meervleermuis*): Around 30% of the European population is in the Netherlands. However, its population has halved since 2023. (La Haye & van der Meij, 2022)
- Pipistrelle bat (dwergvleermuis): Most common bat in the Netherlands, often associated with causing trouble with building regulations.

Birds

Earlier analysis showed that breeding birds, especially in the farmland and open land areas, showed population regression. The following list is compiled from insights from the Red List and experts in this field.

Notable bird species

- Common Tern (*Visdief, Sterna hirundo):* Classified as 'Vulnerable' on the Dutch Red List. Nests primarily on large, flat rooftops, making it an interesting species for rooftop biodiversity strategies.
- Eurasian Oystercatcher (*Scholekster, Haematopus ostralegus*): Not classified on the Dutch Red List, but indicated by experts as facing challenges with nesting opportunities, particularly in urban settings. Refer to Appendix C for further information.
- Black Redstart (*Zwarte roodstaart, Phoenicurus ochruros*): Not classified on the Dutch Red List, but it is indicated that nests are often found on rooftops in urban areas.
- White Wagtail (*Witte kwikstaart, Motacilla alba):* Not classified on the Dutch Red List, but it is indicated that nests are often found on rooftops in urban areas.
- Black-tailed Godwit (*Grutto, Limosa limosa*): Considered a land bird whose habitat is becoming increasingly scarce, mainly due to challenges with nesting in agricultural landscapes. Classified as 'Near Threatened' on the IUCN Red List.
- Northern Lapwing (*Kievit, Vanellus vanellus*): Classified as near threatened on the IUCN Red List, and mainly has a problem due to agricultural intensification.
- Sparrows are currently in much trouble because houses are getting better and better isolated, which causes habitat loss in urban areas. They are often found underneath tiles of rooftops.
- Swallows: The '*Delichon urbicum' (Huiszwaluw*) and '*Hirundo rustica' (Boerenzwaluw*) are both vulnerable on the IUCN red list.
- Common Starling (*Spreeuw, Sturnus vulgaris*): Mainly problems due to habitual loss in urban areas.

Designing a potential solution for upper consumers in specific situations can be considered, but is generally not recommended. Creating environments that favour upper consumers may lead to a negative impact on other species, as these species can suppress other populations. These potential consequences will be evaluated more later in this report, in Section C.

- Peregrine Falcon (*Slechtvalk, Falco peregrinus):* One of the upper consumers in the Dutch ecosystem. This bird is having quite some problems due to pesticide use, leading to eggshell thinning.
- Common Kestrel (*Torenvalk, Falco tinnunculus):* Some trouble due to loss of nesting opportunities. Mentioned as vulnerable on the red list.
- Eurasian Hobby (*Boomvalk, Falco Subbuteo*): Threatened on the red list, is dependent on open landscapes, with sufficient prey. Threatened because of a lack of breeding places and a lack of prey.
- Common Buzzard (*Buizerd, Buteo buteo*): Most common hunting bird in the Netherlands. Uses trees as a nesting opportunity.

Insects

Insects are seen as the typical first consumer when referring to the food pyramid visualised in Figure B.1.1. This makes them an essential fundamental part of the total Dutch ecosystem.

As mentioned before, flying insects especially show a general loss, and this is precisely where a potential Sunbeam product could mean something since all typologies are generally located on rooftops, which will mostly be accessible by flying insects - more about this in the next chapter.

Notable insect species

- Butterflies: As seen in Figure B.1.1, the LPI of butterflies has been declining a lot since 1990. Butterflies tend to look for warmer places, which could be a possible opportunity with PVs and their mounting systems. Butterflies are also insects that could more easily reach higher heights, according to expert interviews.
- Bees: Bees are often considered a keystone species, as they play a crucial role in pollination and maintaining ecosystem health. However, several bee species are struggling and have been placed on the IUCN Red List.
    - Honey bee: Does not occur in the wild in the Netherlands.
    - (red) Mason bee: Ground bees in the wild.
- Hoverflies: Hoverflies are among the most common insect species on the Red List (Rijksoverheid.nl, 2024).

Wild plants

Supporting plant life is always valuable, as plants form the foundation of the food pyramid and enable the presence of higher consumer species. In this way, plants contribute directly to increasing overall biodiversity, as illustrated in Figure B.1.3. Experts emphasise the importance of using plant species native to the original ecosystem, as local biodiversity has evolved in connection with these species.

A supplier of native seeds in the Netherlands is Cruydt-Hoeck.[4] They offer different seed packages for different substrate layer thicknesses. A follow-up interview with one of their ecologists highlighted the importance of a minimum substrate layer of 150mm (or 100mm with water retention) to improve native Dutch biodiversity. More on this interview can be read in Appendix C.

Notable plant species

34% of the total species on the Red List are plants. It can be said that many plants can be noted here. Some examples of plants that are on the red list and originate in the Dutch biome are:

- Field Scabious (*Beemdkroon, Knautia arvensis*)
- Yellow Rattle (*Kleine Ratelaar, Rhinanthus minor)*
- Soft Brome (*Zachte Dravik, Bromus hordeaceus)*
- Wild Marjoram *(Wilde Marjolein, Origanum vulgare)*

Other

Other notable species that may not be directly associated with a specific typology should still be included, as they contribute to a more complete understanding of the overall biodiversity context.

Notable other species

- Fire Salamander (amphibious): Amphibious show a slight increase in LPI, but this is even more evidence that this specific species is in danger, as it is the only amphibious with a significant drop.
- Fungi: Fungi are generally the most prominent representatives on the RLI, more than any other taxonomic group. Being available on the Red List and not seeing current trends going down significantly indicates that their decline in the Netherlands has been long-term and systemic. This reflects historical pressures and lasting vulnerability. As Appendix D outlines, many fungi species are especially sensitive to abiotic stressors.

This list can serve as further backing up of potential concepts, strengthening the argumentation of their potential impact.

[4] https://www.cruydthoeck.nl/

B.3: Current building solutions

This chapter will start with listing current options in the building sector that tend to increase biodiversity. Current solutions are listed to get a more complete general image of what is already happening, and if that aligns with the earlier indicated biodiversity problems. An overview of suitable biodiversity solutions in Sunbeam Typologies is provided in Table B.4.1 at the end of this chapter.

Current biodiversity enhancers

Below, some relevant biodiversity enhancers are listed, featuring green roofs and nest boxes. Insights are made with small interviews on the Solar Solutions fair, online interviews, and further desktop research.

Green facades and roofs

Multiple companies offer different applications of green roofs and/or facades. Here an overview will be given of the current different types of green roofs and facades.

In the context of green roofs, a common distinction is made between intensive and non-intensive systems. Intensive green roofs typically support a wider variety of plant species and therefore have a greater potential to enhance local biodiversity. However, they are generally less applicable to many rooftops due to the greater weight and thicker substrate layers they require. A typical non-intensive system is a Sedum roof, which includes plants that tend to thrive in drought conditions and can survive with very thin substrate (50-80mm). As mentioned earlier, do most native species need a minimum of 100 mm substrate with water retention, and 150 mm without water retention.

Figure B.3.1 on the right illustrates the typical layer structure of a green roof, which applies to both intensive and non-intensive variants, though the thickness and materials may vary.

Figure B.3.1: Fundamental layers of a green roof

Besides these standard layers, some optional additional layers are listed below.

Water irrigation systems. If additional water is needed in specific situations, additional water irrigation systems might be added.

Automatic water distribution systems. 'Zoontjes[10]', a company that specialises in a variety of water distribution systems to optimize rooftops and their efficiency with water.

Protective root layer. Protects the original rooftop against the roots of plants that might get through the first protection layer.

Multiple companies offer different applications of green roofs and facades. The products analysed here are offered by Sempergreen[5], SolarSedum[6], Groendakspecialist[7], ROEF[8] and NatureGreen[9]. In Figure B.3.2, an overview can be seen, and current solutions will be ranked on relative biodiversity effect and ease of application. The effect on biodiversity with these rooftops tends to increase if the difficulty of the application is higher. This mainly has to do with the fact that the difficulty of application increases when adding more space/thickness to a system. Some of these companies offer a combination of a PV installation with a green roof, also indicated in the figure. Further in the report, some of these companies are interviewed, leading to various insights. More about these specific insights can be read in Appendix C.

The biodiversity effect will be based on direct and indirect species enhancement. Direct species enhancement looks at the number of plants that will be able to grow in the product, and indirect enhancement considers the broader ecological benefits these plants can generate.
If a roof, for instance, applies a wide variety of native flowers and plants, this may have positive effects for pollinator species and other insects, which will attract birds, contributing to a richer ecosystem.

The difficulty of application is based on the total weight of the structure per square meter, layer thickness and ease of installation. A lower weight or thinner layer thickness makes products more applicable for a larger variety of rooftops,

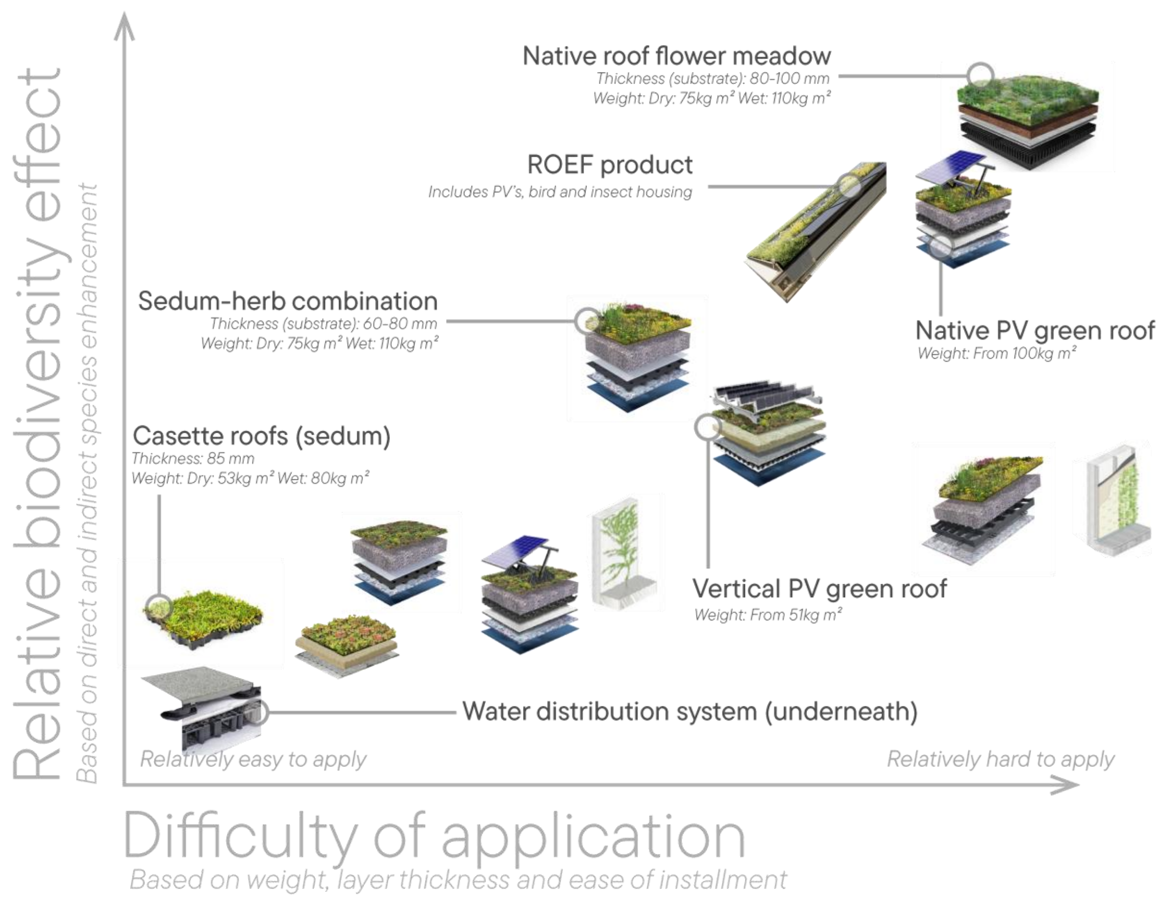


Figure B.3.2: Variety of green roofs and their biodiversity effects

[5] https://www.sempergreen.com
[6] https://www.solarsedum.nl
[7] https://www.groendakspecialist.nl
[8] https://www.roef.amsterdam
[9] https://www.naturegreen.nl
[10] https://www.zoontjens.nl/

Nest boxes

Another way to stimulate biodiversity in urban areas is to apply nest boxes. Different products from companies Unitura[11] and Vivara[12] are analysed here.

Information on Unitura was obtained via online desktop research and an online call with an expert working at Unitura (Appendix C). Unitura is a company that does various activities around nature-inclusive construction. Unitura notes that different landscapes require different animals to settle, and there is different reasons for their customers to choose to build with nature. The reasoning of clients is further developed in the personas of Chapter A.2.

Another company that delivers nest boxes is Vivara. They offer nesting solutions for bats, birds, and insects. Vivara works together with the 'Zoogdierenvereniging'[13] to find solutions with the best outcomes.

Biodiversity 'blockers'

The so-called biodiversity blockers are similar but tend to go for quite the opposite result. Biodiversity blockers can be applied in a variety of forms and can have various reasons for being applied. The companies that offer these products and are visualised in Figure B.3.3 here are Vogelverschrikker.nl[14], Floordirekt[15] and Birdblocker.[16] Species mostly excluded from built environments are feral pigeons, rats and seagulls. The main reason for this is the potential nuisance. Another species that is harder to prevent is mosquitoes. To prevent mosquitoes from piling up, still water should be limited.

Especially BirdBlocker is an interesting application, since it is a company that develops explicitly bird deterrent systems for PV systems, as bird nests underneath PV installations can lead to damaged cables, fire hazards, and reduced energy efficiency (BirdBlocker, n.d.).

In Figure B.3.3, different nest boxes and blockers are again ranked at applicability and the relative biodiversity effect. Literature presents a more critical view of these types of applications in relation to biodiversity. For instance, the effectiveness of nesting boxes is often not systematically verified (Vink, Vollaard, & de Zwarte, 2023, p.31). When used in larger quantities, they may even have negative ecological consequences (Zhang et al., 2023, p. 3). This indicates that the scores here for nest boxes also depend on how and where they are applied.

The overview of current solutions shows us that a variety of current products might have positive effect on biodiversity, if applied correctly. Native plant species can create the environment that was once there and restore possible other species in the ecosystem.

Figure B.3.3: Ranking of effect of nest boxes and biodiversity blockers

[11] https://www.unitura.nl
[12] https://www.vivara.nl
[13] https://www.zoogdiervereniging.nl
[14] https://www.vogelverschrikker.nl
[15] https://www.floordirekt.nl
[16] https://www.birdblocker.com

To see what potential effect Sunbeam can have, the typologies are discussed with experts to point out the solutions that they think would suit the best. The typologies are discussed with Unitura and Birdblocker, to get a general view on what species could be helped and which ones should be avoided to avoid further complications.

The insights regarding specific species are noted in Table B.3.1 and taken into account with further matching in Table B.3.2.

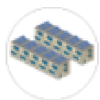
Typologies	**Unitura** *Fitting organisms*	**Birdblocker** *Blocking organisms*
 Agriculture	Most products installed for swallows: *Delichon urbicum' (Huiszwaluw)* and '*Hirundo rustica' (Boerenzwaluw)*	Avoid migratory birds, can transmit diseases to chicken from chicken farms
 Depots	Mostly installing for swifts (gierzwaluw) and house sparrows	If close to garbage processing, seagulls. (also, stone martens, can disrupt cables possibly)
 Flats	Greater building heights create opportunities for predatory birds (3rd consumers)	Seagulls
 Municipal	Mostly installing for swifts (gierzwaluw) and house sparrows	Most nuisance by jackdaws and pigeons. Flat rooftops seagulls
 Dense housing	Better for smaller solar panels on smaller flat rooftops.	Most nuisance by jackdaws and pigeons. Flat rooftops seagulls
 Spacious housing	More often green roofs are installed in this sector, being in general quite good for the biodiversity.	Most nuisance by jackdaws and pigeons. Flat rooftops seagulls

Table B.3.1: Current solutions in typologies

Green roofs and vertical gardens can mitigate some adverse effects of building height by providing habitats and resources for various species. (Rogers, 2022). Urbanisation can generally lead to changes in bird diversity, favouring some, and negatively affecting other bird species (Koch, van der Ree, & Fahrig, 2023). These studies show that it is essential to look at the species mentioned on the list earlier, and create something for the birds that tend to see adverse effects of urbanisation more and more, so we create a more favourable environment for them.

Some inspiration can be taken from the Trekvlietzone Den Haag concept, shown in Figure B.3.4 below. It shows a plan of a concept that is designed by Flux Landscape. 'Trekvlietzone nature inclusive has the potential to set an example for a nature inclusive city with a high ecological value.'- (Flux Landscape, n.d.). The different heights of biodiverse assets make the whole building more accessible for biodiversity, thriving to new heights. The different levels could be seen as 'stepping stones' for biodiversity. A potential ABP integrated into a Sunbeam construction could serve this same function.

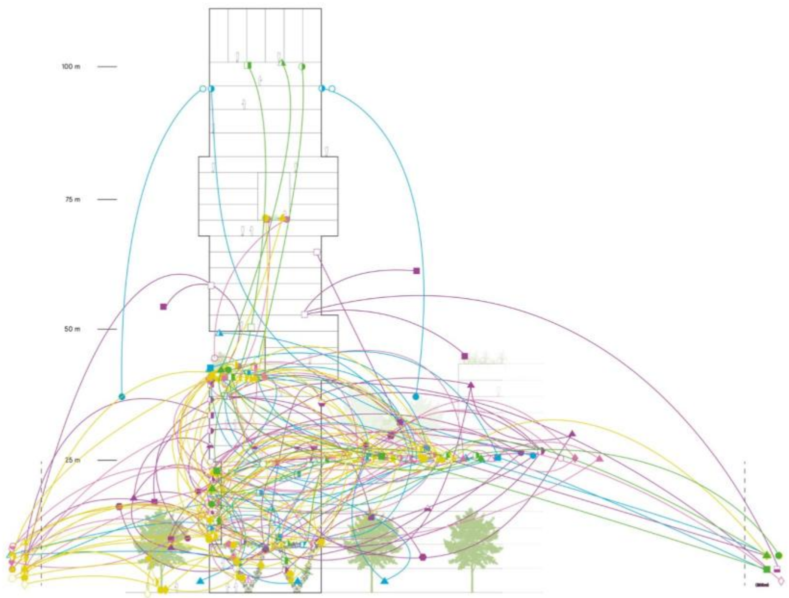


Figure B.3.4: Potential habitual relations at different heights of bats (purple), butterflies (pink), bees (yellow), other insects (green) and birds (blue) at Trekvlietzone, designed by Flux Landscapes

Key design considerations

Combining the knowledge from the desktop research and interviews with ecologists and current urban solution experts, a general overview is created of notable species that we can work with within the typologies of Sunbeam. Regarding the typologies, the height and size of the potential PV construction can be seen as a burden. Other surroundings of the typology are also relevant, whether in an urban, agricultural or open nature setting. On the next page, in Figure B.3.5, a complete overview of potential matches will be given.

This will serve as a baseline for further conceptualisation in section C. Note that this is not only a potential 'manual' for ABPs for Sunbeam, but this could be used for biodiverse, inclusive architecture/design in general.

Typology / Species type	Bats	Birds	Insects	Wild plants	Other
Agricultural	Potentially possible, bats could even be a positive impact for some agricultures, so less pesticides are needed	Potential nesting places are needed (avoid chicken farms for further implications)	Potential fit for flying insects, if (non toxic) environment is created	Wild plants could fit if surroun-ding is not directly affected too much by toxins	Challenging to reach
C&I	Challenging to reach	Different birds seek nesting possibilities here	Potential fit for flying insects, if environment is created	Great fit, if right environment is provided and maintained	Challenging to reach
Flats	Challenging to reach	Only predatory birds nest in these environments	Potential fit for butterflies, if environment is created	Great fit, if right environment is provided and maintained	Challenging to reach
Municipal	Can be applied if needed due to regulations	In dense areas an environment could be created	Potential fit for flying insects, if environment is created	Great fit, if right environment is provided and maintained	Challenging to reach
Residential houses	Can be applied if needed due to regulations	Dense populated birds mostly in need for environment and More open areas possible nesting for breeding birds	Fit if there's an plant rich environment already, otherwi-se environment needs to be created	Great fit, if right environment is provided and maintained	Challenging to reach

Potential match: Great fit — Great Potential fit — Potential fit — Not relevant

Table B.3.2: Indicating Species fitting with typologies for potential ABPs

Section C: Conceptualisation

This section serves as the initial connection between insights from Sections A and B. Visualising the total conceptualisation phase can be compared to the design and innovation process, the 'Double Diamond model.' (Design Council, 2019)

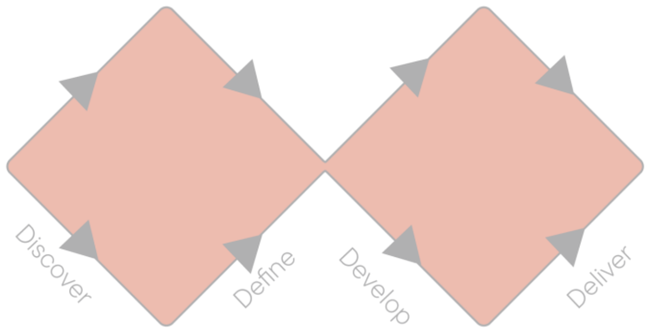


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Figure C.1: Double diamond model, according to the Design Council

It outlines the entire design process. Readers primarily interested in the overall design vision may refer only to Chapters C.1 and C.4.

C.1: Opportunity searching (Discover)
Lists the main opportunities coming from combining the knowledge from sections A and B, as well as the initially sketched concepts. Gives the final advised design direction to follow. *Note that conceptualisation started way before these final design directions, so the initial concepts are not always aligned with the way of thinking presented here.*

C.2: Lists of requirements (Define)
Various lists of requirements were distinguished *(derived from the earlier concepts and further desktop research):* species-related, product-related, and general wishes. These will serve as a foundation for further design and development.

C.3: Final opportunity mapping (Deliver)
Throughout the process of coupling back on feedback on earlier feedback, a final list of key challenges and key opportunities is made.

C.4: Final concepts & selection (Develop)
Showcase of the final three concepts, Anemone, Epiphyte and Acacia, and comparison of the three.

Conceptualising with biodiversity and PVs
Generated with ChatGPT, 2025.

C.1: Opportunity searching

Throughout the research process on biodiversity (Section B) and the solar mounting market (Section A), several opportunities were identified using the methodology outlined below. The outcomes were explored during weekly conceptual sessions and shared with the stakeholders, Sunbeam, and other experts.

This chapter finalises with advised product directions that are specifically linked to this project's scope, while also reflecting on broader opportunities within the biodiversity domain.

With the Morphological chart (van Boeijen et al., 2014, p.120) visualised below, the first concept ideas could be developed. Potential environments (the typologies from section A.1) and indicated potential species categories (section B.2) are combined in different combinations. The morphological chart also included various product locations to explore different building environments beyond the typologies. This extensive approach intentionally goes beyond Sunbeam's core expertise in flat rooftops, as reflected in the diversity of product categories.

Twelve initial concepts and their feedback from Sunbeam and other experts can be seen in Appendix F. These concepts start identifying clusters for conceptualisation. These ideas are not yet final, and they serve as a foundation for further exploration and will continue to evolve during the conceptual design phase.

After these concept initialisations, the concepts are clustered into three different categories, similar to a fish trap model (van Boeijen et al., 2014, p.111), to identify the potential impact on biodiversity in that area.

These final clusters will be analysed on the next page.

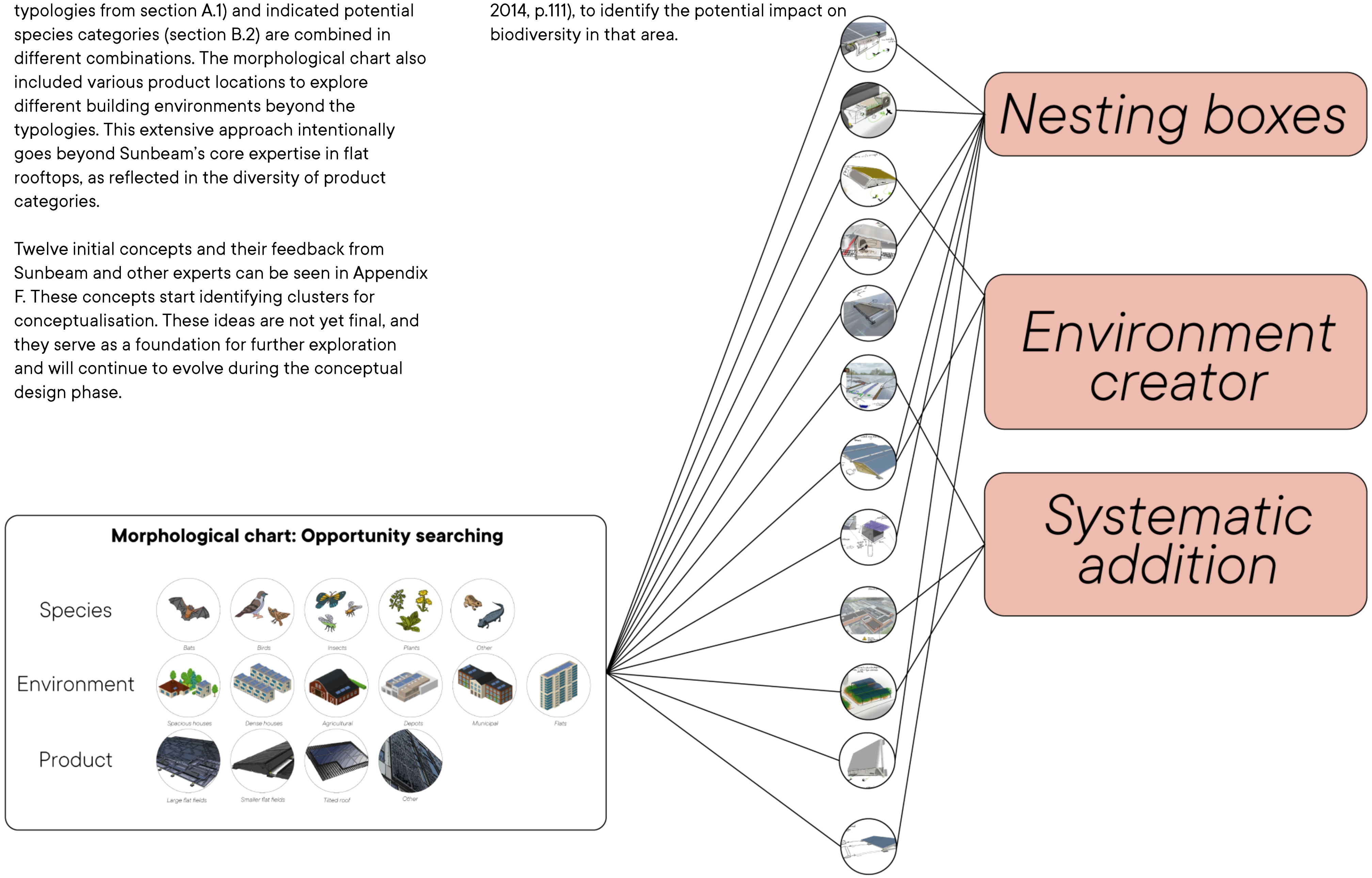


Figure C.1.1: From morphological chart, to initial concepts, to concept clusters

Why these design methods?

Methods such as the Morphological Chart and the Fish Trap Model are traditionally used to break down and structure well-defined sub-functions within a product. However, due to the complex and open-ended nature of this assignment (focused on identifying biodiversity opportunities on PV rooftops), these methods were applied in a more explorative way. In this context, the so-called 'sub-functions' do not represent fixed technical requirements, but rather opportunity areas such as organism types or environmental interventions.

Rather than aiming to solve a single, narrowly defined problem, the goal was to map a vast landscape of possible interventions and combinations. This approach made it possible to explore where the most meaningful and feasible contributions to biodiversity can be made.

While more open-ended methods like the "How Might We" technique are often used in early ideation phases, they were less suited here. Thanks to the earlier done research in Sections A and B, there was already a clear foundation (such as identified roof typologies and potential species lists) This meant the design process could move beyond open-ended brainstorming and instead use structured tools like the Morphological Chart and Fish Trap Model to organize, connect, and assess the available insights.

Analysing the concept clusters

When comparing the three clusters mentioned on the last page, the three categories are mainly clustered to show different investment levels and effects on biodiversity, as indicated by the feedback that various experts gave (Read more in Appendix F). The more systematic and wider the addition is, generally speaking, the greater the effect could be for biodiversity. However, more elaborate systematic additions may require significant financial and developmental investment from Sunbeam before they can be effectively implemented. The primary point of friction between ecological expert preferences and Sunbeam's priorities is represented in the clustering Figure C.1.2.

This trade-off becomes particularly evident in current practices, where companies and contractors often opt for simpler solutions (such as installing insect hotels or nest boxes) rather than undertaking the more complex task of rooftop ecosystem integration. As mentioned at the beginning of chapter B.3, the effectiveness of nest boxes is not always verified, and if implemented in large quantities, can even have negative effects. Prioritising direct support for higher trophic-level consumers may pose ecological risks, as such interventions can unintentionally favour opportunistic or competing species.

A famous example that might not be as good of an example for the Dutch ecosystem, but that is still interesting: In the U.S., the reintroduction of wolves into Yellowstone National Park led to significant ecological changes, including the reduction of elk populations and changes in vegetation patterns. These implications highlight the complex and sometimes unpredictable consequences of managing predator populations. (Estes et al., 2011)

As highlighted in Table B.4.1, species like seagulls can displace target species and lead to ecosystem imbalances. On the other hand, green roofs can provide the Dutch ecosystem with what has been lost, especially in more dense urban areas. Consulting ecological experts in future projects could be essential to identify specific needs in their appropriate locations.

While existing green roof 'environment creators' are more efficient, incorporating them into Sunbeam's product would require significant adjustments and significantly increase costs.

One of the initial concepts praised the most is concept 9, advanced Galileo (Appendix F). It explores several ways in which the Galileo online calculator tool could be expanded to guide biodiversity development at specific locations. Notably it is one of the few concepts that qualifies as a systematic addition while still being feasible to implement.

Sunbeam's Galileo[17] is an advanced online calculator designed to streamline the planning and configuration of solar panel installations using Sunbeam's mounting systems. (Sunbeam, n.d)

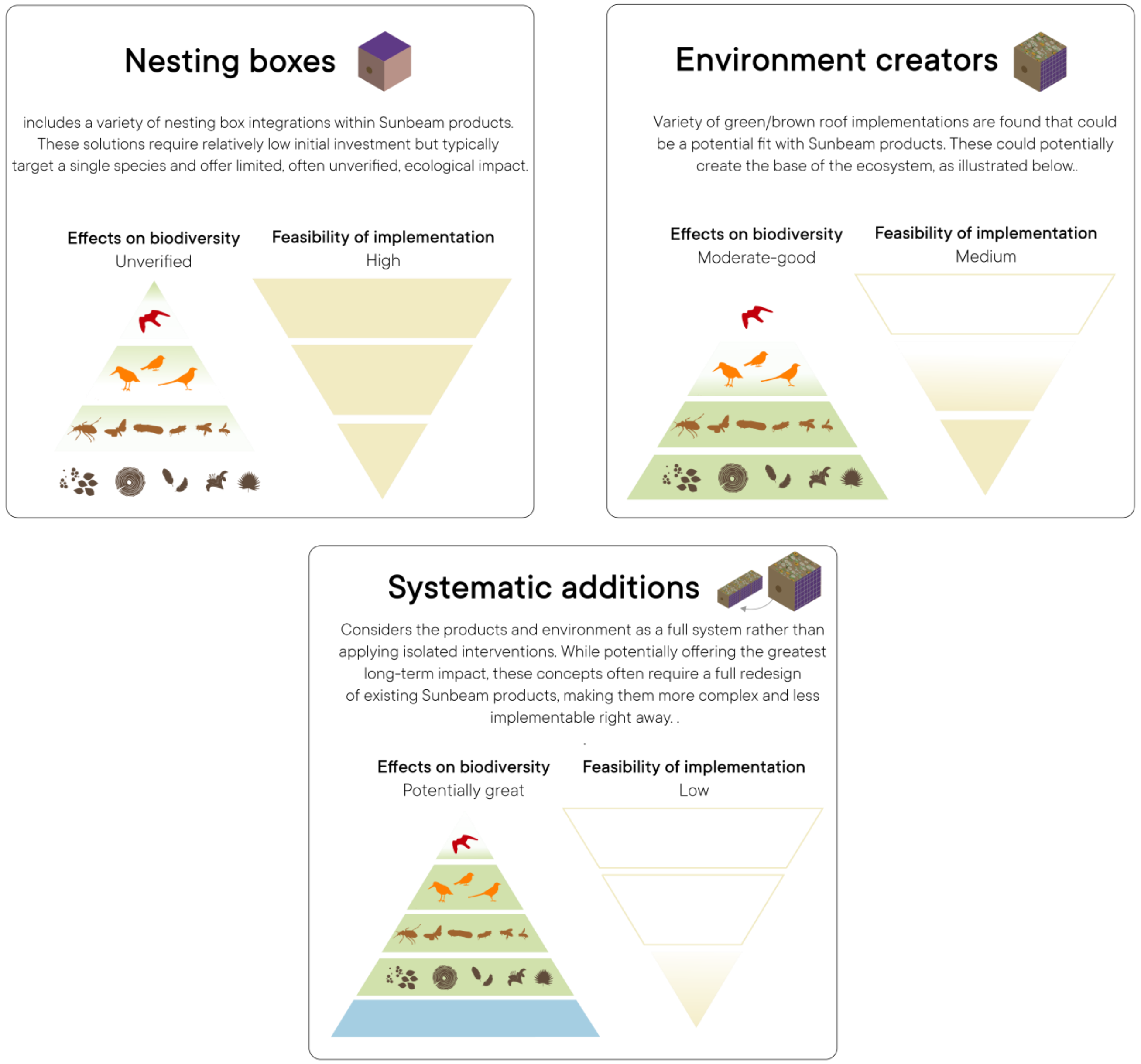


Figure C.1.2: Clusters with potential impact

Key design considerations

In further development, designing an environment that meaningfully supports biodiversity while remaining viable for short-term implementation is advised. By allowing a system to be scaled down or modularised, it becomes not only a practical starting point for Sunbeam but also adaptable to a broader range of clients and use cases.

[17] https://sunbeam.solar/calculator/

C.2: Lists of requirements

The list of requirements is divided into three categories: species-related, product-related, and follows up with general wishes. Together, they outline the key constraints which would eventually lead the design process to converge into final opportunities when designing with biodiversity in mind for Sunbeam. When matched with Sunbeams' product requirements, they help determine how feasible and impactful specific solutions can be.

The **'list of requirements: species'** developed offers general insights that can support biodiversity-focused design beyond this specific context. It is developed by combining the feedback of ecologists with supplementary desktop research done where needed. Important to note is that this list, developed, offers general insights that can support biodiversity-focused design beyond this specific context.

In addition, a set of **'product-specific requirements'** has been developed to quantify the reasoning behind the design of a PV mounting system. These requirements also account for relevant regulations, both for the mounting system and for the integration of ABPs.

The full list of requirements can be found in Appendix H.

Here, a **'list of wishes'** is also presented. Besides the lists of requirements that zoom in on many details of the biodiversity and product side, this list summarises the earlier research from sections A and B into measurable points. In Table C.2.1 all wishes are referred to the Section it's based on. The eventual concepts presented in chapter C.4 will be measured alongside these concluding wishes, following the earlier two lists of requirements. As seen in the table, a variety of wishes is derived from the earlier done research in sections A and B. Further, in the next chapter, C.3, specific opportunities and challenges are identified. These form the basis of some of the main wishes that a design would have to fulfil. The final concept should address these objectives as fully as possible in order to represent the most effective and well-adapted design.

Important to note is that these requirement lists will also extend beyond the conceptual phase, serving as essential tools during development and testing in an iterative design process.

Section	Description	Importance
A.1	ABP is desireable and implementable in a variety of **typologies**	Moderate/high
A.1	ABP is implementable in a variety of **products** of Sunbeam, without having to have a variety of product sizes	Low/moderate
A.2	ABP is implementable for a variety of **clients**; utility, residental and intrinsically or extrinsically motivated	Moderate
A.3	**Material Possibilities**: Possibilities to imply carbon negative materials.	Low/moderate
B.3	ABP offers the owner or user a convenient way to support specific **native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	Low/moderate
B.3	ABP helps ecosystem in a **sufficient** way and helps **foundation** of ecosystem	Very high
C.3	Estimated **cost calculation** relative to other concepts: Total additional cost of ABP	Moderate
C.3	ABP is benificial for biodiversity **and** mounting system	Very high
D	Feasibility in testing possibilities: Experimental steps requi-red are feasible to execute in the time span of the project	High

Table C.2.1: List of wishes

C.3: Opportunity mapping

Throughout the feedback sessions on initial concepts, several valuable insights came to the surface, along with key uncertainties that require further investigation before a concept can be refined. This chapter outlines the most critical issues raised and proposes potential solutions by shaping them as opportunities.

Key challenges

The following challenges highlight the main barriers to implementing ABPs into PV mounting systems, ranging from ecological trade-offs to technical constraints.

Additional disturbances

Various new unfortunate disturbances can occur due to adding an ABP, which are listed below.

How can we prevent damage and contamination caused by birds?

PVs and plants: Plants could grow in front of PVs and reduce PV efficiency, or the PV can adjust the climate negatively, influencing plant growth, even in solar parks (Atlas Leefomgeving, 2023).

Cables could be damaged by birds or other organisms attracted by ABPs.

Reducing the fire resistance of the system.

Temperature

Heating underneath the panels might cause problems for possible organisms habituating there and less efficient PVs. A typical PV might lose 0.3-0.5% of its efficiency every 1°C increase in temperatures above 25°C (8MSolar, n.d.).

Key opportunities

Several promising opportunities emerged from combining biodiversity and a solar mounting system.

Microclimate managing

The earlier-mentioned temperature stagnations could also be turned around into an opportunity. Figure C.3.1 indicates different climates created by adding PV (Snijder & van der Voorst, 2024), listing possible opportunities and challenges regarding temperature stagnations. As mentioned before, heating the PVs on flat rooftops makes the PV less efficient while reducing the chance of organisms' nesting success. PV panels absorb heat; close to the panels, heat can rise to 10-20 degrees above the normal temperature (Björk, 2018). Underneath the rooftop, however, it tends to be significantly cooler than rooftops without solar panels. (Sproul et al., 2018)

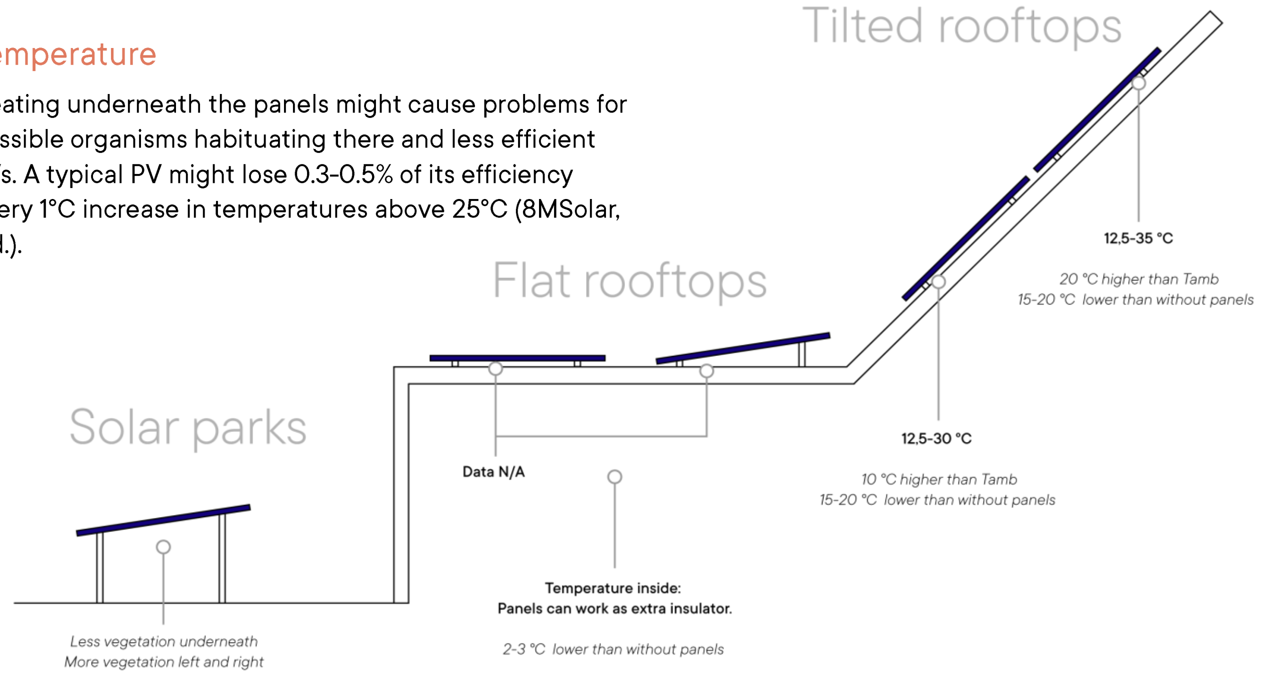


Figure C.3.1: Different climates influenced by PVs

Multifunctional water

The incorporation of water into the PV system offers a multifunctional opportunity that extends beyond panel maintenance. Water could become a strategic element supporting technical performance and ecological resilience by enabling cleaning, contributing to passive cooling, and enhancing habitat conditions.

Efficiency improvement

Many current green roof systems that combine with PVs use the USP that integrating greenery with PVs can boost PV efficiency up to 5-10%. (Sailor et al., 2011)

While this performance gain is often positioned as a unique selling point in existing solutions, the proposed concepts may incorporate this advantage as an indirect benefit.

Figure C.3.2: Current Supra system, with ballast shown underneath the panels

Multifunctional anchoring

Since ballast currently only serves as added weight for structural stability, it presents an opportunity to be reimagined for additional purposes, such as contributing to biodiversity or broader sustainability goals. One of Sunbeam's long-term objectives is to align with net-zero carbon policies. The current ballast components emit carbon during production and transport, despite their sole function being to meet safety and regulatory requirements. An image of the current ballast components is visualised in Figure C.3.2.

This raises the question: could ballast be replaced that fulfils the same structural role and is also designed to reduce CO_2 emissions?

If designed with integrated functionality in mind, such a component could serve dual purposes: First, fulfilling structural requirements while, secondly, simultaneously improving ecological value. Contributing to mechanical stability and biodiversity performance metrics offers a pathway toward more sustainable and functionally enriched design systems.

In further development, the opportunities of microclimate managing, water distribution and multifunctional anchoring are implemented into further ideas.

C.4: Final concepts & selection

The three final concepts presented in this chapter can be seen as an exploration of the key opportunities found in chapter C.3. In this chapter, three ideas are selected and designed according to all requirements mentioned earlier in C.2, and finally compared with each other. This gives us the conclusion of what will be further developed as the final concept. These ideas are all categorised as environmental regulators and could become a systematic system addition. This maximises the potential of the biodiversity impact while initially maintaining viability for Sunbeam.

Analogies of the main objectives

The opportunities outlined above align with the core objective: that the integration of biodiversity and photovoltaic systems results in mutual benefit. The underlying ambition is to develop a concept that embodies a mutualistic relationship, in which both ecological and technical performance are enhanced through their combination.

Mutualism is defined as...

"...an ecological interaction between two or more species where each species derives a net benefit. This relationship increases the fitness or survival of both parties involved."

(Bronstein, 2015)

In this design context, Mutualism refers to both the biodiversity enhancers and the PV system, which benefit from having each other on the same rooftop.

Each one of them tries to use one of the earlier indicated opportunities. The name of the concept is also in line with a species in nature that performs a similar bond; these are shortly described below, and visualised in Figure C.4.1.

Anemone *– An anemone is a plant that helps protect clownfish from strong currents. In this analogy, the ballast of a PV system functions like an anemone,* ***providing anchorage*** *that keeps the PV panel, like the clownfish, securely in place.*

Clownfish and sea anemone: *the fish driving off other parasitic fish and the anemone's tentacles protecting the fish from predators.*

Epiphyte *- An epiphyte is a plant that grows on another plant (typically a tree) for physical support, but does not take nutrients from its host. Instead, it absorbs moisture and nutrients from the air, rain, and debris that accumulates around it. This ABP works as a* ***microclimate regulator****, just as an epiphyte.*

Epiphyte and tree: *Epiphyte grows onto the tree for support, while creating a benificial microhabitat for the tree.*

Acacia *– Acacia trees and ants are one of the more famous examples of mutualism.*

Acacia tree and ants: *Acacia tree provides food and shelter for the ants, while ants protect the tree by agressively attacking herbivores eating from the tree.*

Figure C.4.1: The examples of mutualistic bonds

Concepts and their comparison

The three concepts are visualised on two A3 sheets on the following pages. On the first page, the concept is shown and visualised as integrated into a Sunbeam product to give a full view of the product in its habitat. More in-depth information can be found on the second page of each concept, like expected material costs per concept and other product specifications.

The three solutions are explorations of the three main opportunities identified earlier. Each concept is visualised based on a single east-west-oriented PV pair within a flat roof setup, ensuring consistent conditions for comparison.

To see the full effect of the concept, it is also important to see the vision of the bigger picture when the concepts are applied in bigger solar fields. All three concepts are modular, allowing the client to determine the quantity based on their needs. This aligns with one of the core advantages of Sunbeam products: their broad applicability across various settings.

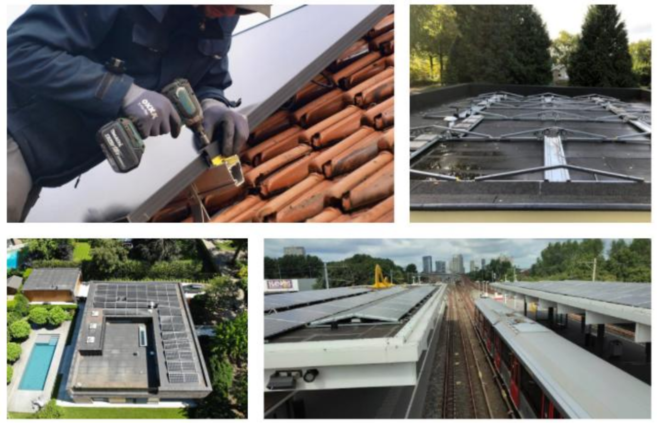


Figure C.4.2: Some examples of installations on smaller rooftops

It is important to note the empty space that some solar fields have, especially in the larger solar fields. The online calculator of Sunbeam **Galileo** calculates how the panels could be most efficiently organised to reach a specific energy goal of the client. To visualise this, some examples of larger Sunbeam fields in this sector can be seen in Figure C.4.3 below. For comparison, smaller installations are visualised in Figure C.4.2. One of the key requirements is adaptability across a wide range of typologies; the configuration shown here represents only one possible application. However, the gaps are often seen when larger fields are applied in the C&I typology.

Figure C.4.3: Some examples of installations on larger flat rooftops

Ranking the concepts

To rank the concepts, the wishes from C.2.3 are projected in the Harris profile (van Boeijen et al., 2014, p.139), visualised in Table C.4.1 below. A Harris Profile is a design method where each wish is ranked on a relative score. The wishes are ranked from most significant (higher) to least significant (lower). These ratings are based on how the three concepts rank across each other. These rankings visualised later, and could be based on some new calculations or possible amounts and outcomes earlier in the report example: as seen in implementation under clients: 1-4 personas.

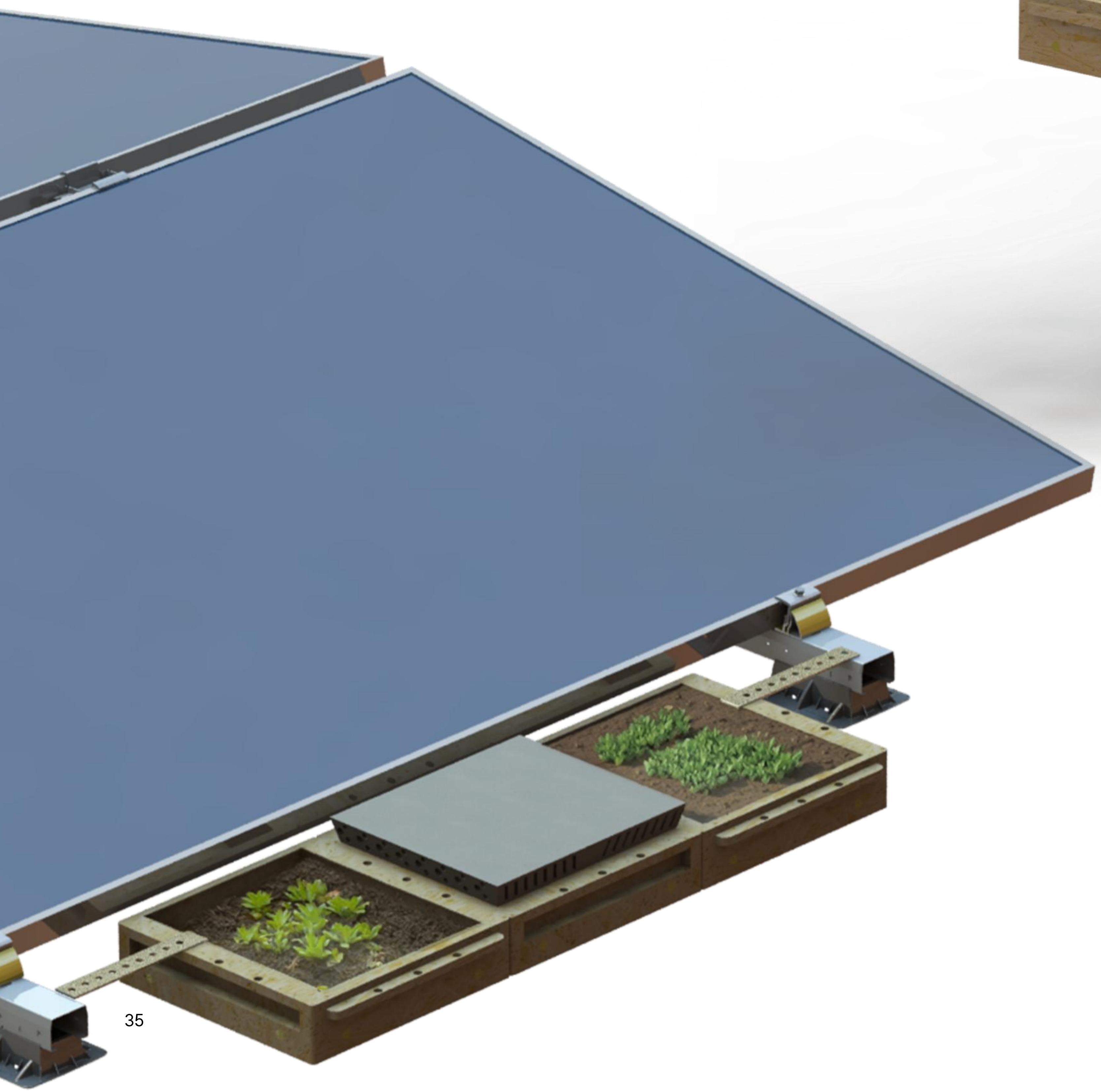
Important points regarding a specific ranking
If the ABP is beneficial for biodiversity and the mounting system is ranked on potential benefit for both (mutualism), benefit for one but no drawback for the other (commensalism) or a significant drawback for one of the two (parasitism)
Some wishes cannot be completely quantified at this stage of the design process. I.e. material studies have not entirely been done at this part of the process, so potential materials and their impact are explored, but this is not yet final.

Description	Rating			
	--	-	+	++
ABP is benificial for biodiversity **and** mounting system	*Possibly parasitic*	*Possibly parasitic/ commensalistic*	*Possibly commensalistic*	*Possibly mutualistic*
ABP helps ecosystem in a sufficient way and helps **foundation** of ecosystem	*Only consumers*	*Only consumers/ reducers*	*Helps multiple layers*	*Producers and/ or fundamental*
Feasibility in testing possibilities: Experimental steps required are feasible to execute in the time span of the project	*Not feasible in project timeframe*	*Some excessive background research*	*Most points are feasible*	*(Almost) all points are feasible*
ABP is desireable and implementable in a **variety of typologies**	*0*	*1-2*	*3 or more*	*5 or more*
Estimated material **cost calculation** relative to other concepts: Total additional cost of ABP	*Way more expensive than others*	*Bit more expensive than others*	*Bit cheaper than others*	*Way cheaper than others*
ABP is implementable for a **variety of clients**; utility, residential and intrinsically or extrinsically motivated	*None applicable*	*1/4 personas*	*2/4 or 3/4 personas*	*All personas*
Material Possibilities: Possibilities to imply **carbon negative materials.**	*No*	*Yes, few parts*	*Yes, most parts*	*Yes, almost all parts*
ABP is implementable in a **variety of products** of Sunbeam, without having to have a variety of sizes	*1 and needs a variety of versions*	*2, but needs a variety of versions*	*2, but adjustable to different sizes*	*3, and modular to different sizes*
ABP offers the owner or user a convenient way to support **specific native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	*Attracts invasive species*	*Possibly attracts invasive species*	*Only fits native species*	*Native species are directly implemented into concept*

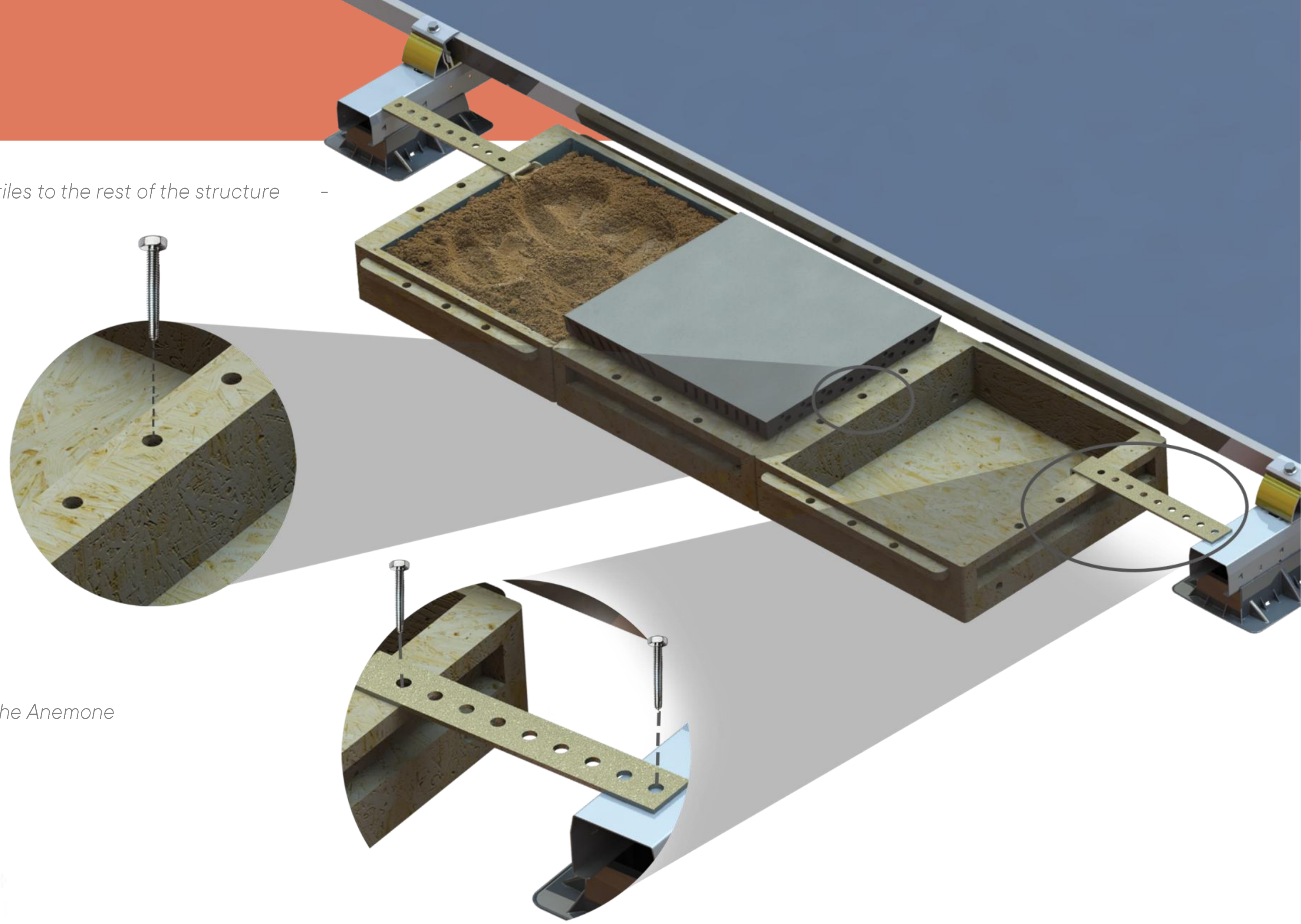
Table C.4.1 All wishes ranked in a Harris profile with possible ratings

The Anemone

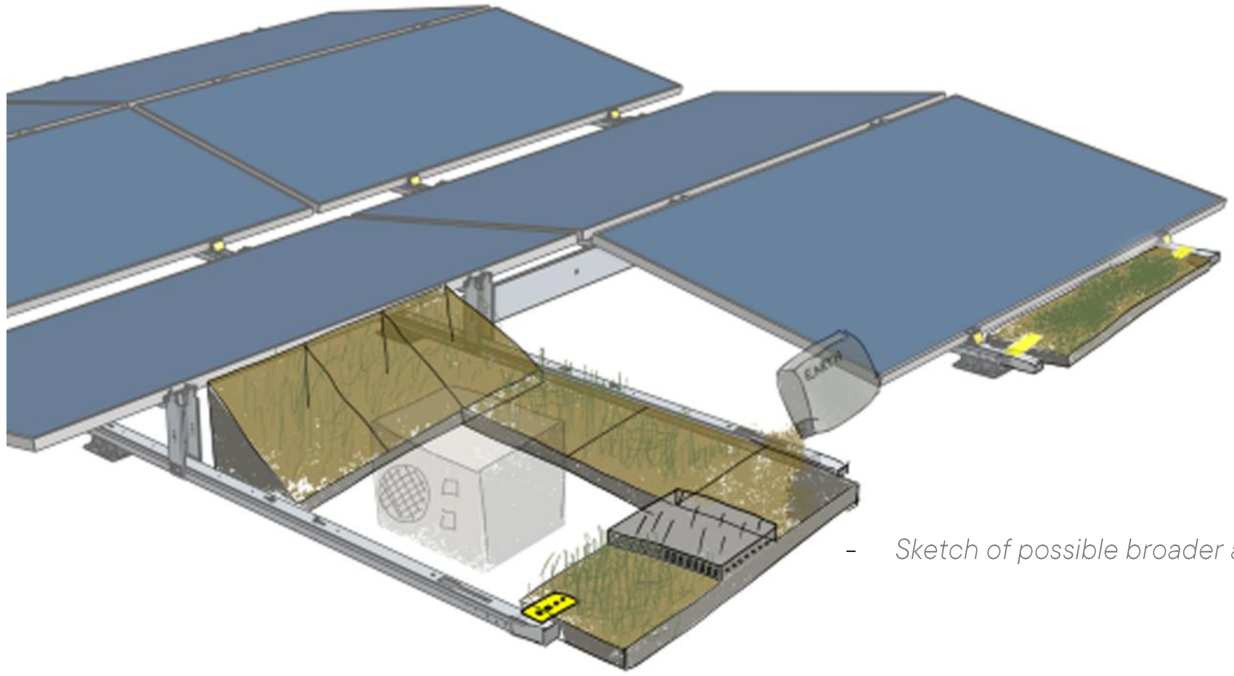
The anemone protect clownfish against strong streams



The Anemone concept replaces the traditional ballast system's function, enabling modular plates that can be made heavier or lighter as needed. For example, additional weight can be added by integrating features like insect hotels. The plants can grow inside the trays and create a biodiverse surface as big as the rooftop allows. This approach allows the longitudinal connection to be handled by the Anemones components, eliminating the need for traditional ballast plates and tiles.



Potential mounting of Anemone tiles to the rest of the structure -



- *Sketch of possible broader application of the Anemone*

- *Lists of parts, their potential materials and relative environmental impact*

Expected costs:

Connectors: €6 – €10
Insect hotel: €4 - 10
Water plugs: €3 – €6
Green tiles: €30 – €45

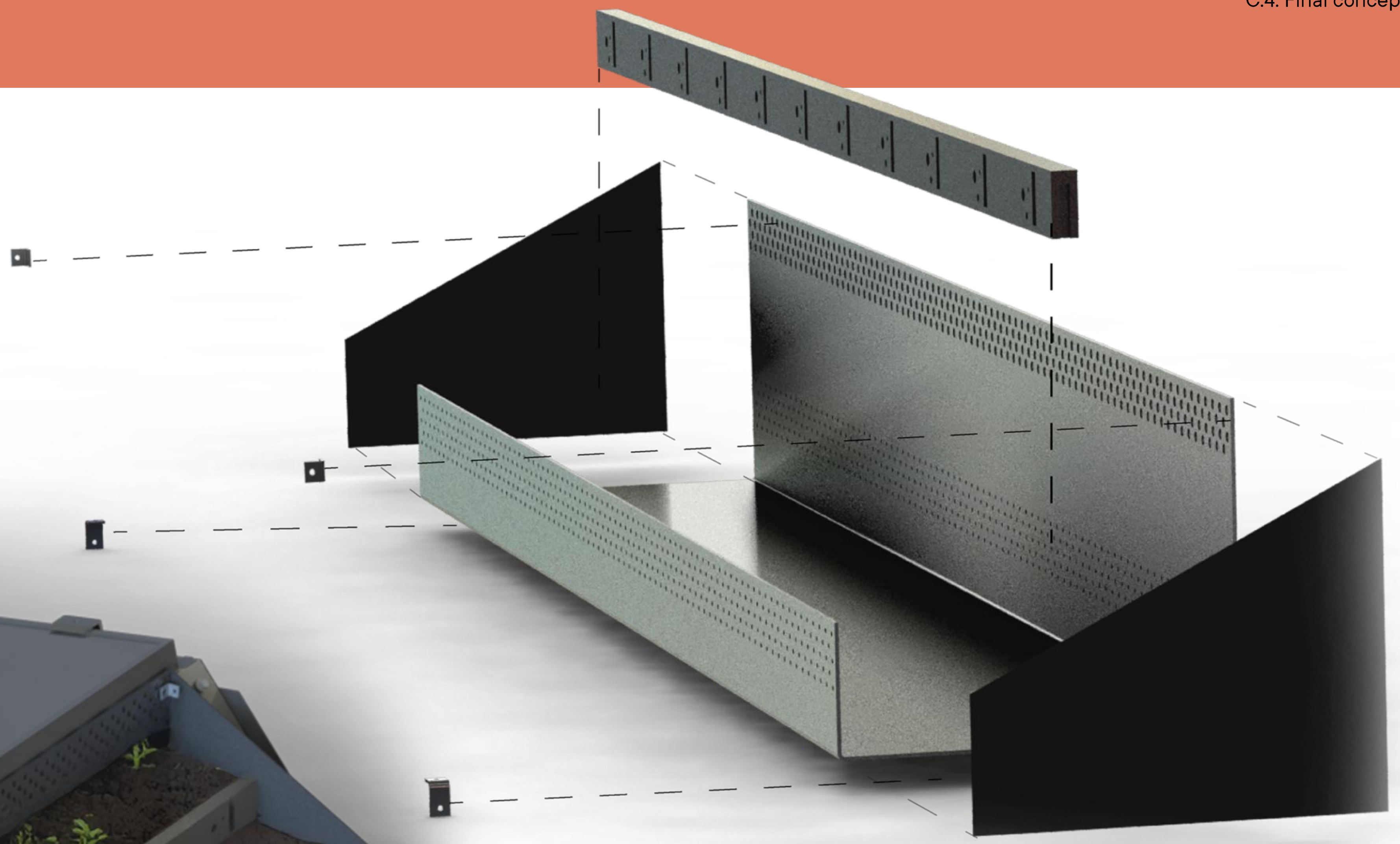
Total per set: €40 – €75

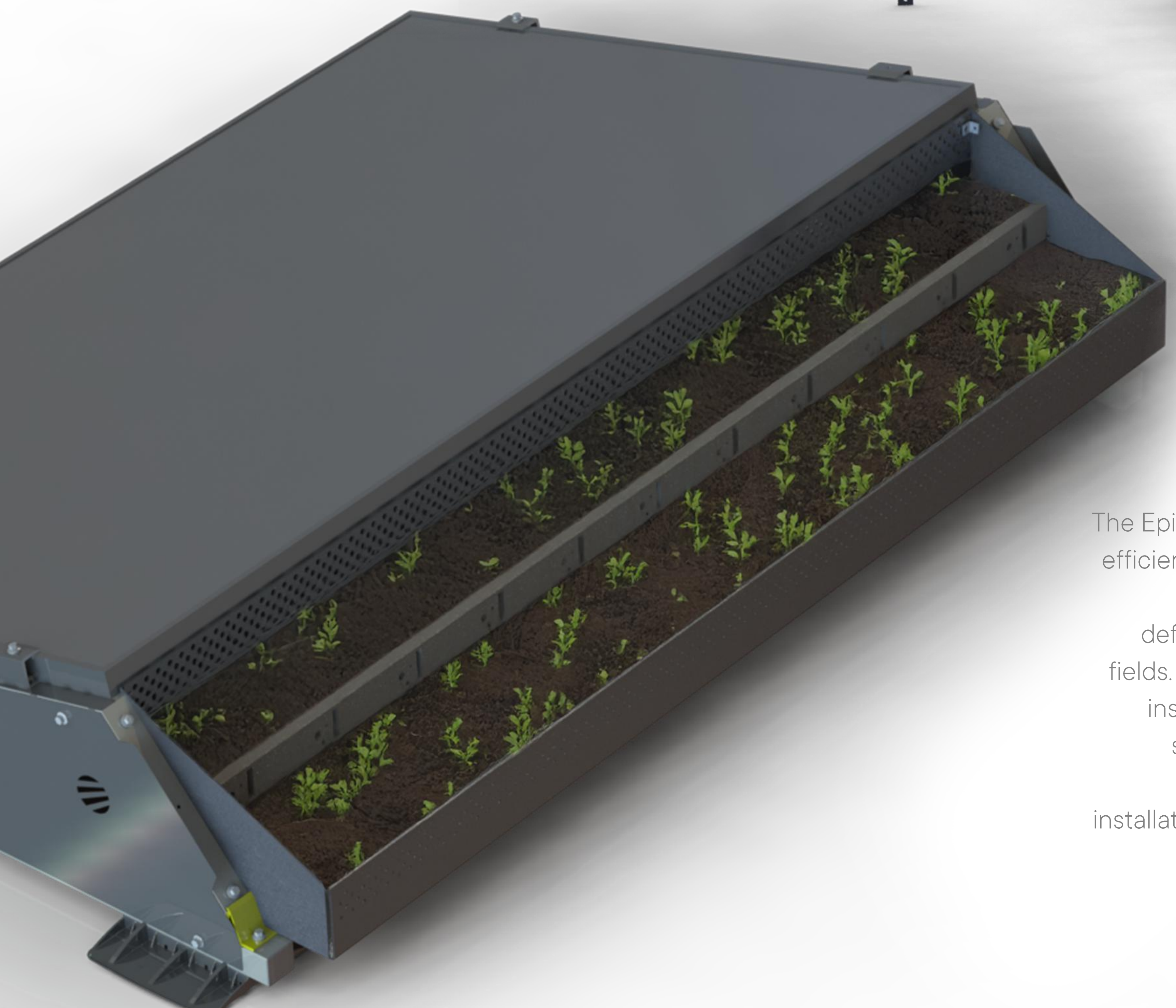
Important further validations:

Water retention, force distribution, Panel coverage of plants

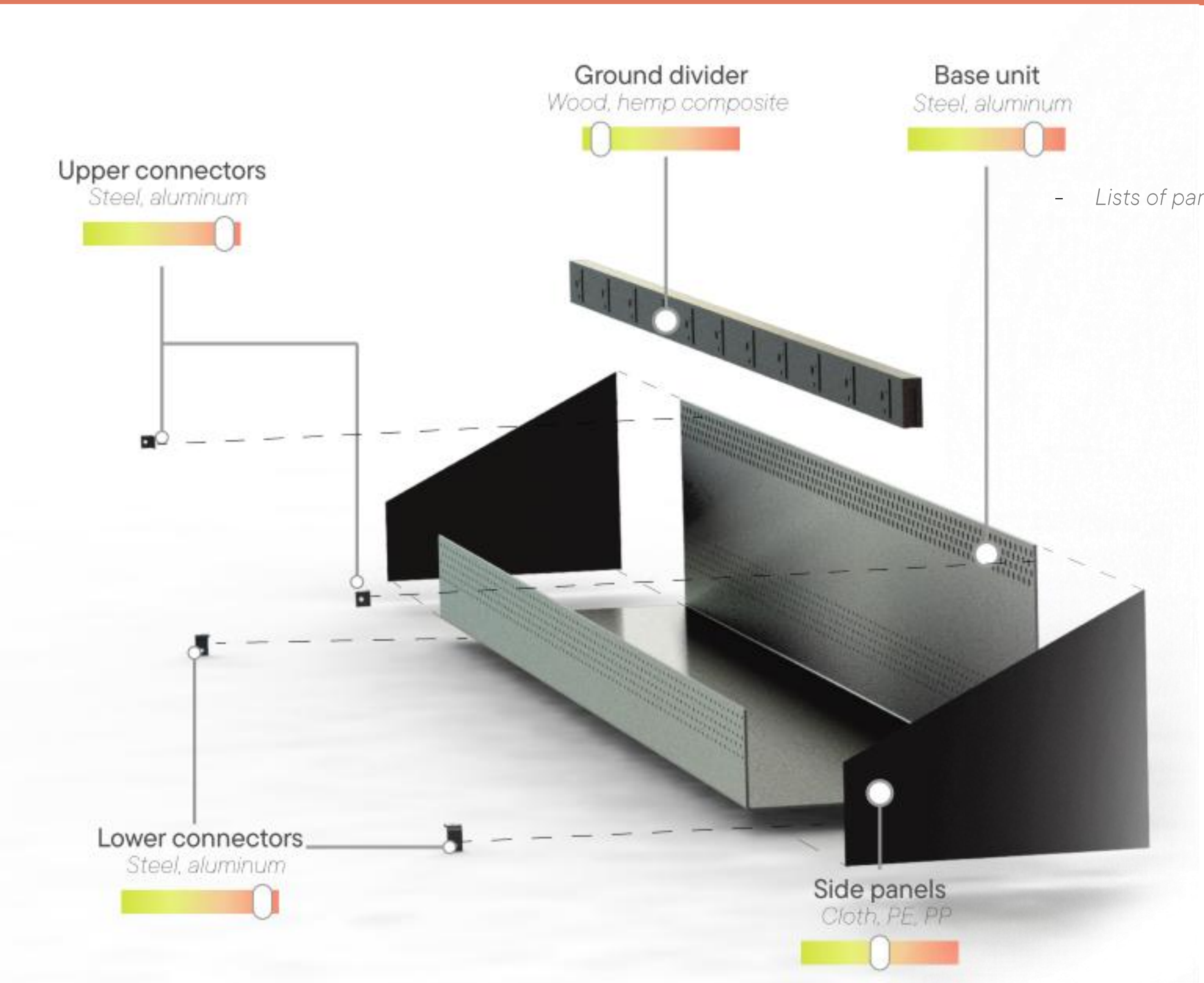
The Epiphyte

Epiphytes live on host trees; create microclimates by retaining moistures and creating shadows



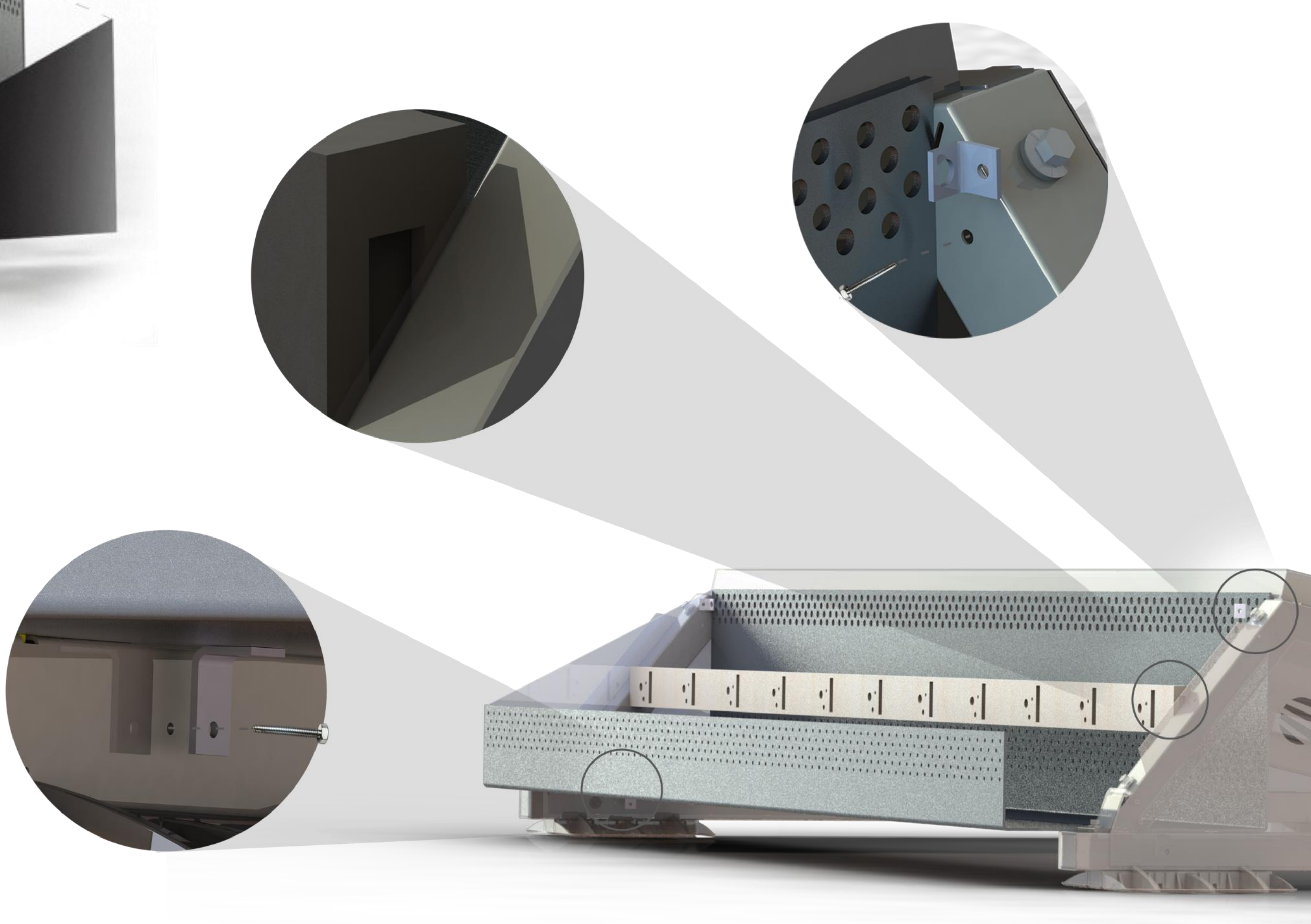


The Epiphyte explores the opportunity of microclimate management to improve the efficiency of the PV. It does so by letting warm air flow out at the upper holes of the product, and letting plants grow in front to be still able to function as a wind deflector. The product has multiple layers of plant growth, inspired by Asian rice fields. This way, the steep ground can be maximised for plant growth, and potential insect housing can be added in between. The Epiphyte is compatible with both small- and large-scale Nova systems and can be implemented across various applications, from commercial and industrial (C&I) settings to residential installations. It utilises various existing mounting points for seamless integration with the panel frames.



- *Lists of parts, their potential materials and relative environmental impact*

Potential mounting of the Epiphyte -



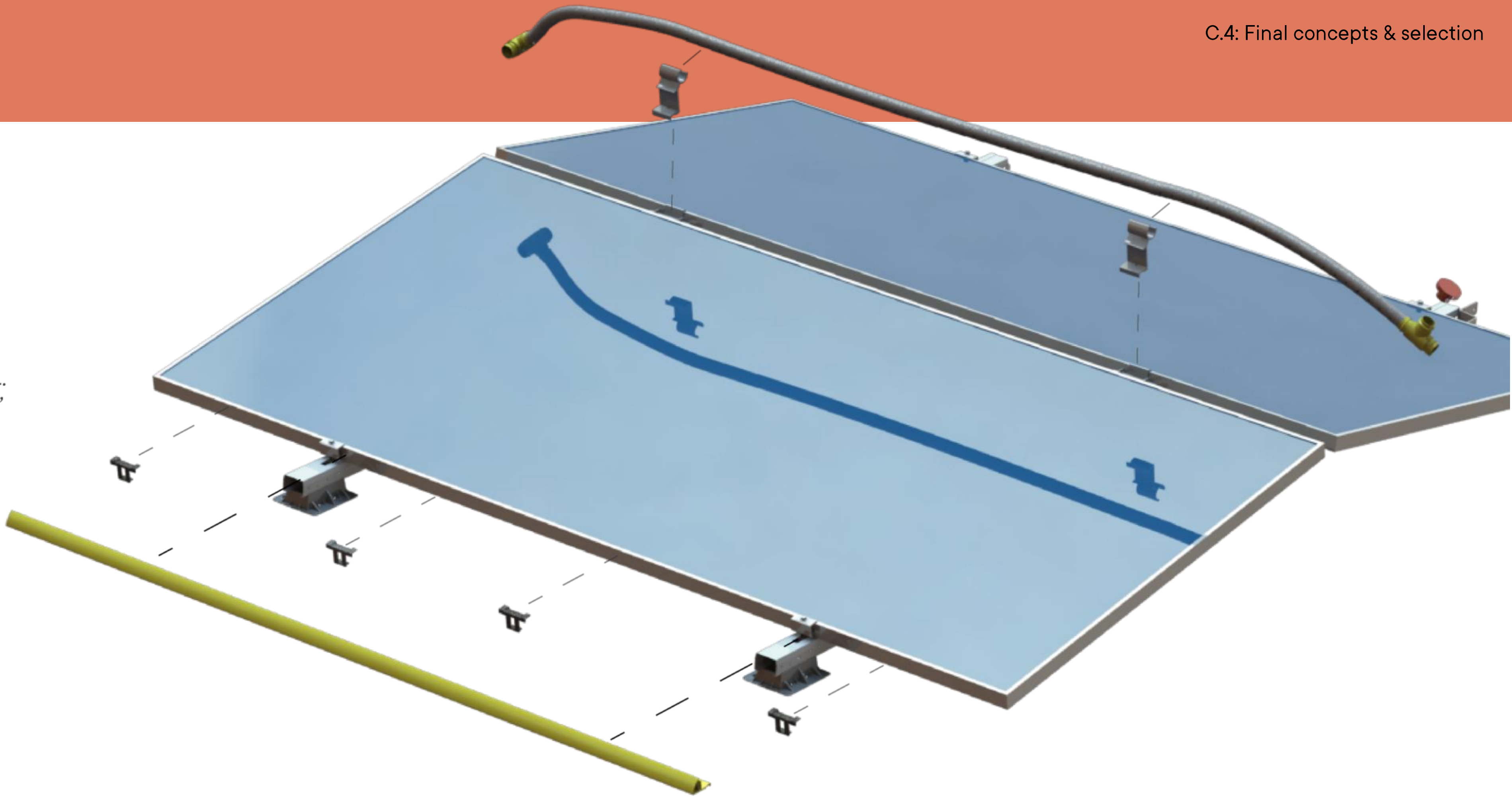
Expected costs:

Base unit: €20 – €35
Ground divider: €2 – €5
Connectors (4x): €12 – €20
Side panels: €3 – €6

Total set: €42 – €76.

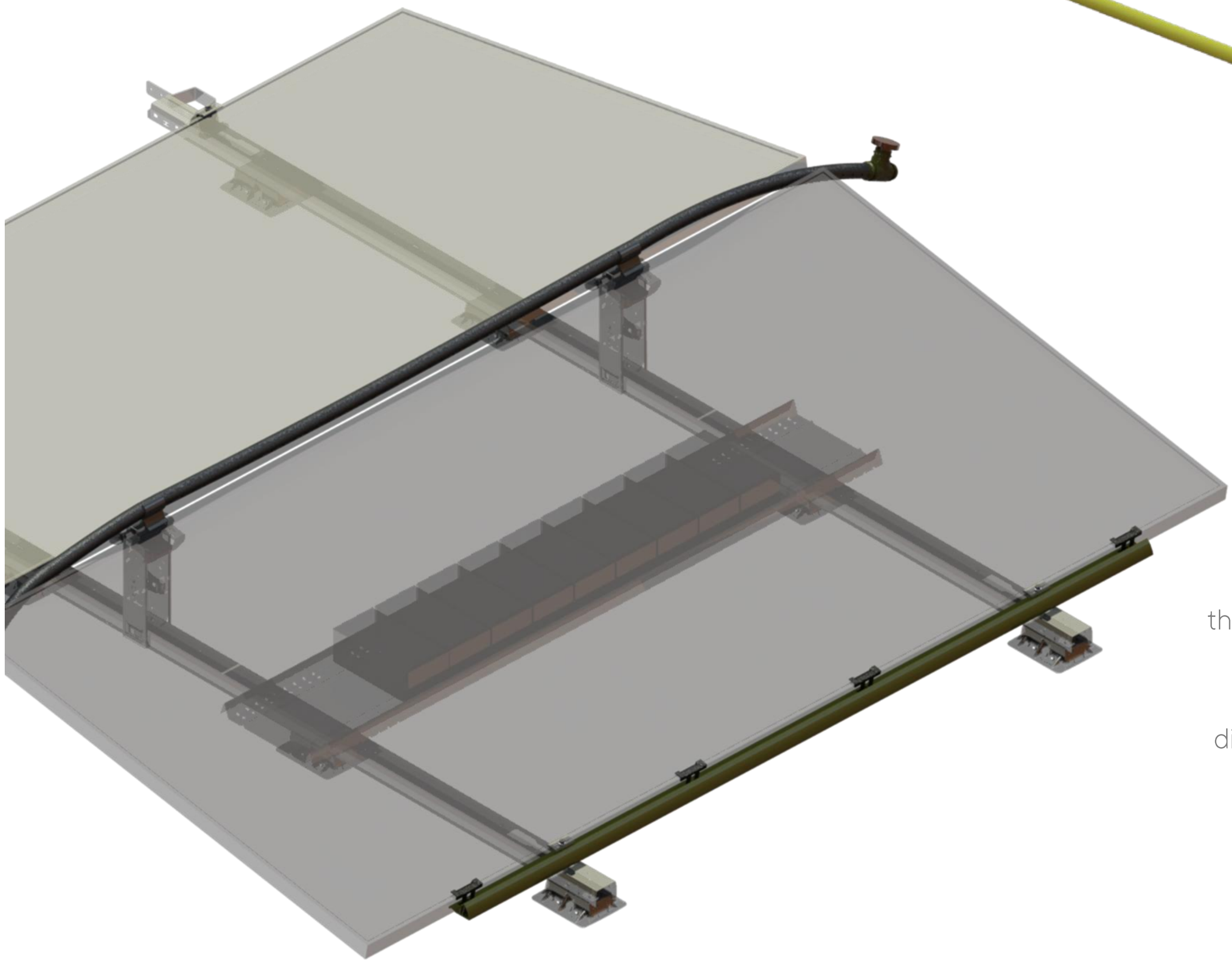
Important further validations:

Water retention, force distribution, Panel coverage of plants

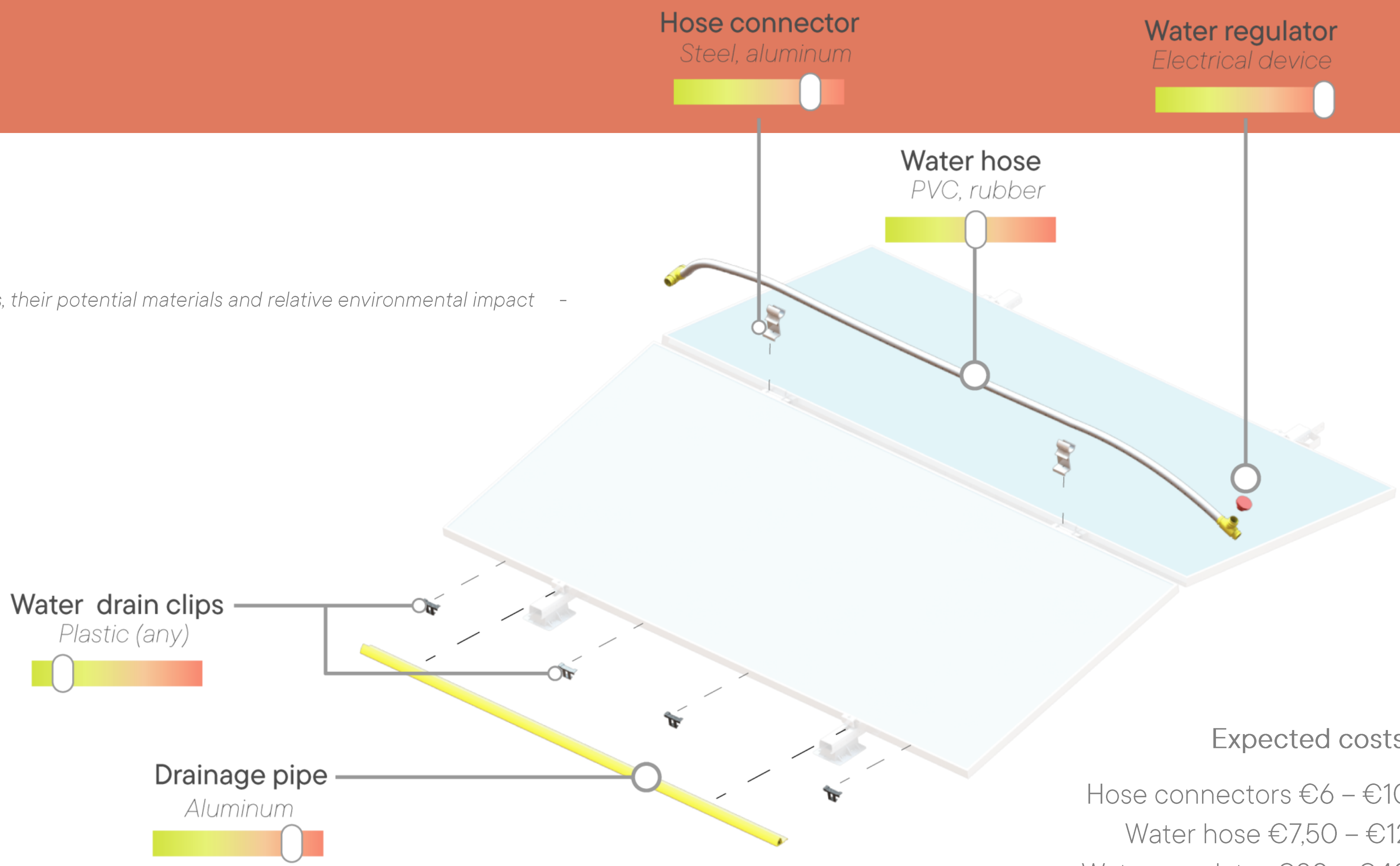


The Acacia

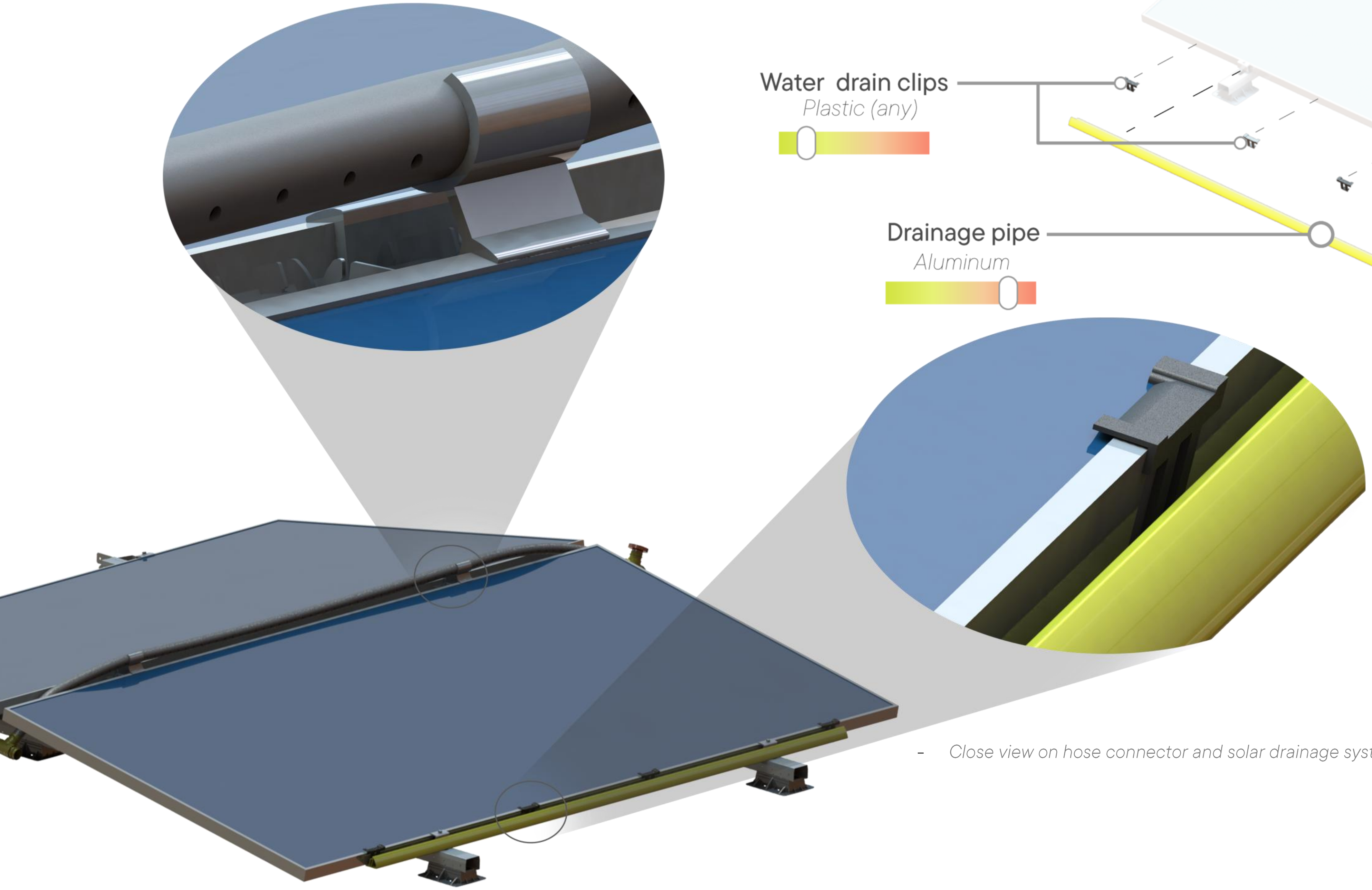
Acacia trees provide ants with water rich nectar and shelter; while the ants defend the tree



The Acacia system can be implemented on Supra mounting systems and explores the opportunity of multifunctional water distribution. The water will be applied at the panels' upper edge (can be bi-directional), and flows down into the drain clips and drainage pipe below. This runoff, containing accumulated debris, can then be directed towards designated areas to irrigate vegetation. In this way, the system not only manages water efficiently but also redistributes it to support plant growth where needed.



Lists of parts, their potential materials and relative environmental impact -



- *Close view on hose connector and solar drainage system*

Expected costs:

Hose connectors €6 – €10
Water hose €7,50 – €12
Water regulator €20 – €40
Water drainage clips €2 – €4
Drainage pipe €15 – €25

Total set: €50-100

(Costs become less per panel for larger fields, since the water regulator can be managed effectively so that not every panel needs its own regulator.

Important validations:

Water retention

The Anemone, Epiphyte, and Acacia concepts are evaluated using the previously constructed Harris profile to support a well-informed design decision in selecting the most promising concept regarding feasibility, viability, and desirability. As can be seen, some boxes have been coloured in different ways:

Dark: Secure, validated and fair comparison.

Light grey: Not fully validated (yet). These outcomes are not verified, and further research in these categories might be needed.

Red: Indicated at the Acacia; since this concept does not contribute to biodiversity directly, these wishes cannot be compared here, since some of the requirements have not been fulfilled. This indicates the fundamental weak point of the Acacia concept: The concept could only be seen as a biodiversity enhancer if it is combined with another concept.

Further development considerations

Based on the ranking, **the Anemone emerges as the most promising concept and will be further developed in Sections D and E of this report.** Several design criteria still leave room for improvement. In particular, the foundational support for biodiversity could be improved and looked into. The final concept should deliberately incorporate valuable elements from the other designs, particularly the Acacia's potential for foundational ecological impact. Water plays a key role as a driver for attracting and supporting ecosystems, and **a hybrid approach combining features of the Anemone and Acacia concepts may offer a particularly promising and effective solution for further research.**

Further development is needed, especially at the places where the wishes are not verified yet. This will happen in the next section, D, Development.

Rating Anemone

	− −	−	+	+ +
ABP is benificial for biodiversity **and** mounting system	Possibly parasitic	Possibly parasitic/ commensalistic	Possibly commensalistic	Possibly mutualistic
ABP helps ecosystem in a **sufficient** way and helps **foundation** of ecosystem	Only consumers	Only consumers/ reducers	Helps multiple layers	Producers and/ or fundamental
Feasibility in testing possibilities: Experimental steps required are **feasible to execute** in the time span of the project	Not feasible in project timeframe	Some excessive background research	Most points are feasible	(Almost) all points are feasible
ABP is desireable and implementable in a variety of **typologies**	0	1-2	3 or more	5 or more
Estimated **cost calculation** relative to other concepts: Total additional cost of ABP	Way more expensive than others	Bit more expensive than others	Bit cheaper than others	Way cheaper than others
ABP is implementable for a variety of **clients**; utility, residental and intrinsically or extrinsically motivated	None applicable	1/4 personas	2/4 or 3/4 personas	All personas
Material Possibilities: Possibilities to imply carbon negative materials.	No	Yes, few parts	Yes, most parts	Yes, almost all parts
ABP is implementable in a variety of **products** of Sunbeam, without having to have a variety of product sizes	1 and needs a variety of versions	2, but needs a variety of versions	2, but adjustable to different sizes	3, and modular to different sizes
ABP offers the owner or user a convenient way to support specific **native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	Attracts invasive species	Possibly attracts invasive species	Only fits native species	Native species are directly implemented into concept

Rating Epipfyte

	− −	−	+	+ +
ABP is benificial for biodiversity **and** mounting system	Possibly parasitic	Possibly parasitic/ commensalistic	Possibly commensalistic	Possibly mutualistic
ABP helps ecosystem in a **sufficient** way and helps **foundation** of ecosystem	Only consumers	Only consumers/ reducers	Helps multiple layers	Producers and/ or fundamental
Feasibility in testing possibilities: Experimental steps required are **feasible to execute** in the time span of the project	Not feasible in project timeframe	Some excessive background research	Most points are feasible	(Almost) all points are feasible
ABP is desireable and implementable in a variety of **typologies**	0	1-2	3 or more	5 or more
Estimated **cost calculation** relative to other concepts: Total additional cost of ABP	Way more expensive than others	Bit more expensive than others	Bit cheaper than others	Way cheaper than others
ABP is implementable for a variety of **clients**; utility, residental and intrinsically or extrinsically motivated	None applicable	1/4 personas	2/4 or 3/4 personas	All personas
Material Possibilities: Possibilities to imply carbon negative materials.	No	Yes, few parts	Yes, most parts	Yes, almost all parts
ABP is implementable in a variety of **products** of Sunbeam, without having to have a variety of product sizes	1 and needs a variety of versions	2, but needs a variety of versions	2, but adjustable to different sizes	3, and modular to different sizes
ABP offers the owner or user a convenient way to support specific **native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	Attracts invasive species	Possibly attracts invasive species	Only fits native species	Native species are directly implemented into concept

Rating Acacia

	− −	−	+	+ +
ABP is benificial for biodiversity **and** mounting system	Possibly parasitic	Possibly parasitic/ commensalistic	Possibly commensalistic	Possibly mutualistic
ABP helps ecosystem in a **sufficient** way and helps **foundation** of ecosystem	Only consumers	Only consumers/ reducers	Helps multiple layers	Producers and/ or fundamental
Feasibility in testing possibilities: Experimental steps required are **feasible to execute** in the time span of the project	Not feasible in project timeframe	Some excessive background research	Most points are feasible	(Almost) all points are feasible
ABP is desireable and implementable in a variety of **typologies**	0	1-2	3 or more	5 or more
Estimated **cost calculation** relative to other concepts: Total additional cost of ABP	Way more expensive than others	Bit more expensive than others	Bit cheaper than others	Way cheaper than others
ABP is implementable for a variety of **clients**; utility, residental and intrinsically or extrinsically motivated	None applicable	1/4 personas	2/4 or 3/4 personas	All personas
Material Possibilities: Possibilities to imply carbon negative materials.	No	Yes, few parts	Yes, most parts	Yes, almost all parts
ABP is implementable in a variety of **products** of Sunbeam, without having to have a variety of product sizes	1 and needs a variety of versions	2, but needs a variety of versions	2, but adjustable to different sizes	3, and modular to different sizes
ABP offers the owner or user a convenient way to support specific **native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	Attracts invasive species	Possibly attracts invasive species	Only fits native species	Native species are directly implemented into concept

Table C.4.2: Comparison of final concepts with help of Harris profiles

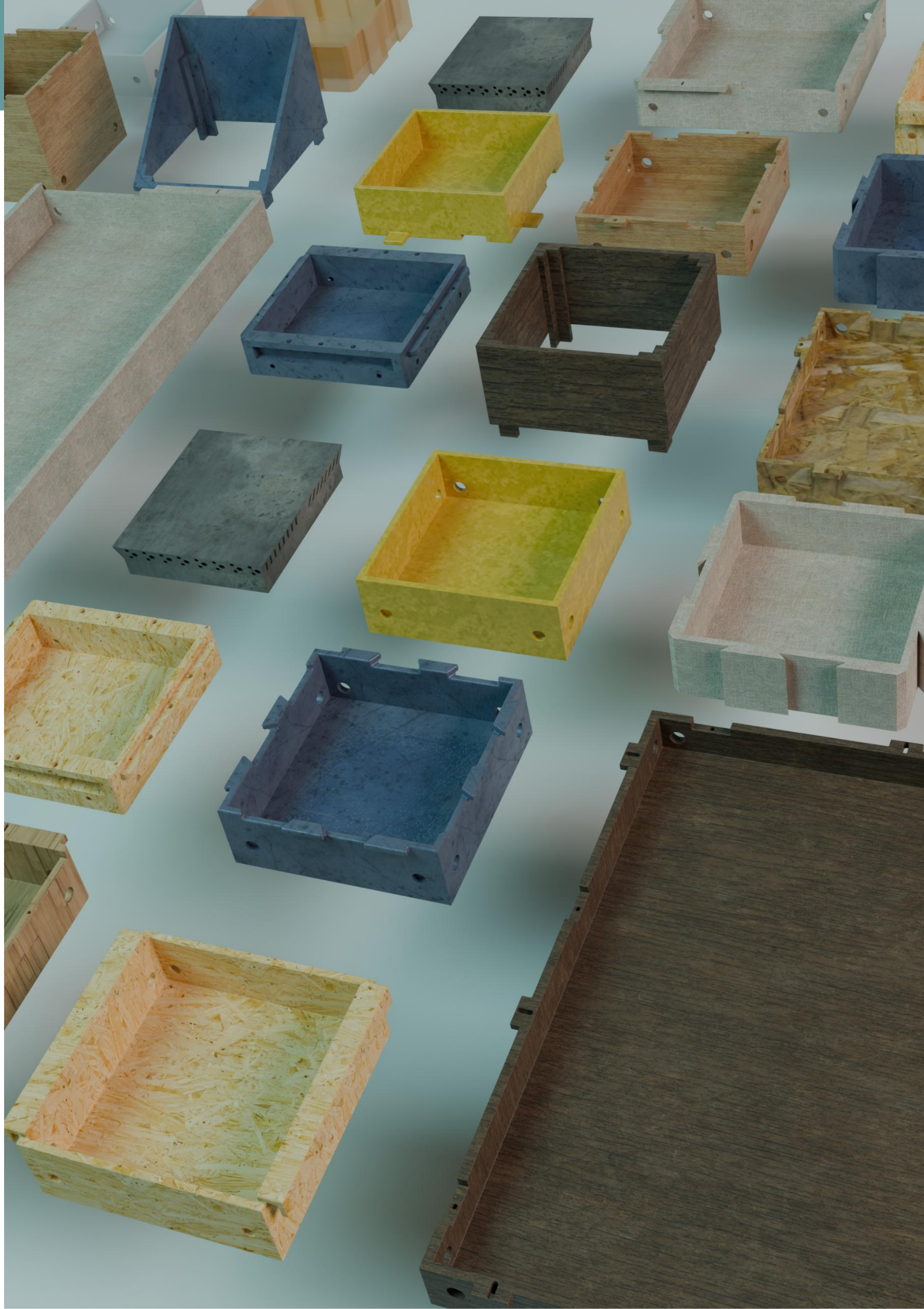
Section D: Development

This section outlines the development phase of the Anemone system, moving from conceptual exploration to technical evaluation. It begins by breaking down the system into key subfunctions and ends with structural and environmental validations that shape the final design.

D.1: Exploring subfunctions
Iterations explored under so-called subfunctions will be evaluated according to wishes and test initial viability, feasibility, and desirability. These wishes can be called 'sub wishes' and contribute to the main wishes cited in C.2. The chapter ends with takeaways about the explored possibilities. It gives us the starting point from which combinations will be technically evaluated in D.2.

It is worth noting that the subfunction studies also explore alternatives to the final design decisions and can serve as inspiration for future iterations aimed at optimising the system.

D.2: Final validations
The top-rated subfunction combinations are tested for structural integrity using CAD simulations, which help identify the final design adjustments needed to ensure a well-integrated system. Additional final cost and emission estimates are provided to assess the final product's financial and environmental feasibility.



Different Anemone tiles with different subfunctions applied

D.1: Exploring subfunctions

This chapter explores the different options for developing the optimal Anemone's modular tile system, according to specific product requirements. The product requirements will be divided under specific subfunctions, each with specific requirements. For each subfunction, the most interesting options are presented. The most fruitful combinations will be evaluated on some structural CAD testing in D.2, and further evaluated with the final prototype in D.3.

The Subfunctions described in this chapter are material selection, tile dimensioning, frame connection, and tile connections, as seen in Figure D.1.1 below. Tile dimensioning is split into two subfunctions, surface area and tile height, since they each have specific requirements. This exploration aims to create the ultimate base of the product, which can function in a mutualistic bond between the PV and biodiversity system. This will set the base of the Anemone's design.
Each subfunction explored in this chapter will initially have its main requirements and wishes listed, making design decisions easy to follow.

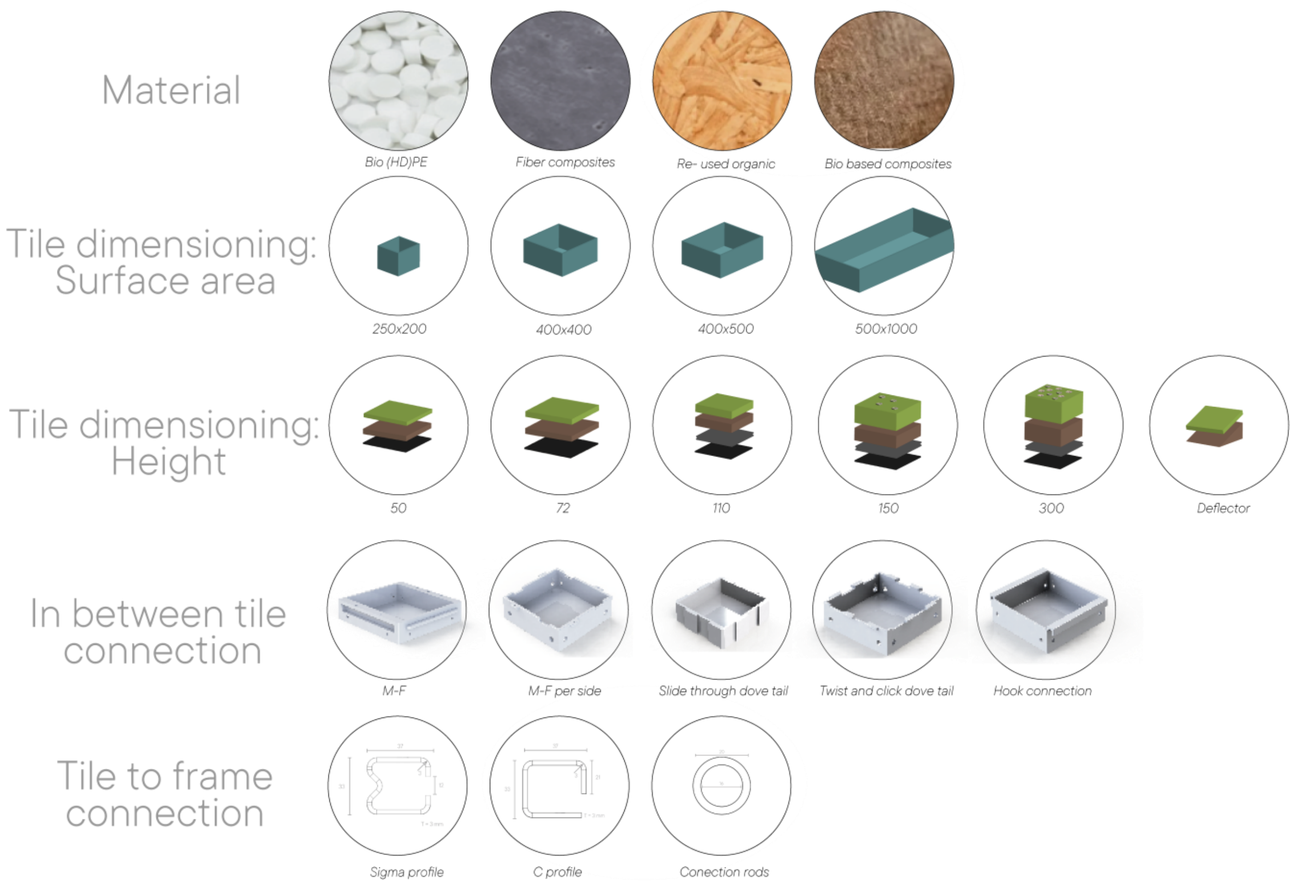


Figure D.1.1: Morphological chart with all evaluated subfunctions

Material selection

Below the requirements and wishes are listed.

Requirements
1) All materials should suit the following requirements when shaped into a tile (further described in chapter C.2).
1.1) Acceptable pressure weight (on rooftops, to not damage rooftop materials).
1.2) Corrosion resistance.
1.3) UV resistance.
1.4) Water resistant.
1.5) Temperature stagnations from -20°C to +60°C without deforming, cracking or weakening
1.6) Structural strength to support:
Weight of saturated soil
Can function as ballast and transfer longitudinal forces within the PV mounting system, ensuring the structural stability of the overall setup
1.7) Weight of a tile should be

Wishes
1) Material impact is minimal.. There are different ways to optimise for carbon storage in a product by
... optimising on product longevity.
A product lasting long is not a bad thing in this case. The general requirement for a PV mounting installation of Sunbeam is to last 30 years.
... optimising on total carbon storage per tile.
More about this on the right.
... optimising an efficient end of life.
This is already quite optimised in the general concept, since the product, soil, and other parts can be taken apart.
... optimising on producibility and transport.

2) Cost per unit as low as possible, the material should fit manufacturing methods, so that it can be done easily in larger quantities.

On the next page, four good material choices will be briefly discussed and ranked on how they score across the earlier indicated wishes.

Why carbon negative materials, and how?

Sunbeam products are certified climate neutral by compensating for their remaining CO_2 emissions. Sunbeam aims to reduce its carbon emissions to 0 by 2040, thereby decreasing reliance on offset certificates (Sunbeam, n.d.). This strategic shift is influenced by evolving regulations in the Netherlands and the European Union, which tighten carbon offset mechanisms' standards and availability.

So, since the materials used in the existing frame contribute significantly to an overall product footprint, achieving a fully carbon-neutral product is challenging when introducing the Anemone concept alone. Instead, the focus will be on reducing the impact as much as possible.

As seen in the described wishes on the left, several design drivers should be considered to optimise products for carbon storage (Bessai, 2021). The materials explored on the next page all look for a different way to optimise those factors.

The carbon storage values used in this analysis are based on indicative estimates derived from a mix of literature and industry reports that could be found. Actual carbon storage capacity may vary depending on material composition, local differing processing methods, and differing variable supply chain specifics in the Netherlands. Further research and Life Cycle Analysis would be needed to validate these figures when applied to Sunbeam's logistics stream.

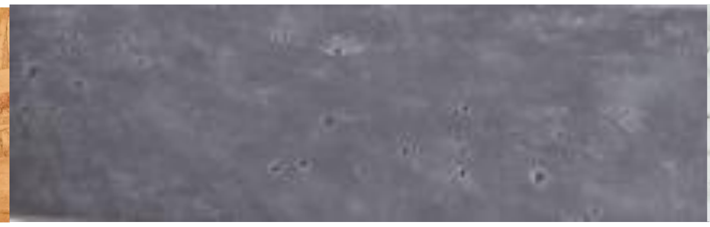
The design of the Anemone base tile is intentionally designed to be manufacturable using a range of materials, like the ones mentioned on the next page. This flexibility allows the production method and material choice to be determined by specific project needs and availability. In other words, the final selection is advised to remain adaptable, so that the most appropriate solution can be chosen based on real-world constraints and opportunities in the manufacturing processes.

Reused organic material

Wood is an optimal material for low production quantities, since most of the tooling needs to happen manually. These materials pose significant challenges when scaling up. The main limitation lies in the labour-intensive nature of assembly and finishing, making automation and mass production difficult. Precise cutting, joining, and treatment steps (for weatherproofing or fire resistance) often require manual intervention or specialised tools, increasing both time and cost. Reused organic materials are a solution for lower-scale projects or initial prototyping.

Price per tile (400x400x100mm) (estimate): ~ €8.00 incl. initial costs
Weight per tile: App. 2.3 kg per tile.
Manufacturing methods: CNC milling, manual joinery

Fibre clay composites



Fibre clay composites offer a different balance: A better robust structural performance, fire resistance, and formability, while incorporating natural fibres that can offset some of the emissions associated with clay processing. However, the actual carbon impact is hard to indicate since the binders in this material can require high-temperature firing or cement binders. These factors can fluctuate the actual carbon outcome, so their carbon performance and total producibility remain indicative.

Price per tile (400x400x100mm) (estimate): ~ €13–€24
Weight per tile: App. 7.2 kg per tile.
Possible manufacturing method:
Compression moulding (initial costs: ~ €2.000)

Bio (HD) PE

In bioplastics, bio-(HD) PE stands out for its potential carbon uptake of 950 kg/ m^3 (Braskem, 2021), even higher than the bio-composites. Although Bio-HDPE is chemically identical to its fossil-based counterpart and thus recyclable, the recycling process is not entirely closed-loop. Mechanical recycling can degrade material quality over time, and the infrastructure for effective recycling varies globally (Gandhi et al., 2021).

Choosing a non-biodegradable plastic like Bio-HDPE may offer product longevity and durability advantages, especially in outdoor applications. However, this same characteristic makes effective end-of-life recycling a must.

The costs of a sustainably sourced bioplastic are significantly higher than those of its fossil-based variant, which could be a significant barrier to widespread adoption.

Material price per tile (400x400x100mm) (estimate): ~ €17–€26
Weight per tile: App. 3.8 kg per tile.
Possible manufacturing method:
Injection moulding (initial costs: ~ €10.000)

Bio composites

Bio composites that are most interesting for their **high carbon storage potential and use of rapidly renewable resources.** Two options that particularly excel in this advantage are hemp fibre and bamboo fibre composites. Hemp fibre is known to be relatively weaker, but has a relatively higher carbon uptake of 476 kg/ m^3 (Mohanty, Misra, & Drzal, 2002). Bamboo fibre has an uptake of 267 kg/ m^3 (Gu et al., 2019).

Despite these environmental benefits, durability is highly dependent on the binder system used, which can vary widely in performance and environmental impact. While some formulations offer water resistance and mechanical strength, others may degrade quickly under outdoor conditions. When this material is selected, the durability of the selected binder must undergo significant testing before the material can be applied.

Price per tile (400x400x100mm) (estimate): ~€5.40–€13.50
Weight per tile: App. 5.0 kg per tile.
Possible manufacturing method:
Resin transfer moulding (initial costs: ~ €3.000)

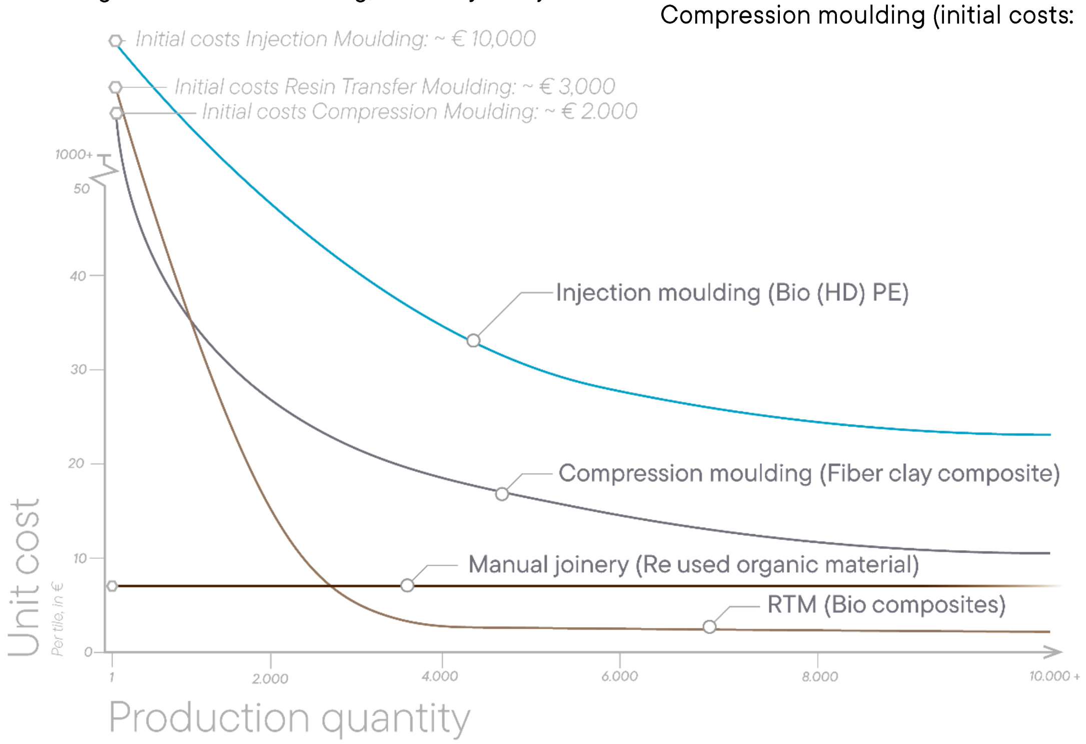


Figure B.1.2: Cost comparison of materials, and their manufacturing method

Takeaway study:
For the eventual product, an accessible bio composite is recommended.
Reused organic material for initial smaller-scale projects.

Tile dimensioning: surface area

This chapter explores the possible tile width and height that could be the most favourable, as shown in Figure D.1.3 below. The tile height influences plant suitability and will be further tested in Chapter D.2, technical testing.

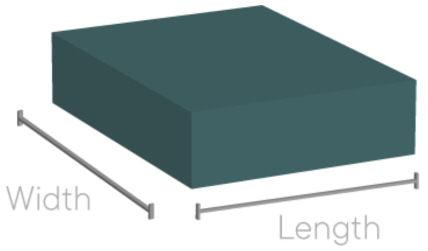


Figure D.1.3: Referred tile dimensioning

Requirements
1) The tile (without soil) should not weigh over 20 kg.
2) The maximum dimension of one tile is 1000 mm in the length direction and 500 mm in the width direction.

Wishes
1) The tiles are easily stackable and placeable for transport.
2) The tiles are easy to assemble into each other and the current frame.
3) The number of tiles is wished to be low to lower the installation difficulty and assembly steps.
4) The coverage of possible areas in open spots of a Supra frame is optimised maximally. In other words, the coverage % of the red areas indicated in Figure D.1.5 is covered as much as possible.

As can be seen, some of the wishes are contradictory. A relatively smaller tile generally gives the areas a higher coverage but is also more labour-intensive during installation. To tackle this problem, a mathematical model is made to find the most optimal dimensioning for the tiles fitting various Supra frames. In Figure D.1.4, the potential areas for Anemone tiles are indicated and defined as four areas A, B, C and D. Areas A and B are the potential areas where ballast replacements can be. C and D are spots where potential gaps in the solar field can be filled, if no PV is/can be placed. *Areas A and B are tackled as one-dimensional problems (since the tile width determines the width of the area), and C and D are tackled as two-dimensional problems.*

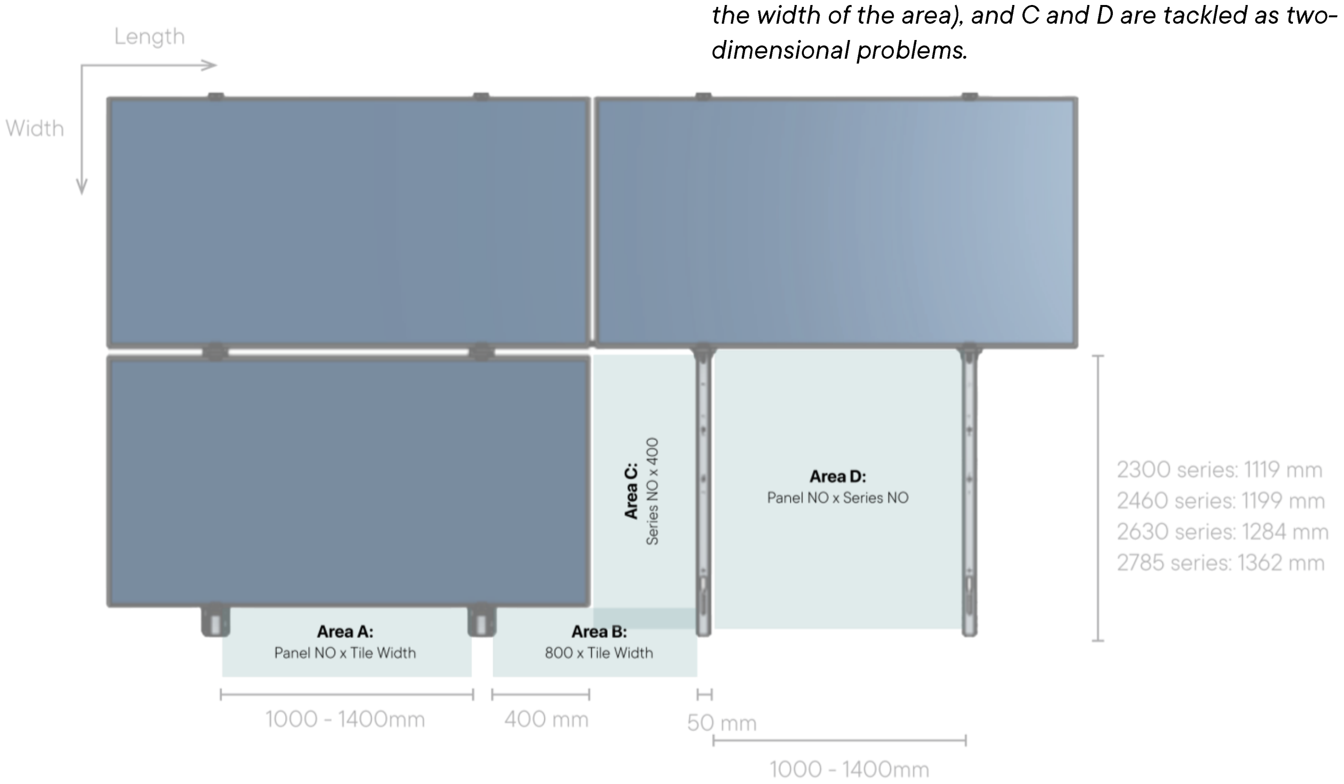


Figure D.1.4: Possible placements of Anemone tiles, in Supra frame (top view)

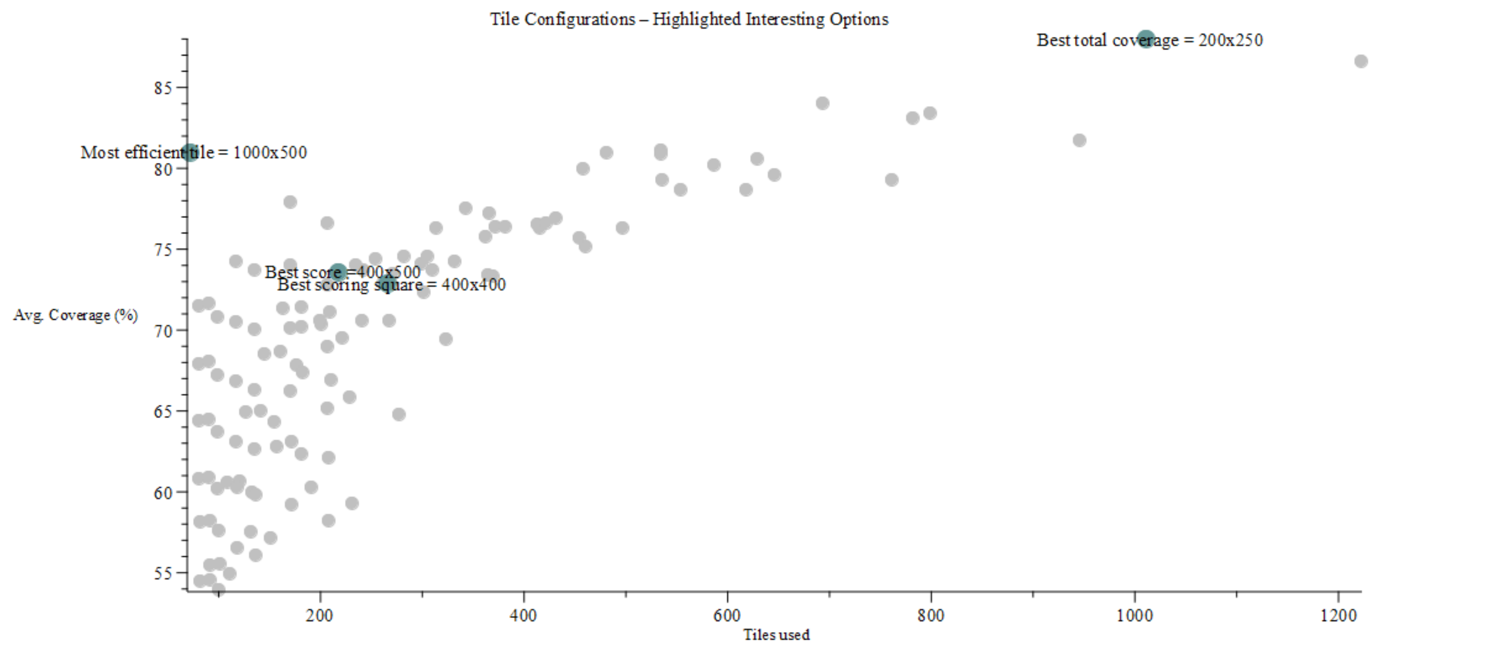


Figure D.1.5: Calculated tile configurations and highlighted interesting options

Above in Figure D.1.5, all possible tile configurations (with the smallest tile being 200x200 and the largest being 1500x500) have been plotted on coverage % *(% covered of all possible areas A, B, C and D)* and the total tiles used. This figure gives a great indication of which tiles score best on wishes 3 and 4, indicated earlier.

However, not all Supra frames are as common as others, so optimising the tile size for the more common sizes is wise. This is taken into account by an additional $Weight$ factor, and added into the calculation. This weight factor makes more common dimensions, like the area length of 1200 mm, more important. The full calculation can be found in Appendix I.

When *(without the weight factor included)* looking at the optimal average coverage %, the **200x250** tile, one of the smaller configurations, achieves the highest overall coverage. The largest tile, the **1000x500** tile, is one of the most efficient. It is the only tile covering over 80% of all surfaces, using 71 tiles.

The 400x400 and 500x400 tiles are also highlighted in the graph, as they achieved the highest scores once the weight factor was taken into account.

The **500x400** scores best on the overall score, while using 180 tiles total. This formula calculates the overall score as *(simplified)*

$$Final\ score = \sum_{k=1}^{51} score\ all\ areas$$

Where

$$Score\ specific\ area\ (AB\ or\ CD) = Weight * \frac{coverage\ \%}{tile\ amount}$$

The **400x400** is also highlighted, since this is the best-performing square format (240 total tiles used). Its symmetrical design facilitates easier assembly, since all sides are potentially interchangeable. It almost scores as well as the 500x400, but has a significant assembly advantage.

Takeaway study:
The 400x400 tile scores the best regarding all wishes, but if more structural integrity is required the 1000x500 and 500x400 tile are alternate good scoring options.

Tile dimensioning: height

The height of the tile determines the volume of the tile, which, on its own, determines the thickness of the possible substrate layer. That is why the wishes below also refer back to the specific species requirements described in chapter C.2.

Figure D.1.12 refers to all the tile dimensioning.

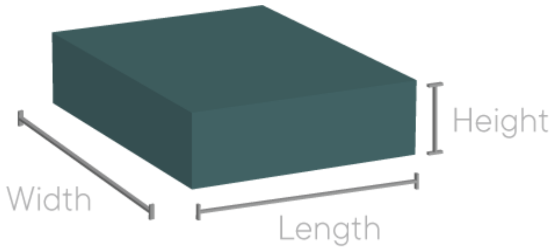


Figure D.1.6: Referred tile dimensioning

Applicable Wishes
1) ABP sufficiently helps the foundation of the ecosystem.
By incorporating possible native plant species where possible.
2) Minimal cast shadow of plants onto the PVs.
3) Easily mountable to the frame.

Another wish we could include is the potential increase of energy uptake, as mentioned in Chapter C.3, Opportunities. Since this is hard to quantify in the time of the project, and a variety of research shows different results, this wish is considered more of a future recommendation than a design factor now.

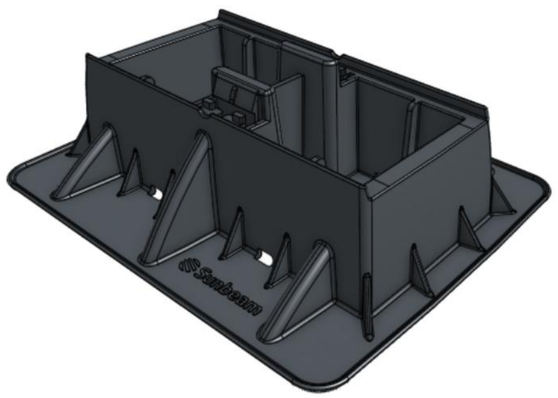


Figure D.1.7: Supra foot

The amount of soil required also depends on what you try to grow inside the Anemone. As indicated in the applicable wishes, it is desired that the plants that can grow offer opportunities for native species higher in the food pyramid, and are potentially native themselves. This increases significantly when applying a thicker layer of substrate, or water retention, as can be read in the requirements for species (chapter C.2).

Requirements for Species:
1) Extensive roofs (sedum) need a layer thickness of 4-7 cm minimum.
2) 10 cm minimum layer thickness for native species with water retention.
3) 15 cm minimum layer thickness for native species without water retention.
4) A variety of water is needed to maintain the plants.
5) The type of optimised soil is different for each plant.

A seemingly straightforward approach to increase the space for biodiversity is to elevate the frame more from the ground, by increasing the height of the plastic foot units. These plastic feet, shown in Figure D.1.7, prevent direct contact between steel components and the roof surface, protecting against damage. This way, the total height increases, the PVs are located further away from the rooftop, and there is more space for ABPs. Higher structures would trigger stricter regulations since they are more susceptible to wind loads, necessitating additional ballast, complicating installation and increasing material use and environmental impact. Secondly, implementing such changes would compromise backwards compatibility for current Sunbeam products. Existing Sunbeam clients could not be provided with Anemone tiles if desired. One of the opportunities mentioned in the SWOT analysis in chapter A.3 is current client contact, and providing them with optional benefits of upgrades. It would be a nice addition if the tiles could be installed on current installations.

To get a clear image of what heights are possible, it is important to get a clear image of the height dimensioning of a Supra system. Even though there is a variety in the sizes of Supra systems, this is only variable in the 'width' and 'length' of the system, and fortunately not in the 'height' dimension. This makes a modular height, at first glance, <u>not</u> needed.

This image shows that, in the Supra system, most of the structural height is concentrated on the right side, where the structure reaches its maximum elevation. This side is only accessible when working with south-oriented panels; however, another PV would occupy this space in east-west orientation.

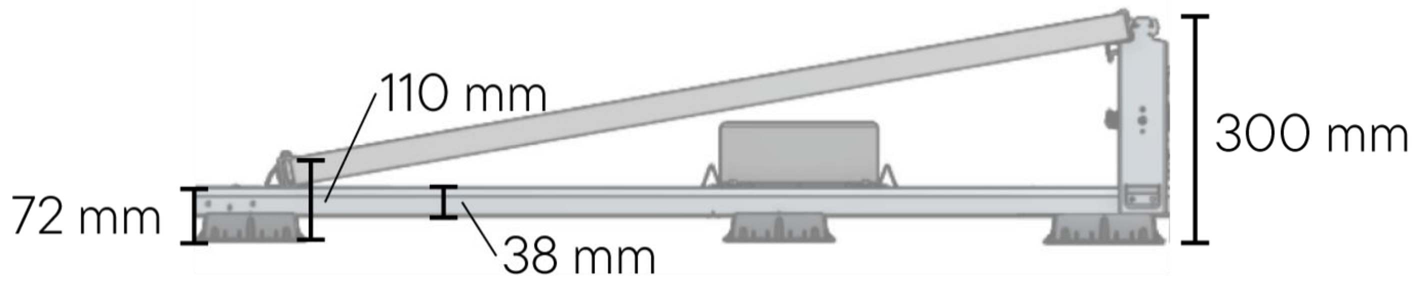


Figure D.1.8: Side view of Supra system with dimensions

The next page will discuss Several possible subfunctions, each with a different approach to efficiently fulfilling the wishes. The plant growth system is simplified into the layers: **vegetation, substrate, water retention and roof protection** (tile thickness). This is done in a similar approach to existing green roof solutions, as seen in Figure B.3.1. The eventual height of each subfunction is given with vegetation and without, where the actual tile height is the height without vegetation.

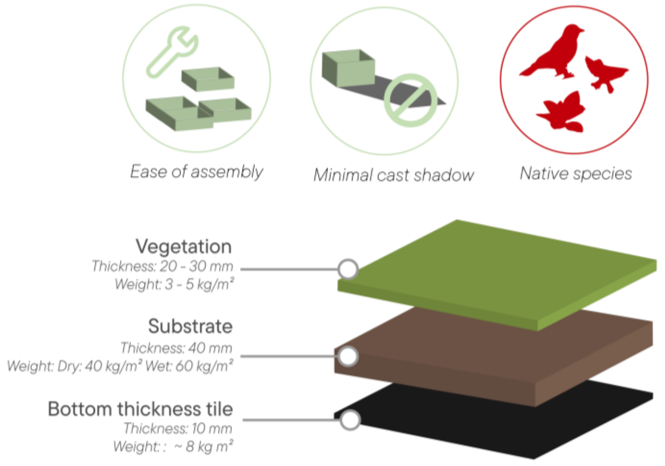
For **vegetation**, an estimation of certain plants' growth is made**,** alongside the expected weight. This research does not look at the possible variety of thicknesses of the suggested vegetation, such as plant density. This could also influence actual panel cast shadow coverage and shadows the plants create.

The **substrate** is indicated by an estimated thickness, dry weight, and saturated weight. Saturated weight indicates the weight of the substrate when fully saturated by water. The actual weight of the substrate at a particular time will be somewhere between the (fully) saturated and dry weight.

A **water retention** layer in a green roof serves to hold water for plant use while allowing excess to drain, preventing root rot or over-saturation. One of the advantages of the Anemone tile system is that its form (featuring integrated water plugs as can be seen in Chapter C.2) can mimic the function of a traditional water retention layer. Water inside the tile collects below the drainage holes, enabling water storage, and flows out once it reaches the height of the water plugs. The central tiles could then connect via the water plugs to the outer ones, effectively creating a distributing retention system. That said, the feasibility of this built-in drainage concept has not yet been thoroughly tested and would require further validation. Therefore, an additional 20 mm of space has been allocated for subfunctions where vegetation requires reliable water retention.

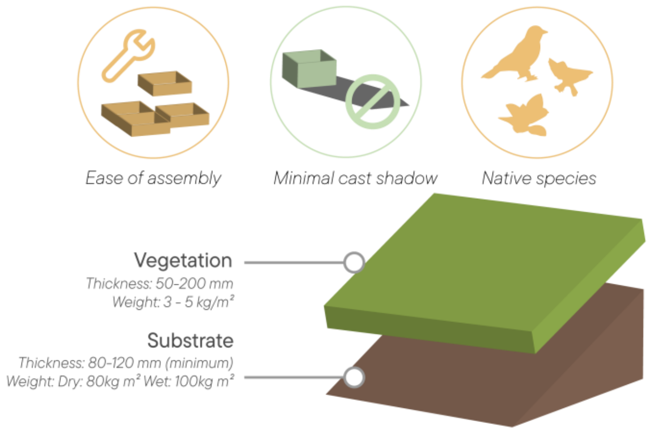
For the **bottom thickness or roof protection,** a thickness of 10 mm is used. The density of an average wood is used for the tile.

Minimal (50 - 80 mm)



When using minimal height, minimal plants are possible, like Sedum Album. The thinnest Sedum plants do not require any water retention.

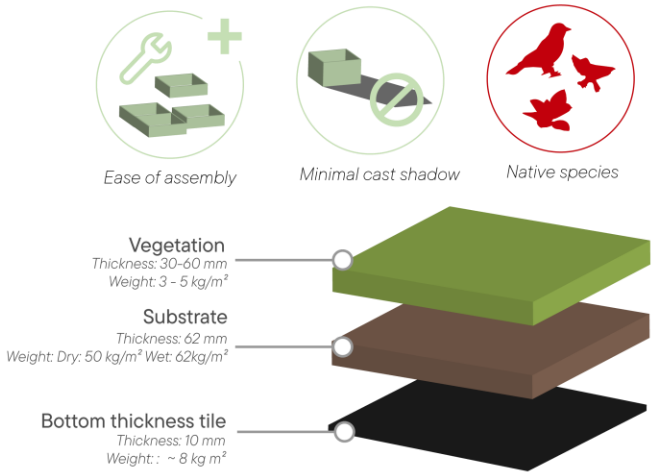
(Special) Modular deflector (0-300 mm)



The modular deflection subfunction explores the idea of possibly creating a steep add-on. As shown in Figure D.1.13, the highest point of the panel in the Supra system reaches 300 mm. In south-facing solar installations, an open section is oriented toward the north, creating a surface with limited sun exposure. This subfunction is similar to the earlier Epiphyte design, which investigated the use of the rear side of the structure for ecological purposes.

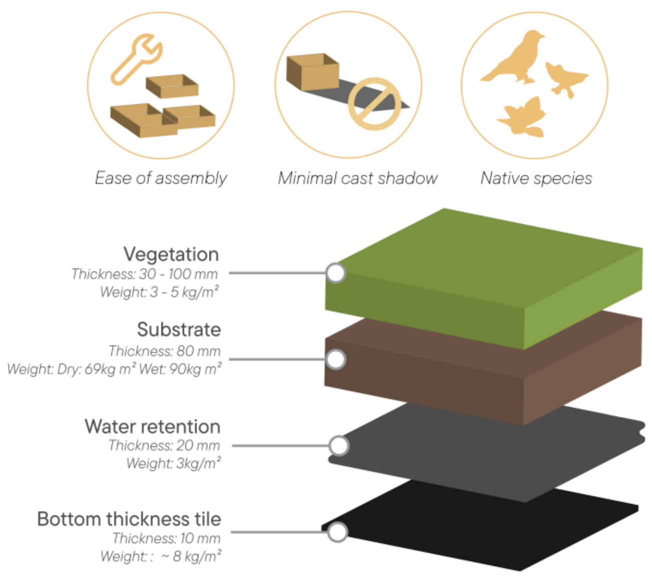
Although this space offers limited sunlight, it could still support shade-tolerant vegetation. Species that require much sunlight are not suitable here, as they would lean towards the light and possibly interfere with the functioning of the PVs by causing shading. Suitable low-light native species for this location include *Ajuga reptans* (bugleweed), *Luzula sylvatica* (greater woodrush) or *Primula vulgaris* (primrose).

Height of frame (72 - 132 mm)



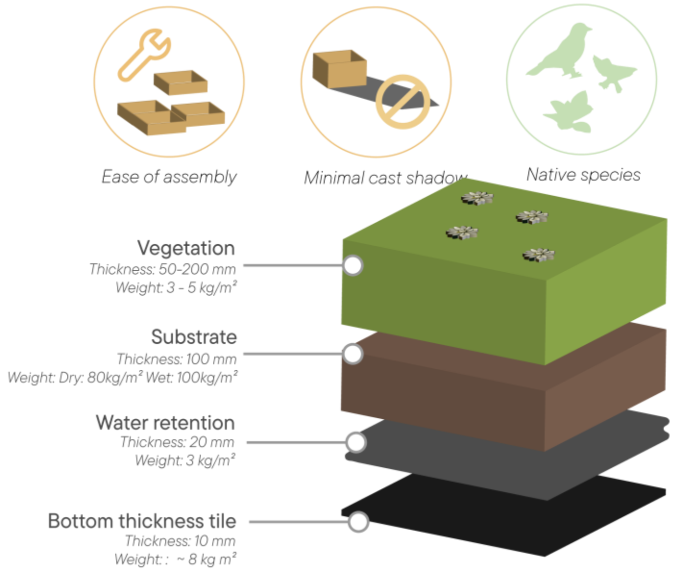
Like the minimal approach, this subfunction consists of three minimal layers, with more space for substrate. This subfunction utilises the height of a Supra carrier as the height of the eventual tile, which gives a significant advantage for ease of assembly. However, this height is still quite minimal for actual biodiversity enhancement. The plant selection here does not go much further than Sedum, but Lichens or potential herbs like creeping thyme can also be options.

Panel height (110 - 210 mm)



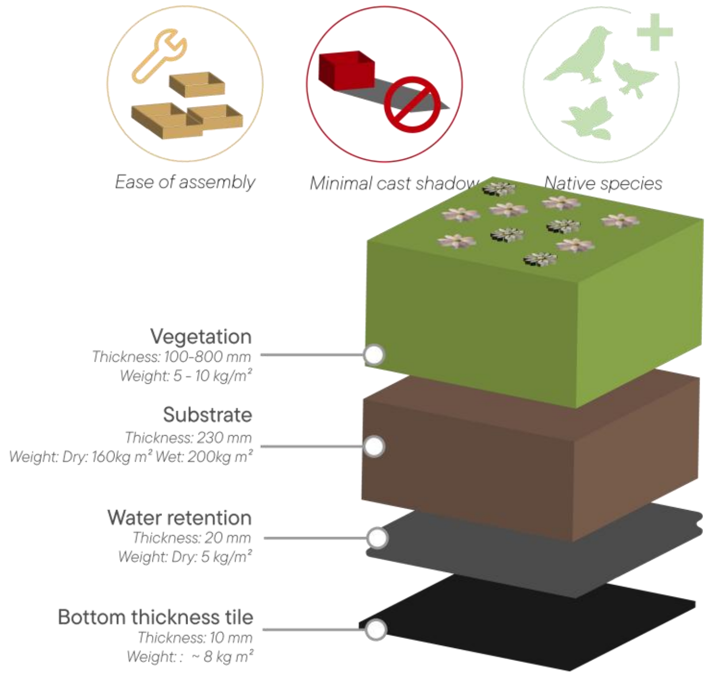
Using the actual panel height as a reference for the total tile height increases the potential for supporting native biodiversity, particularly when a water retention layer is included. However, this may slightly reduce assembly efficiency and increase shadowing.

Native minimal (130 - 330 mm)



When exploring the opportunities for maximum biodiversity enhancement, a variety of native species is recommended. A specific selection of seeds must be made to limit the cast shadow effect. Native species that grow around 50 mm are short grasses, low herbs and small forbs, but with a mixture of plants, it is hard to say if they actually stay at that height, so cast shadows could still be created. As indicated by the wishes, the minimal substrate thickness here would be 100mm, including water retention, letting the total estimated height get up to 330m, including vegetation.

Native (260 – 1060 mm)



To fully support native biodiversity, a broader range of native plant species could be introduced. With a substrate depth of 220 mm combined with a water retention layer, most native species could thrive in the rooftop microenvironment, creating optimal conditions for biodiversity enhancement. However, the height would increase significantly, making cast shadow effects inevitable.

Takeaway study:

The panel height should not compromise overall energy output. A uniform height across all areas is impractical to make optimal use of available space, making an adjustable system preferred to fulfil all indicated wishes. Ideally, the system supports native plant growth where possible, incorporates low-growing sedum in more constrained zones, and provides wind protection at the back of south-oriented PVs.

Standardising a base tray of 72 mm for mass production is recommended, with modular add-ons to increase the height where needed. Since these height extensions are only for wind deflection and not structural load-bearing, they can be produced from lighter, cheaper, and lower-impact materials that do not require high structural strength.

In between tile connections

One of the main assembly steps in installing an Anemone system is the in-between tile-to-tile connection, visualised below:

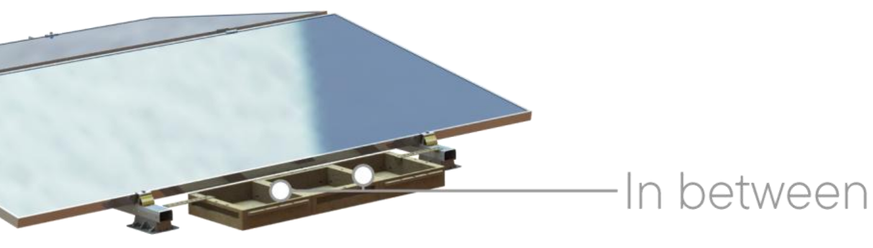


Figure D.1.9: Indication of in between connection

A variety of connection possibilities have been developed and tested.

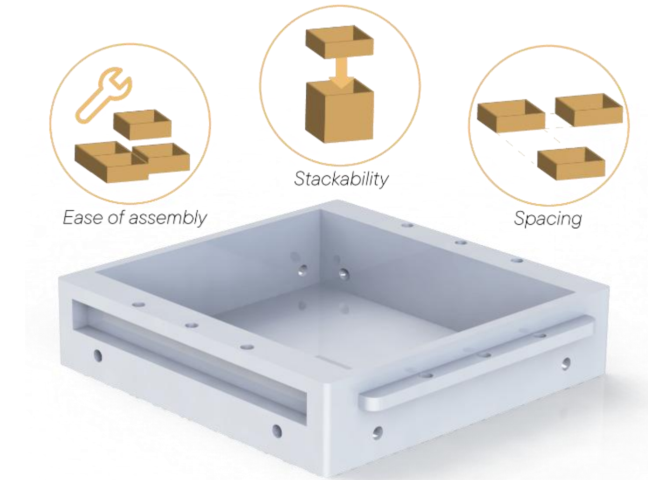
Requirements:
1) Helps to transfer structural forces: Can function as ballast and transfer longitudinal forces within the PV mounting system, ensuring the structural stability of the overall setup.
2) The tile connections can be provided with extra fasteners if needed.

Wishes:
1) The tiles are easily stackable and placeable for transport.
2) The tiles are easy to assemble into each other.
3) The connection takes up as little space as possible.

The connection selection mainly influences the amount of 'stackability' and the connection taking up as little space as possible. The last is significant, as the maximum surface can be utilised for soil and biodiversity enhancement.

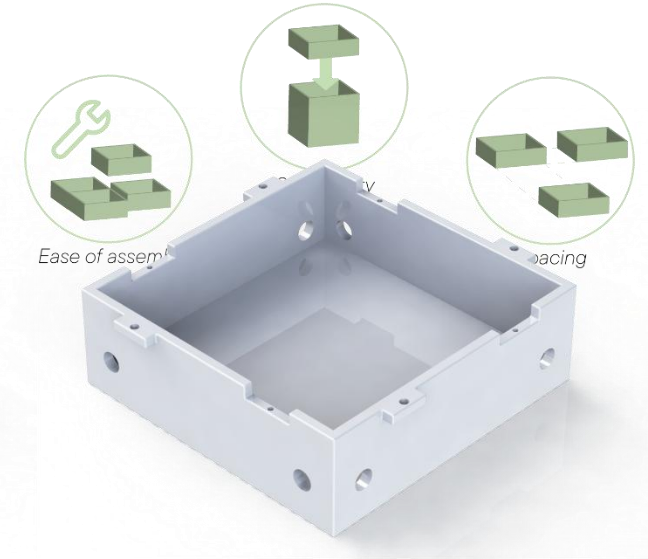
The ease of assembly and stackability were tested with **3D printed models.** These models made it possible to see how the subfunctions would rank compared to the wishes. *The spacing of the models could be determined in each final subfunction's* CAD model.

M-F connection



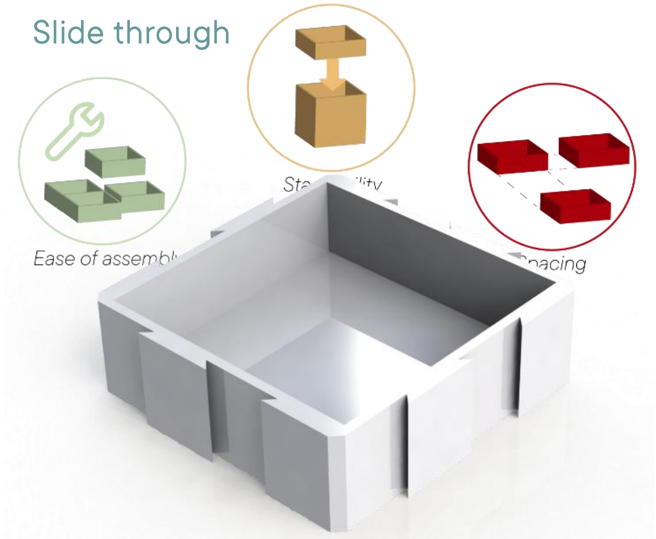
M-F connection is the first version of the anemone tile, giving each tile 'male' and 'female' sides. While these robust connectors could transfer structural forces, all wishes suffer relatively. *Ease of assembly:* For larger fields, aligning might become a puzzle. The tiles cannot be *stacked* fully, and the female sides add additional *spacing*.

M-F connection per side



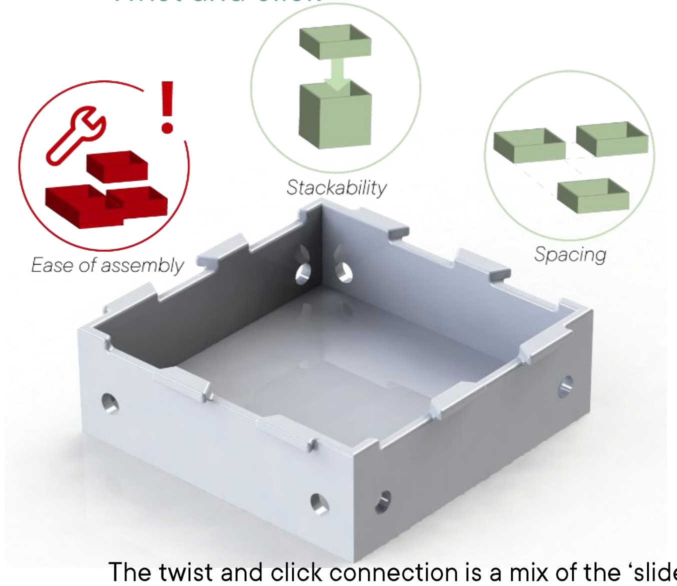
All wishes could be fulfilled relatively better if each side of the tile has male and female connectors. *Ease of assembly* becomes easier since no puzzling is needed, *stackability* since the connectors are at the upper side, and decreased size improves *spacing*. The decreased size here might reduce structural strength, and further technical testing is needed to verify if this tile would still fulfil the structural requirement.

Slide through



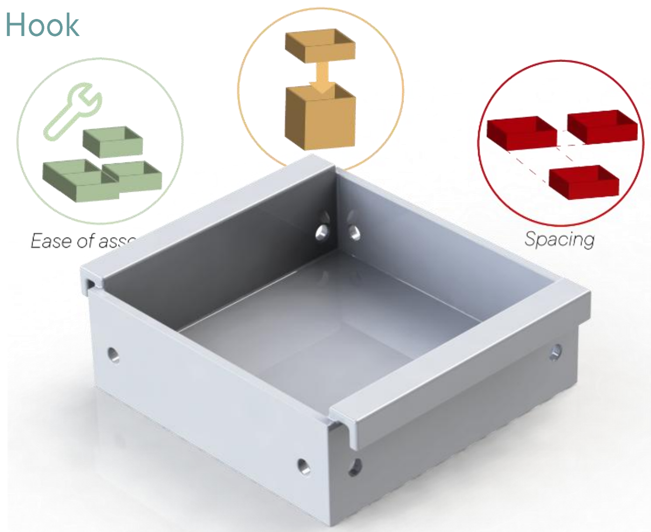
Rubber flooring mats inspire the 'slide through' connection you often see in home gyms. This connection would give great structural integrity, since every tile is connected by friction from top to bottom. 3D models show significant advantages in *stackability* and *ease of assembly*, but a higher wall thickness is required, making this tile score worse than other tiles on *spacing*.

Twist and click



The twist and click connection is a mix of the 'slide through' and M-F connection. It tries to improve the *spacing* of the slide through a dovetail connection; however, the more complex connector makes *ease of assembly* more difficult, since the connectors need to be twisted into place. This would be less of a problem if you use a material that would deform elastically. However, this would not be suitable for the requirements.

Hook



The hook connection uses a basic hook system to assemble multiple tiles. This significantly increases the ease of assembly by working intuitively, but takes up more space. Stackability would also not be ideal since the hooks take up more space than other connections.

Takeaway study:

The indicated wishes favour the M-F connection per side tiles.

Tile to frame connection

By structurally connecting the tiles to the existing product frame, their weight can serve as a ballast system, key to the mutualistic concept introduced in Chapter C.3. To make this feasible, the system must comply with Dutch structural building standards. To reduce production costs, the connectors are designed as prefabricated parts. All connections will be secured by screwing into and clamping around the carriers, ensuring a stable attachment to the frame. This analysis focuses solely on the structural performance of the connection itself, assuming that any additional screws will not be the failure point. Only steel connectors are considered to avoid the added complexity of complying with additional NEN regulations related to ballast requirements in solar mounting systems. Using alternative materials would likely trigger a cascade of regulatory challenges.

The requirements that are used for designing the connection are:

1) Helps to transfer structural forces: (NEN-7250) Can function as ballast and transfer longitudinal forces within the PV mounting system, ensuring the structural stability of the overall setup, even when the system is lifted from the ground, as well as connecting two carriers. The possible weight that can be mounted is 741 N per ballast plate, equal to 3 filled tiles. (20 kg of soil plus 5,18 kg per tile). This weight can be attributed to the assemblies' strength and stiffness.

1.1) Assemblies' strength: Possible weight can be handled without the connection beginning to yield.

1.2) Assemblies' stiffness: Not more than 5 cm of bending from one to the other carrier when picked up.

2) Parts are easily prefabricated and made of steel.

In addition to ensuring structural integrity, several other design wishes should be addressed as thoroughly as possible:

1) The connection fulfils the requirements with a decent safety factor.
2) Ease of assembly.
3) Environmental impact.
4) Flexibility: The tile connection allows adding multiple panels in different areas around the same carrier (so combinations like area A and D from Figure D.1.5 are possible).

This chapter examines the different subfunctions that can serve as tile-to-frame connectors. All the options presented meet the basic requirements, and their alignment with the design wishes is also evaluated. A general trend emerges: the more material used (and thus the higher the CO_2 emissions), the greater the potential for structural reinforcement. The required material quantity is specified for each subfunction to support this comparison. The recommended approach is to select the connector that uses the least material while meeting structural demands. While all the final subfunctions discussed here satisfy the stated requirements, their performance may vary when implemented in larger assemblies of Anemone tiles. More comprehensive testing of the complete Anemone system will be addressed in Chapter D.2.

For each subfunction, only connectors that directly interlink Supra carriers are introduced, as this is necessary to meet the required stiffness. Shorter connectors (those that do not provide a direct connection between the two carriers) were shown earlier in Chapter C.4 during the initial conceptual showcase of the Anemone, as well as in Figure D.1.10. The shorter variants were found to be insufficiently stiff, so will not be included in the outcomes of the following study. Figure D.1.10 also indicates the view planes, which are shown in Figures D.1.11 and D.1.12, that will visualise the forces that will be simulated in this study.

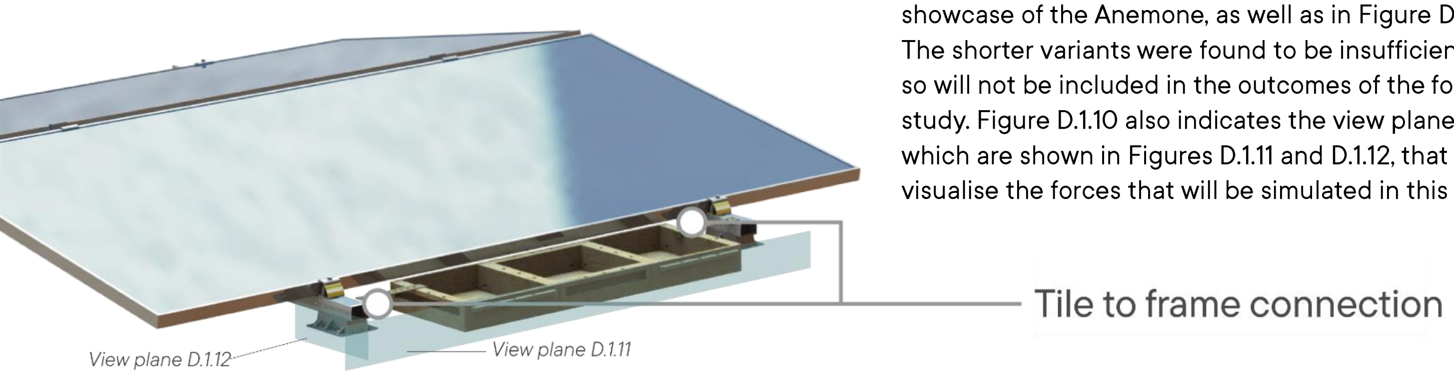


Figure D.1.10: Tile to frame connectors, mounted between Anemone tiles and two Supra carriers, and indicated plane views of following Figures D.1.11 and D.1.12

The total force on one ballast (when picked up, as described in requirement 1) can be described as shown in Figure D.1.11, as a distributed load, with a total force downwards of approximately 741 N.

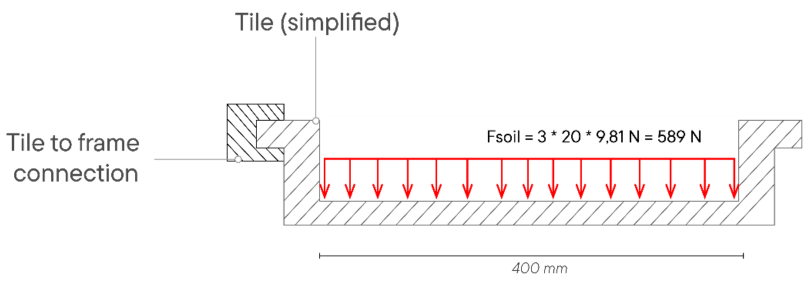


Figure D.1.12 Sectional view of Tile that will be connected to frame, with additional weight of the soil

To test if the profile fits the structural requirements, a Solidworks simulation is done with a simplified rigid body of the tiles, as shown in Figure D.1.12 below. The tiles have a mass of 5,18 kg (bamboo fibre composite), so the total mass of this rigid body is 15,5 kg. The load will be defined as the total soil of 60 kg (589 N).

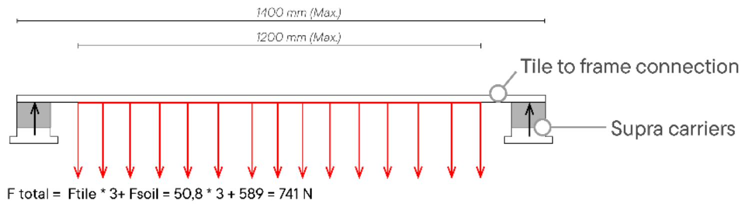


Figure D.1.11: Sectional view of the total distributed load, if system is picked up via carriers

During lifting, the connection must also bear the weight of the soil contained within the tiles, as illustrated in Figure D.1.12. Because the tile is mounted on only one side, the centre of mass is offset from the connection point, resulting in an additional moment load and significantly increasing the required structural strength.

On the next page, each subfunction will be tested to verify whether the simulation yields an acceptable safety factor relative to the steel's yield strength. Assembly ease, environmental impact, and flexibility will also be evaluated.

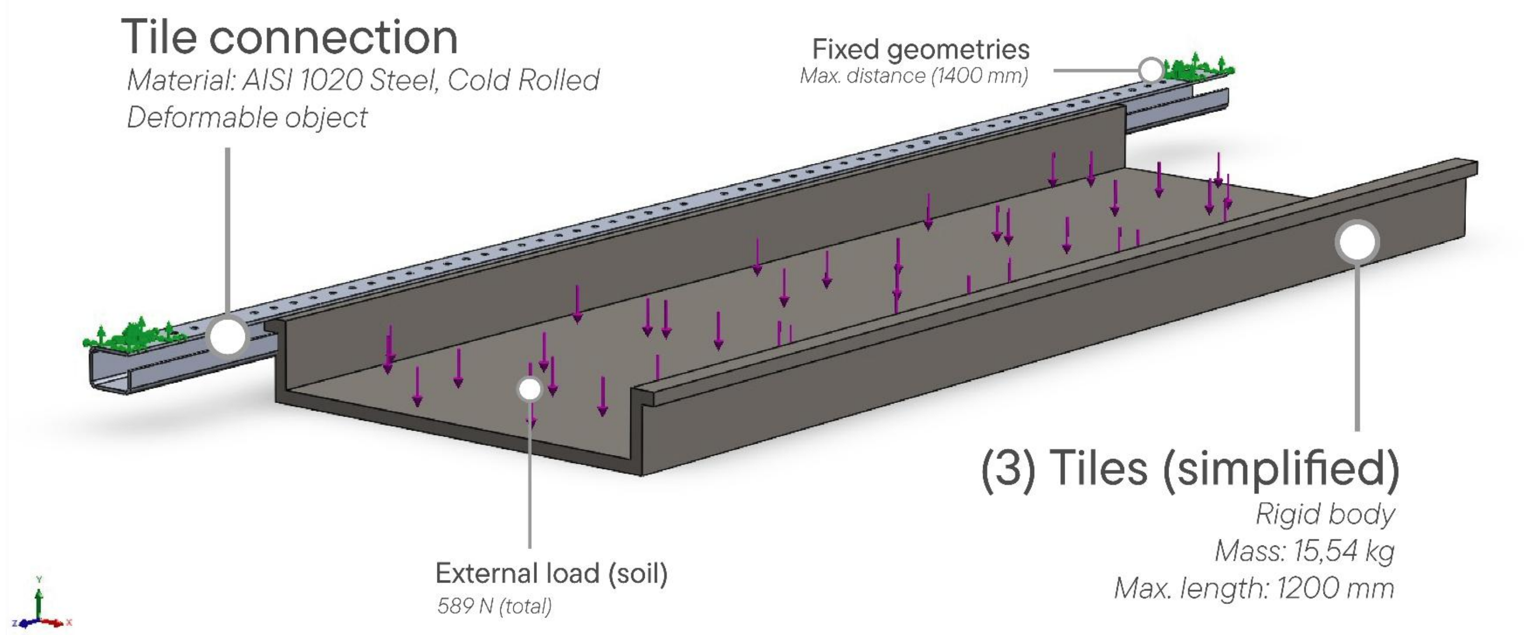
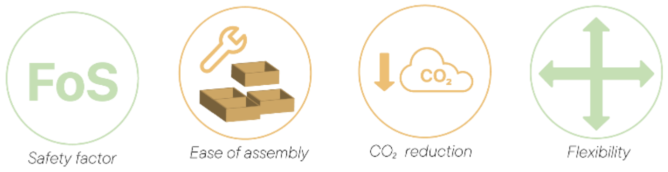


Figure D.1.13: Solidworks' static 3D simulation imputs to validate if structural requirements are met

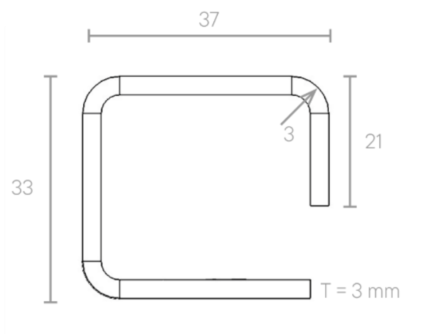
C connection



A simple way to connect the tiles with prefabricated parts is a C connection. (Voestalpine Sadef, 2017, p. 37) With additional punched holes to connect the connection to the Supra carrier or a tile. For easy installation, the connection would need one additional part (excl. screws) around each carrier as can be seen in Figure D.1.14. As can be seen, this subfunction explores if the connection is placed underneath the Supra frame.

A drawback of this connection, primarily due to its placement beneath the Supra frame, is the significant reduction in assembly ease. Mounting the connector would require access from underneath the Supra carrier, making installation more complex and less ergonomic. The total volume of one C connection is 553 cm³, which makes the environmental impact relatively average.

This connection can be shortened relatively easily, making it a flexible option. A shorter version could be positioned in various locations around the Supra carriers, allowing for adaptable placement.



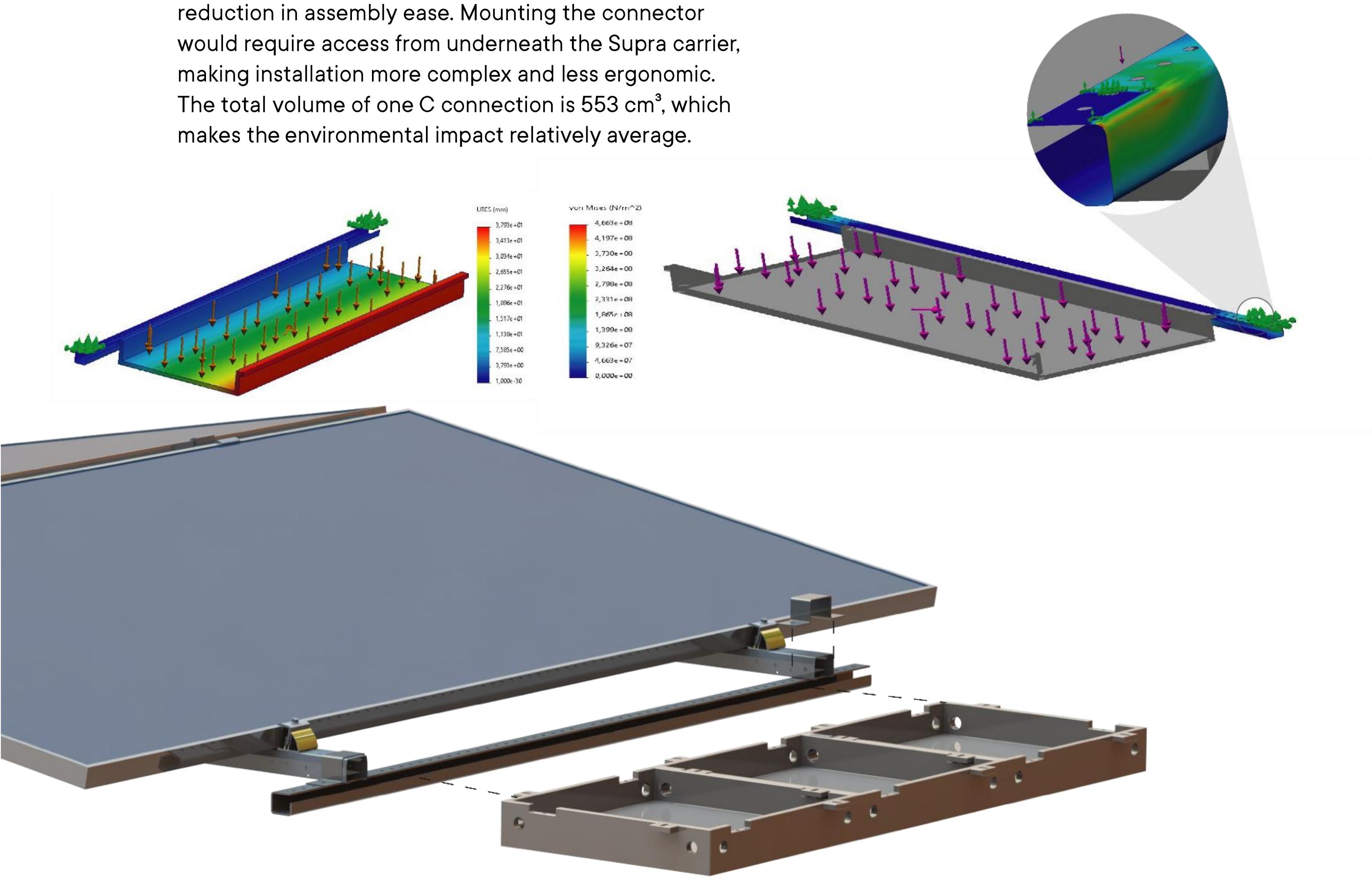
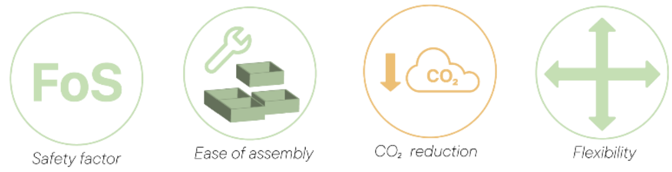


Figure D.1.14: Application and testing of C connection

Sigma connection

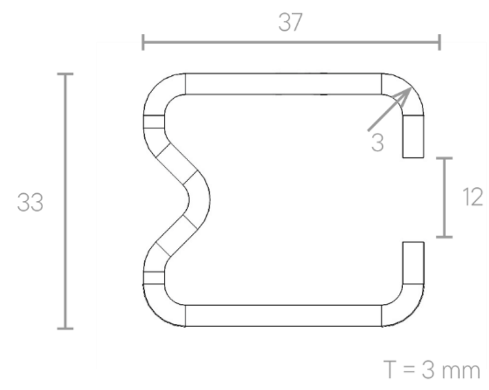


Another often used steel rolled profile is a sigma profile. (Voestalpine Sadef, 2017, p. 36) For easy installation, the connection would need one additional part (excl. screws) around each carrier as can be seen in Figure D.1.15 As can be seen this subfunction explores if the connection is placed above the Supra frame.

The Sigma connection, as shown in Figure D.1.15, is relatively easy to assemble, since it is easy to access when Supra carriers are previously aligned (this is shown in Figure D.2.2). The total volume of one Sigma connection is 574 cm³, which makes the environmental impact relatively average.

Just as the C connection can the Sigma connection relatively easily be shortened, which could make the connection relatively flexible.

Another important benefit of positioning the connection on top of the frames is the improvement it brings to the overall tile height.



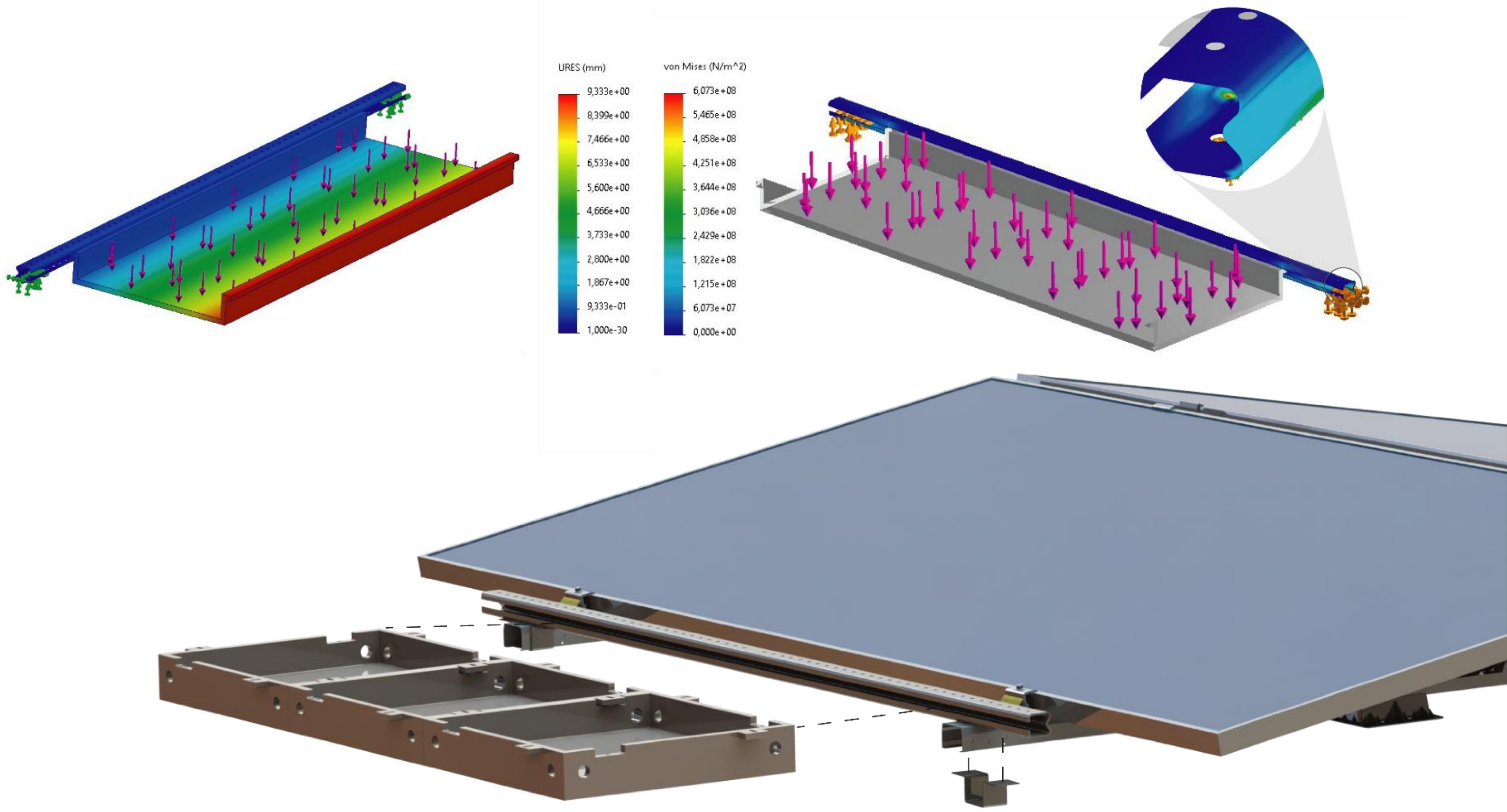
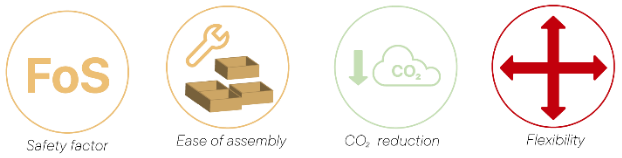


Figure D.1.15: Application and testing of Sigma connection

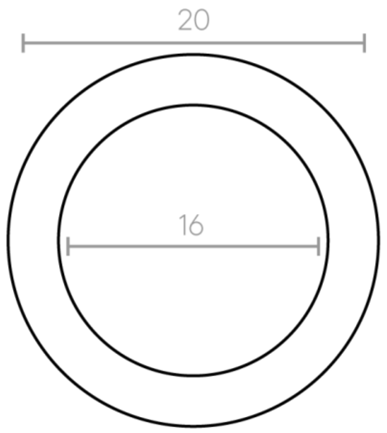
Connection rods



An alternative approach is to connect the tile using two separate connectors, positioning it between two Supra carriers to function purely as ballast. This setup eliminates the previously described moment arm, reducing the external forces acting on each connection. An often-used prefabricated part is a steel tube (Metaalshopper, n.d.) Each connector would wrap around a Supra carrier, requiring four mounting components for a single ballast tile.

One advantage of this approach is that it uses significantly less material, reducing the overall volume to approximately 340 cm^3.

However, this connection can only function as a dedicated ballast plate and lacks the additional application potential offered by the other two connector types in the Anemone system, and would only be possible to add where a significant amount of space is free on the carriers, as can be seen in the application example in Figure D.1.16



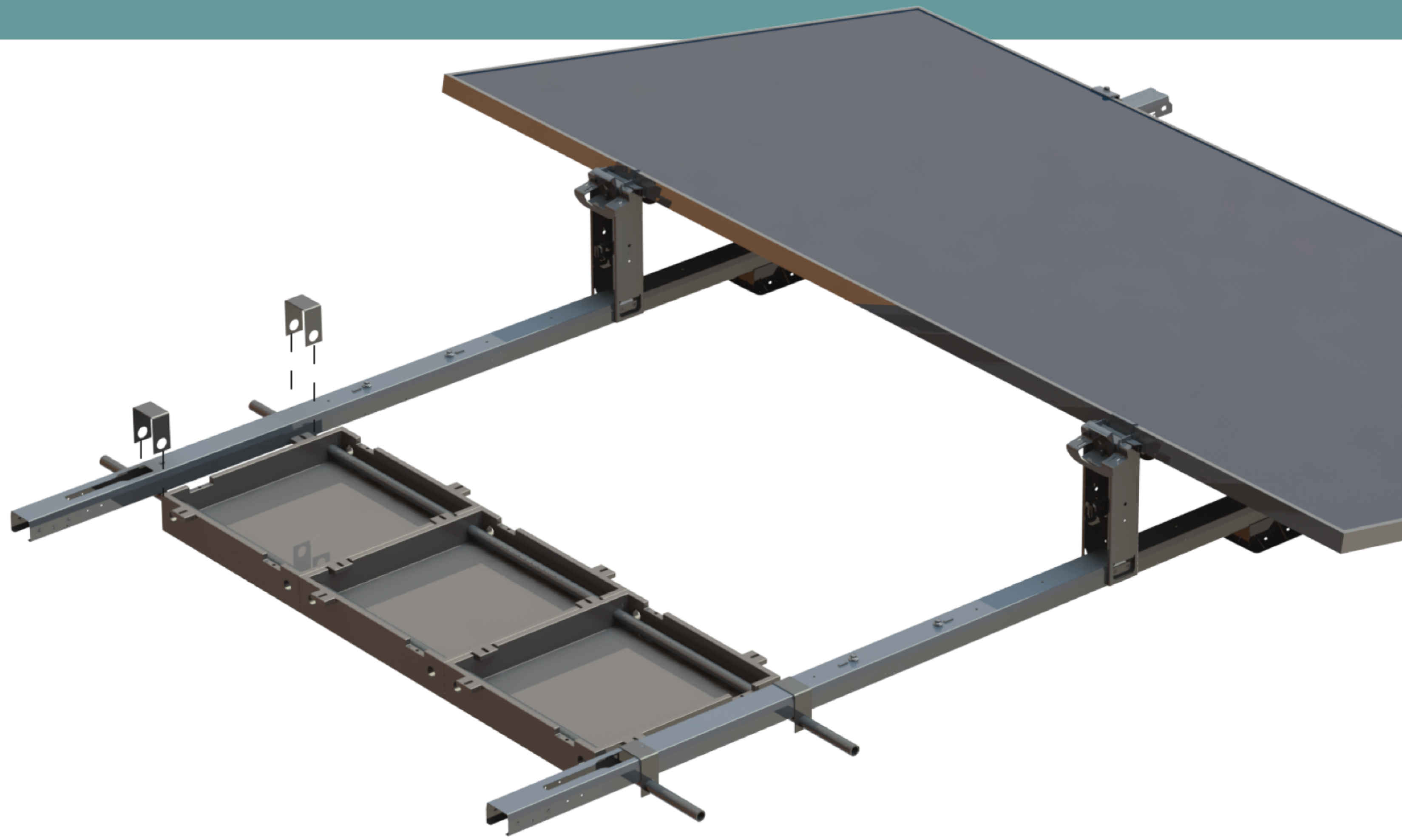


Figure D.1.17: Application of connection rods

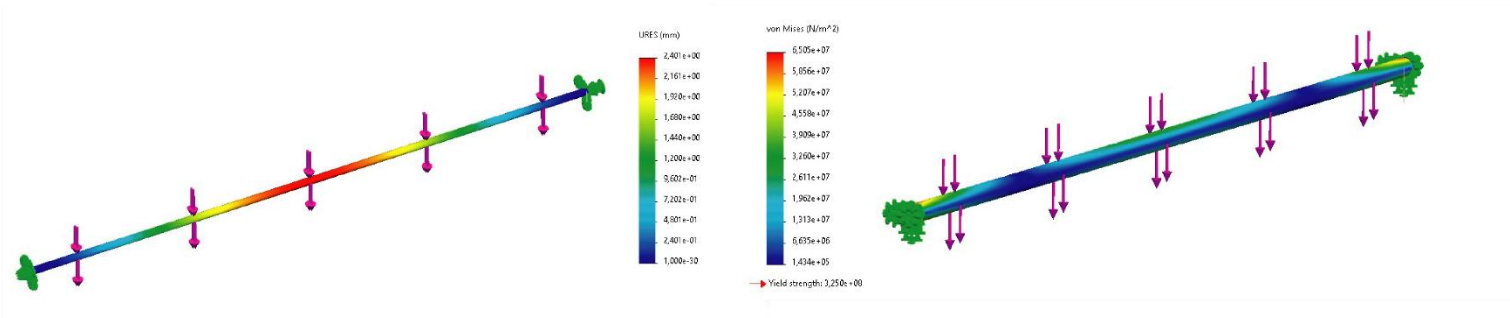


Figure D.1.16: Testing of connection rods

Takeaway study:
A connection that is mounted on top of the Supra carriers can give sufficient structural integrity, while ensuring that there is enough space for tiles to be placed and used as the foot of the System. So, in the final product, a Sigma profile on top of the Supra carriers would be the best alternative

Overall design considerations

The material chosen for the tile is a **bamboo fibre composite**. This option stood out due to its potent combination of mechanical properties and environmental benefits. Compared to other bio-based or reused materials, bamboo composite offers a higher carbon uptake potential while remaining suitable for resin transfer moulding. It balances strength, durability, and sustainability, making it the most viable material for the intended rooftop application.

For the surface area dimensioning, the **400×400 mm** tile was selected. Since this size allows for flexibility in placement and alignment, it offers a good compromise between system modularity and assembly efficiency.

Regarding tile height, the design must allow for easy mounting to the frame connection. The exact required height will be further investigated in Chapter D.2. To support biodiversity, **additional components are needed to raise the soil level to the top edge of the solar panels**, allowing native plant species to grow wherever space is available.

The in-between tile connection makes use of an **M-F interlocking system.** This design ensures that adjacent tiles align and stay in place without requiring additional tools or fasteners. It simplifies assembly while ensuring the tiles form a coherent, stable layer, even in irregular rooftop layouts.

The tile-to-frame connection is made through a **long, top-mounted Sigma connector that wraps around both Supra Carriers.** This solution directly connects both structural elements, providing the required stiffness to handle static and dynamic loads, including lifting scenarios. It improves performance and assembly ease compared to alternatives by allowing top-side installation and minimising moment arms.

Finally, in the next chapter (D.2), some of these subfunctions are adjusted to ensure they can be implemented together as a complete system. Specific dimensions or design choices might be slightly refined to allow compatible integration.

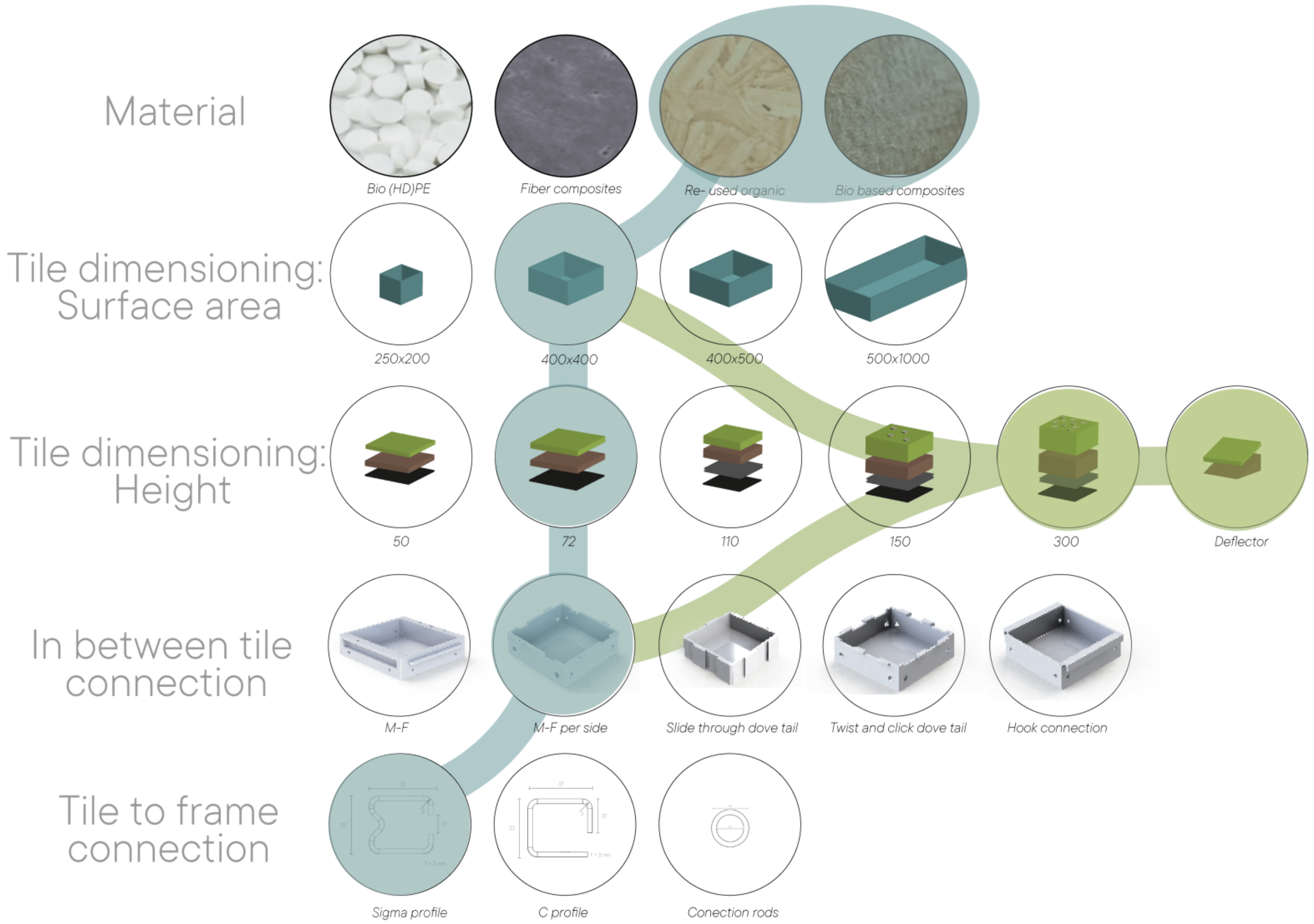


Figure D.1.18: Total overview of all design takeaways of Chapter D.1, blue indicating the main chosen option, and green adding additional modules

D.2: Final validations

In this Chapter, the focus shifts from isolated subfunctions to the performance of the complete Anemone ballast assembly. Building on the component-level evaluations from D.1, this chapter examines how the proposed tile-to-frame connections behave when integrated into the complete Supra system. A simulation of the assembled structure is carried out to assess mechanical feasibility and identify any system-level challenges related to weight distribution, assembly method, or structural loading.

In addition to technical validation, this section also explores the new designs' estimated material costs and CO_2 impact, providing a final comparison between the current and potential new system.

To make comparisons to the old ballast frame clear, the terms in Figure D.2.1 describe certain parts and/or directions in this chapter for further comparisons.

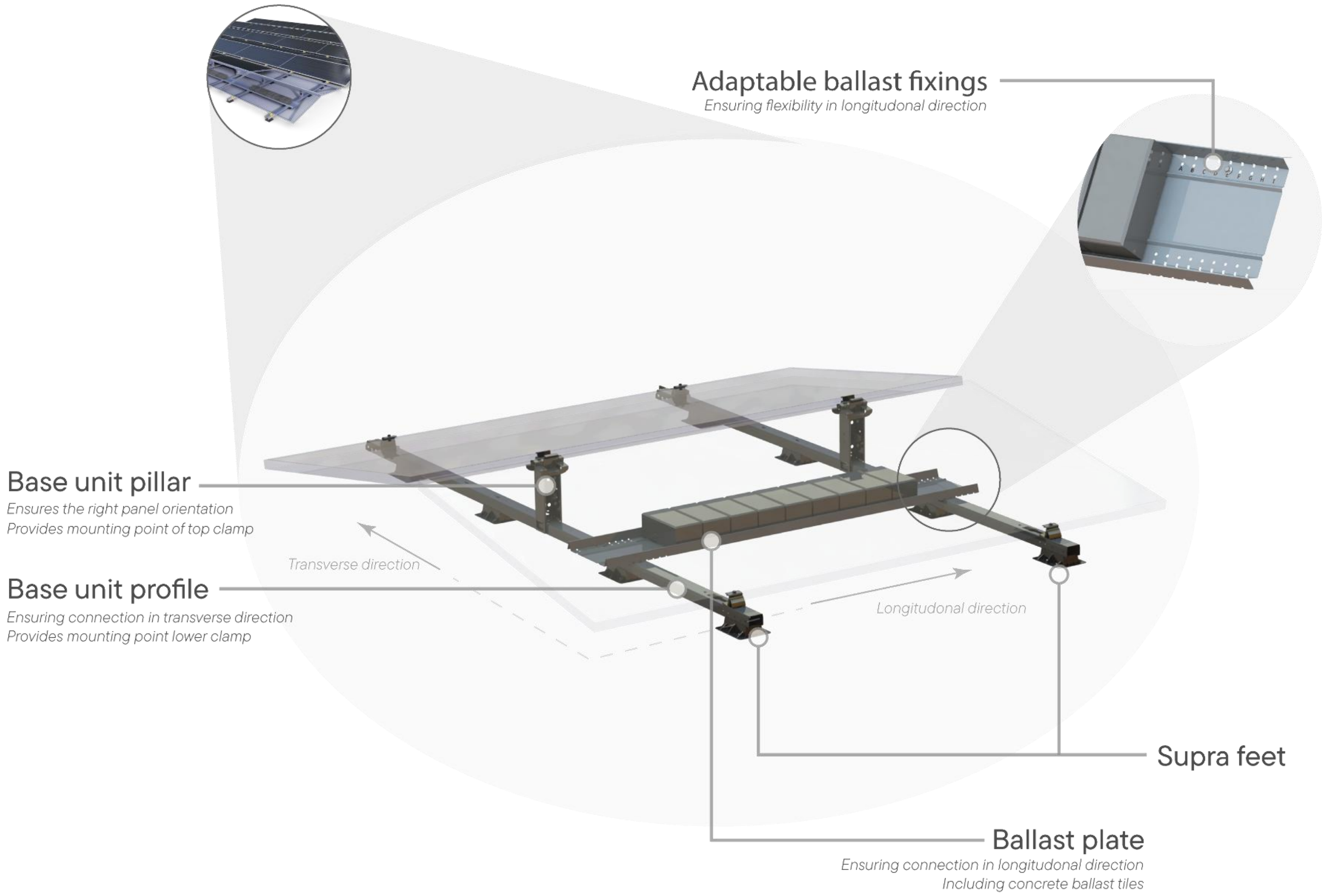


Figure D.2.1: One current ballast system of Supra, with adjustable ballast fixings to adjust to the PVs length

Figure D.2.2: Example of a layout of the Supra mounting system

The current ballast plate fulfils two functions: it adds weight to meet structural integrity requirements and connects multiple Supra carriers in the longitudinal direction. An example of a currently applied Supra field is shown in Figure D.2.2. While Chapter D.1 led to an optimal outcome for each subfunction individually, this chapter focuses on the final adjustments needed to ensure that these subfunctions can operate together as a fully integrated system and be implemented within the configuration shown above.

Optimally, all PV panels are structurally linked through the Supra frame, allowing the system to meet required standards with less overall ballast. Treating the entire PV field as one interconnected unit means less ballast will be needed. To still achieve this, the Anemone system must take over the longitudinal connections, as the original ballast plates will be replaced wherever possible.

Final tile validation

In addition to the tile-to-frame connection bearing significant structural loads, as discussed in Chapter D.1, the tiles must also meet structural requirements. Specifically, they need to be able to support their weight when lifted from a single male connector. This issue was addressed by redesigning the connectors, increasing their surface area to distribute the load better and reduce stress on individual connection points.

The technical testing of the redesigned tile is summarised in Figure D.2.3.

Finally, the tile height must be optimised to slide into the tile-to-frame connection perfectly. Since connections will be on top of the base unit profiles, the final tile will have an actual height of 96 mm rather than the earlier indicated 72 mm in Chapter D.1.

For composites, specific material properties vary depending on the composition, particularly the binder-to-fibre ratio. Research shows that bamboo-fibre composites tend to reach optimal mechanical performance at around 30–40% fibre volume fraction, where both tensile strength and modulus increase significantly (Thwe & Liao, 2002). For this study, mechanical properties corresponding to approximately 30% fibre content were used and are listed in Table D.2.1 (Gu et al., 2019).

In the final tile design, the male–female connection was enlarged to prevent plastic deformation during structural integrity testing, as confirmed by the bending simulation shown in Figure D.2.3. These tests demonstrated that the tile meets strength requirements, provided that this connection is sufficiently reinforced. The chosen binder-to-fibre ratio supports the required mechanical performance and increases bamboo content, enhancing the tile's carbon-negative potential. Although ballast tiles in practice will be structurally supported through interlocking with adjacent units, the simulation was performed on a single tile in isolation to represent the most critical loading scenario without additional reinforcement, and to see if one tile could already be applied as a (relatively light) ballast.

Property	Value	Units
Elastic Modulus	6250	N/mm^2
Poisson's Ratio	0.3	N/A
Shear Modulus	2450	N/mm^2
Mass Density	1250	kg/m^3
Tensile Strength	70	N/mm^2
Compressive Strength	85	N/mm^2
Yield Strength	50	N/mm^2
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.2256	W/(m·K)
Specific Heat	1386	J/(kg·K)
Material Damping Ratio		N/A

Table D.2.1: Estimated material properties of a bamboo composite (30% fibre content)

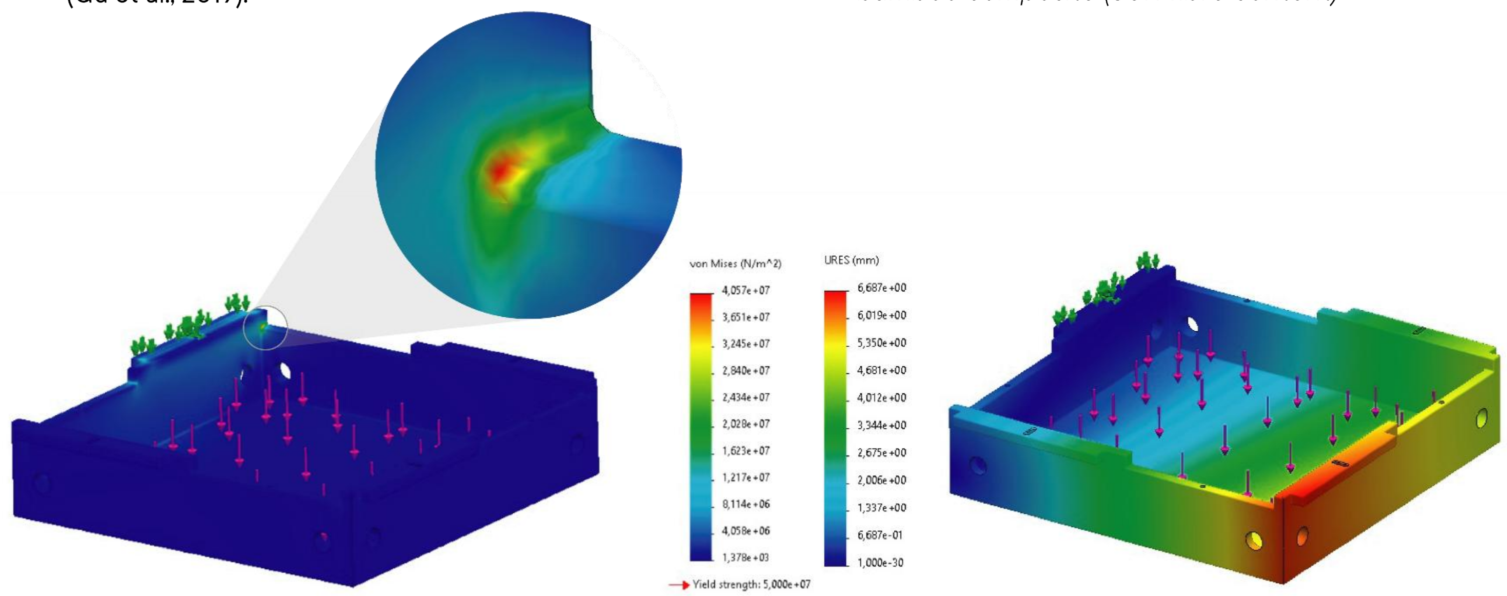
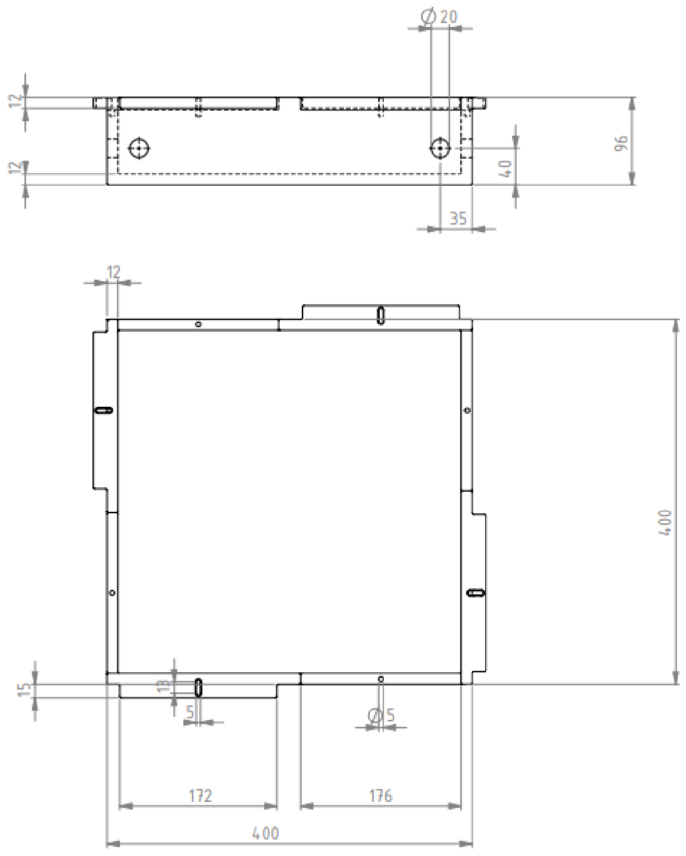


Figure D.2.3: Bending simulation to test structural integrity of one tile

The increased height of the tile creates additional space for soil and a potential water retention layer, as shown in the 1:1 prototype in Figure D.2.4. This layer can still drain excess water through side openings, which may be connected to the water outlets of adjacent tiles in multi-tile setups, allowing runoff to be guided away effectively. In this way, the tile's form contributes to water management, similar to how green roof systems retain and release water. While the tile is designed to accommodate a water retention layer, further research is needed to determine which additional layer/mat is most effective within the relatively limited volume.

The tile is designed to be compatible with multiple moulding methods, including RTM, injection moulding, and compression moulding. Among these, injection moulding requires the most critical draft angle. For the tile's height of 92 mm, a draft angle of approximately 3.5° is recommended to ensure proper demoulding (Hubs, n.d.). The potential parting line and mould are shown in Figure D.2.4 below.



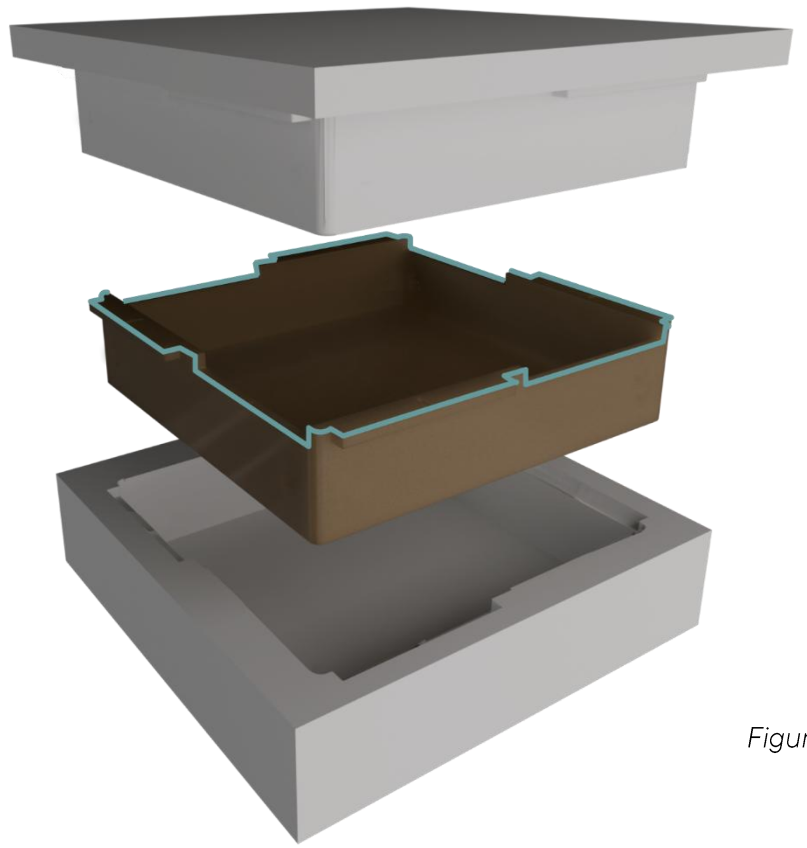


Figure D.2.4: Technical drawing and mould layout (with indicated parting line)

Final ballast assembly

The tile-to-frame connection selected in Chapter D.1 is designed to meet the structural requirements outlined earlier. To enable this connection, additional components are required besides the connection frame itself; specifically, clamping connections and M6 fasteners. The M6 bolts and nuts are standard within the existing Supra (yellow) lower and upper PV clamps. In this updated setup, the same diameter of screws maintained, but the bolt length in the new connections is increased from 20 mm to 50 mm to accommodate the added material thickness and ensure a secure connection through the entire Sigma profile, as shown in Figure D.2.5.

All fasteners used in the ballast system are mounted from above, reducing installation time and minimising interference with other components to simplify installation.

The connection frame facilitates two types of connections: the tile connection (Connection A) and the connection to the base unit profile (Connection B). Both use the same type of fasteners to ensure clarity during installation, but are positioned slightly differently along the transverse axis. The correct mounting points for each connection are highlighted in green in Figure D.2.5.

During assembly, the connection frame can serve as a measuring guide to align the base unit profiles, replacing the need for a separate measuring tool. Once alignment is complete, Connection B is mounted first to fix the base profiles in the correct position. Afterwards, the Anemone tiles are secured via Connection A. Finally, the PV panels and their standard clamps can be mounted onto the base unit profiles without obstruction, thanks to the maintained spatial clearance.

The slightly lateral holes corresponding to Connection A are intended to link with the Supra tile. In contrast, the centrally positioned holes for Connection B align precisely with the clamping connection and are used to secure onto the base unit profiles. The various holes punched through the Sigma frame provide flexibility regarding PV panel size (just like the old frame illustrated in D.2.1) while ensuring flexibility where the Anemone tiles serving as ballast will be precisely mounted.

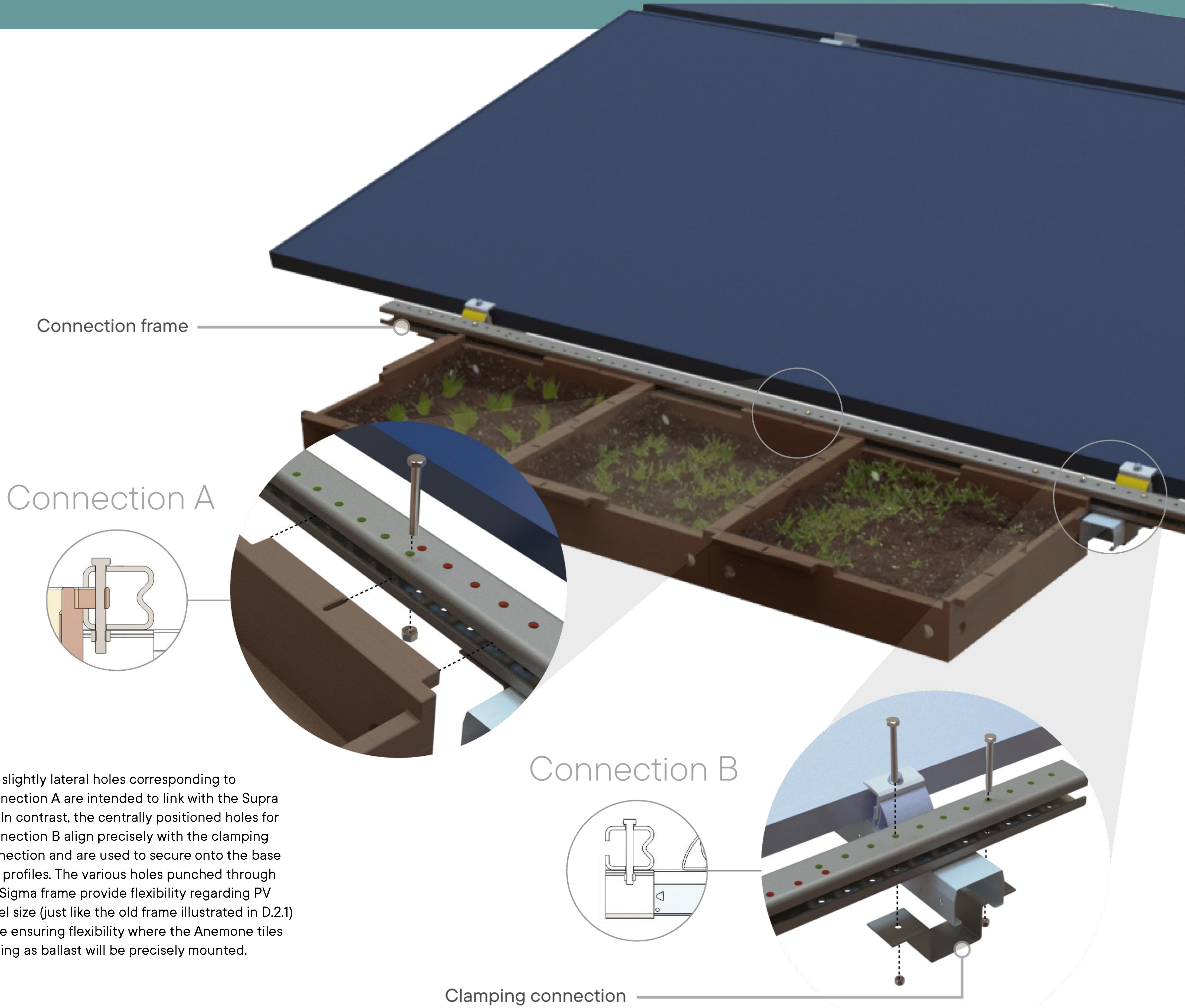


Figure D.2.5: Illustration of the connection frame, showing its dual function: linking the Anemone tiles (Connection A) and securing the system to the Supra frame (Connection B)

Costs

Costs can be expressed both in expenses and as emission-related impacts. This section examines the potential reduction in CO_2 emissions, followed by an overview of the cost difference between the current ballast system and the Anemone. The ballast system adds mass; comparisons are based on equal added mass to the Supra structure. A typical' application of the Anemone tile system would have a total mass around 78,3kg for a full product, as illustrated in Figure D.2.5.

*78,3 kg is derived from: 60 kg (weight of soil in 3 tiles) + 4,6*3 (weight of 3 tiles themselves) + 4.5 (weight of one connection frame)*

For a current ballast system to weigh 78,3 kg, two ballast plates would be needed, since 19 concrete tiles (divided over two ballast plates would be needed to meet this weight.)

For further sources and argumentation of the calculation, refer to Appendix K.

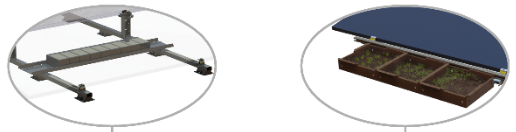
Material and manufacturing emission costs

Reductions in embodied carbon may contribute to future certification benefits or support the broader objective of achieving a more climate-neutral system. This was indicated in the SWOT analysis to be a focus point for Sunbeam in the future, since the regulations in Europe regarding compensating carbon emissions will change. To quantify this potential, the current emissions associated with the components the Anemone tile would replace are indicated, and compared to the potential emissions of the Anemone system itself. Each part's manufacturing and material emissions have been compared to provide an initial indication of potential benefits. Due to time constraints and a lack of reliable data, a full LCA could not be conducted within this project's scope. Transport, use phase, and end-of-life impacts were excluded from the comparison, as they are expected to remain relatively similar between the current and replacement systems. For a more complete assessment, it is recommended to track all life cycle stages in future research.

Additional ballast	19 concrete tiles *7.36. kg CO_2 eq*	60 kg substrate *0.6kg kg CO_2 eq-* Sedum vegetation *0.45 kg CO_2 eq-/yr*
Ballast connection	2 current ballast plate *13.4 kg CO_2 eq*	Sigma frame *12.00 kg CO_2 eq* Clamping connections *2,64 kg CO_2 eq*
Foot	2 Supra feet *0.6 kg CO_2 eq*	3 Anemone tiles *0.03 kg CO_2 eq*
Total	21,36 CO_2 eq	5,07 CO_2 eq *in 20 years*

Total expenses

For the current product, costs are validated by Sunbeam, and for the Anemone ballast system, estimations have been made based on similar products.



Additional ballast	19 concrete tiles *€10,26*	60 kg substrate *€48,-* Sedum vegetation *€0,25*
Ballast connection	2 current ballast plate *€9,54*	Sigma frame *€11,-* Clamping connections *€1,-*
Foot	2 Supra feet *€0,518*	3 Anemone tiles *€25,-*
Total	€19,85	~ €85,-

Table D.2.3: Expenses comparison between current ballast system and Anemone system

This study suggests that developing a potentially carbon-negative product is feasible. However, achieving this outcome will significantly higher upfront costs in comparison of commodity plastics

A more detailed life cycle assessment (LCA) and supply chain analysis are necessary to validate these current estimates, which should clarify whether investing in carbon-negative materials is economically justified or whether alternative strategies may offer more effective emission reductions.

Section E: Product showcase

This section presents the final outcome of the project. Following the research (Sections A & B), conceptualisation (Section C), and development phase (Section D), the focus now shifts to highlighting the unique selling points and potential implementations of the concept. Here the outcomes of the project and translates them into visual, spatial, and functional applications. It marks the shift from validation to implementation.

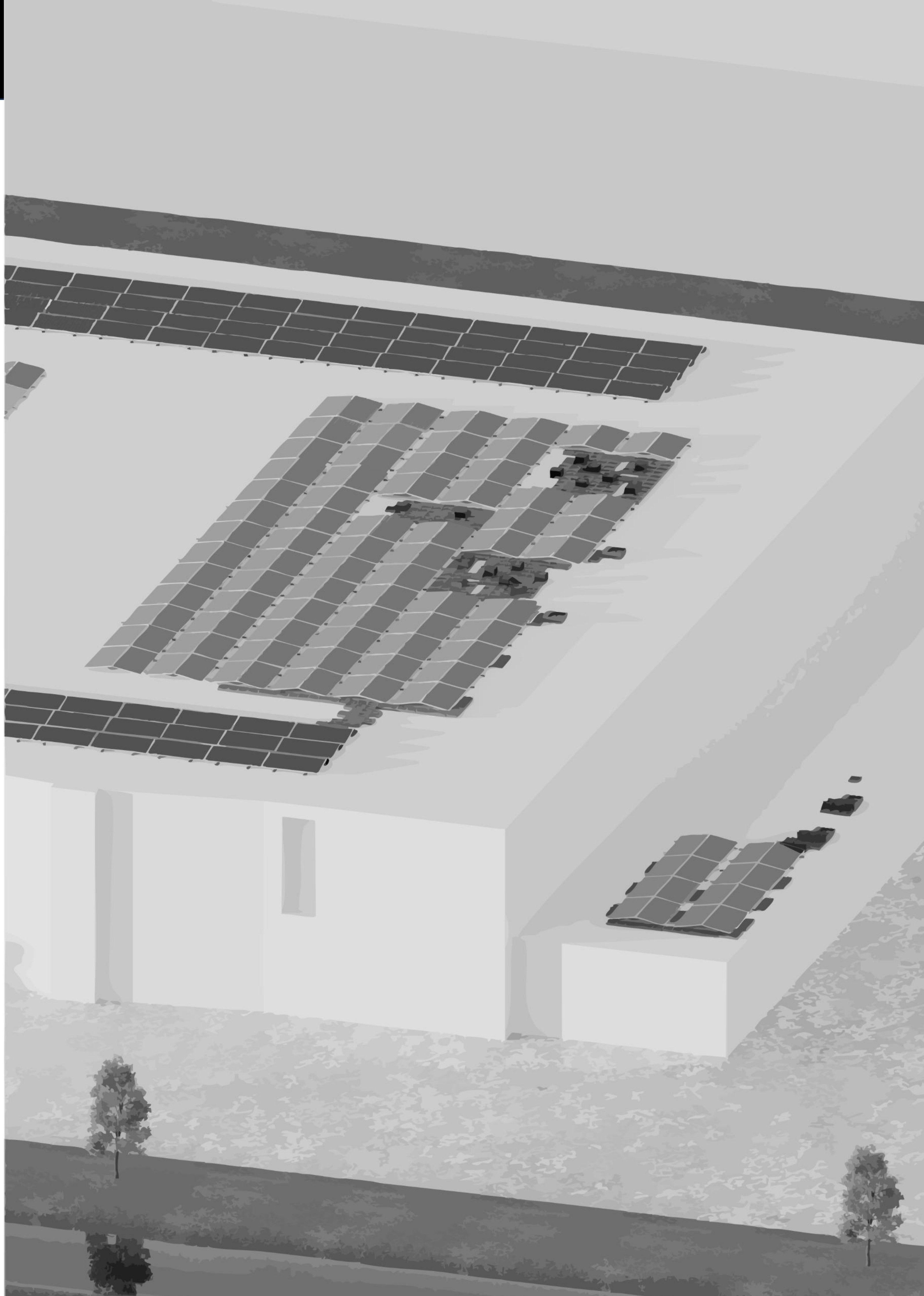
The Anemone system is not a fixed product but a configurable design strategy. It can be implemented in different configurations depending on location, available space, ecological goals, and budget. The main goal of this section is to envision this flexibility, and does so with the following chapters:

Chapter E.1: Design in practice
A detailed design study of one site, giving a full view of the potential impact.

Chapter E.2: Current product application
Shows an alternate typology with other constraints.

Chapter E.3: Component catalogue.
Shows additional information of all new modular components that enable this customisation and adaptation.

It is important to note that these results return to a more conceptual level, and are here as an illustration of possibilities. Specific requirements, such as roof load capacity or potential dirt accumulation, cannot yet be fully validated at this stage. These aspects are addressed in more detail in the recommendations.



Preview of potential layout adaptation, further discussed in this section

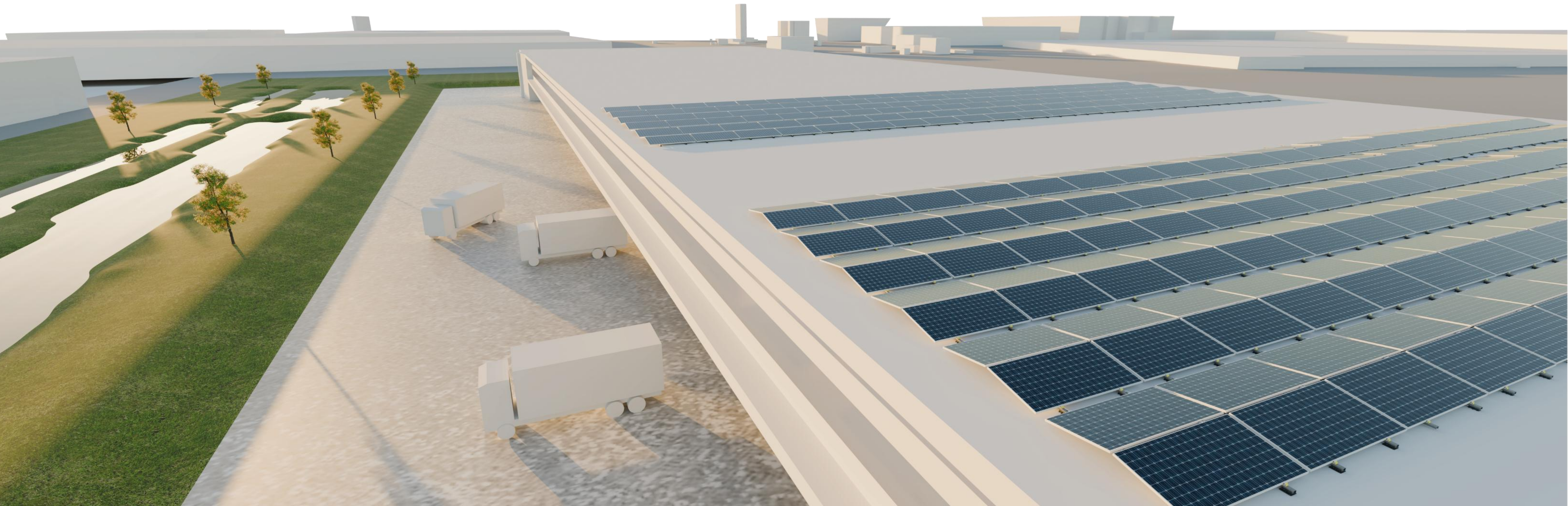
Chapter E.1: Design in practice

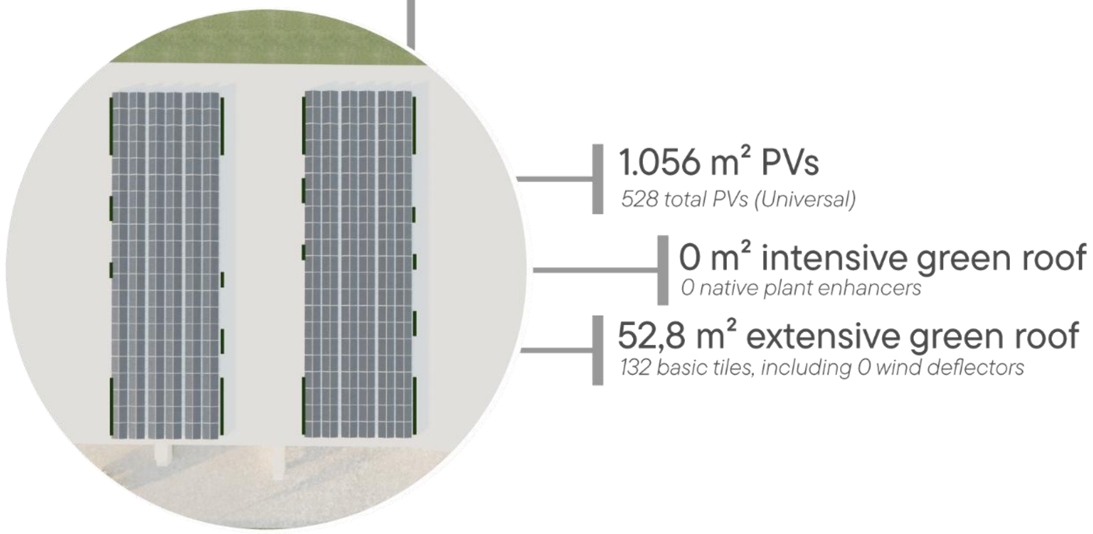
This chapter presents a full case study of a representative Dutch rooftop, used to explore how the Anemone system can be applied with varying levels of implementation preference and spatial configuration.

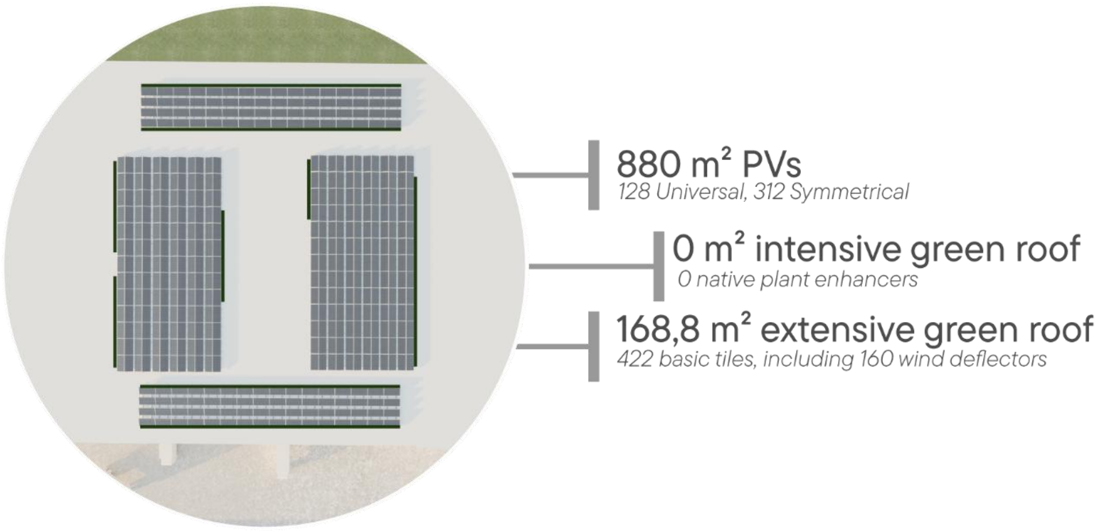
As shown in Table A.1.1, the most suitable typology for the Supra product line is the Commercial and Industrial category. This includes large flat rooftops on depots, warehouses, distribution centres, and light-industrial facilities.

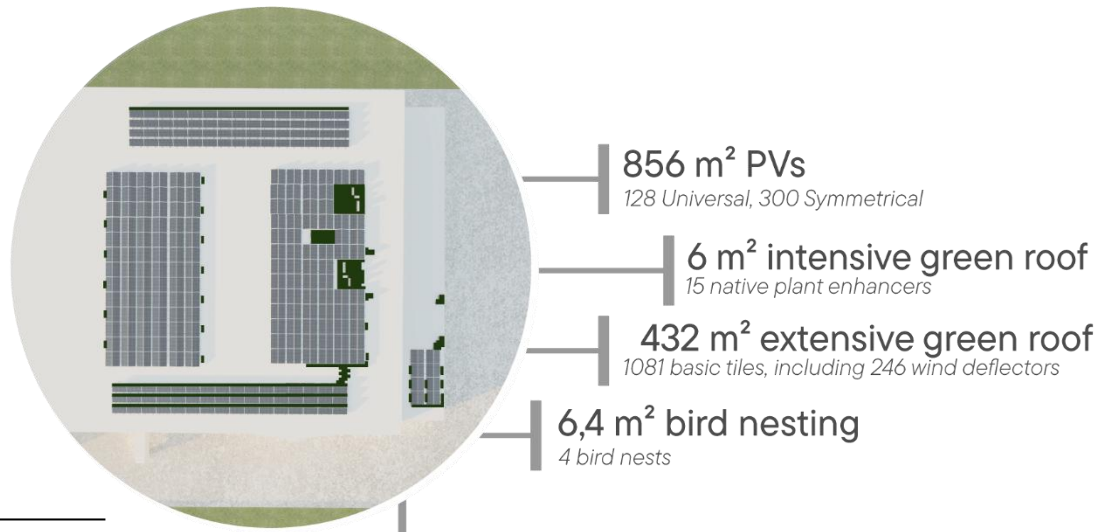
A strong example of a potential future client with a clear focus on biodiversity is Greenport Venlo, a nationally recognised, climate-adaptive industrial estate. Greenport Venlo is one of the top three nature-inclusive business parks in the Netherlands, where over 30% of the area is dedicated to ecological functions such as places for native plant growth, wetland systems, and species-specific habitats (Klimaatadaptatie Nederland, n.d.).

Integrating the Anemone system would build upon an existing ecological foundation, making it even more effective. The presence of insect and bird populations in the area means that added rooftop biodiversity would not function in isolation, but would strengthen already existing habitat networks, one of the key design considerations from earlier studies in Section B.









Finding the optimal balance

The Greenport Venlo case is presented in three scenarios, each illustrating a different balance between solar energy output and biodiversity enhancement. While a mutual benefit exists between the two, spatial and weight limitations remain a limiting factor, regardless of roof size. This is where the potential of Sunbeam's Galileo[18] calculator becomes especially relevant. By integrating biodiversity impact into its interface, users can explore how shifting the balance affects energy and ecological outcomes, as visualised in the examples.

These scenarios communicate the system's flexibility and show how decision-makers can adapt the design based on ecological targets, policy, or funding. Integrating biodiversity impact into tools like the Galileo calculator supports this flexibility, allowing users to visually explore the trade-offs between solar yield and ecological benefit depending on the placement and configuration. As shown in the customer satisfaction research, not all clients are yet convinced of the added value of biodiversity. If Sunbeam wants every client to consider this, it is essential to communicate that more solar panels do not always lead to better outcomes, whether in terms of energy yield or biodiversity. Ideally, Galileo could provide real-time feedback to clients on both energy yield and biodiversity potential. This would allow us to demonstrate that even for clients focused purely on output, integrating biodiversity features can improve overall performance. As a result, conventional full-coverage panel layouts may no longer be the optimal solution in any scenario.

In Scenario 1, a conventional east-west PV layout is implemented, similar to the current setup at this location. This configuration provides minimal environmental variation, as the area is almost entirely covered with panels, with some sedum ballasting in front.

Scenario 2 takes a more dynamic approach by varying the orientation of the panels, not only east-west but also incorporating south-facing panels. In current south-oriented PV setups, wind deflectors are typically installed along the elevated edge to meet technical requirements.

Scenario 3 explores the impact of introducing mounting systems, PVs and ABPs on varying heights. By adding vertical variation, the system provides more accessible environments and increases the likelihood of successful habitat creation for insects and birds. Since the PVs are also more scattered, there is more space for extensive plants. In the rest of the chapter, this scenario will be explored further. Note that the following showcase is exploratory and does not cover all technical aspects in detail. The showcase is intended to inspire what potential benefits the mutualistic bond of Anemone tiles and a PV installation can have.

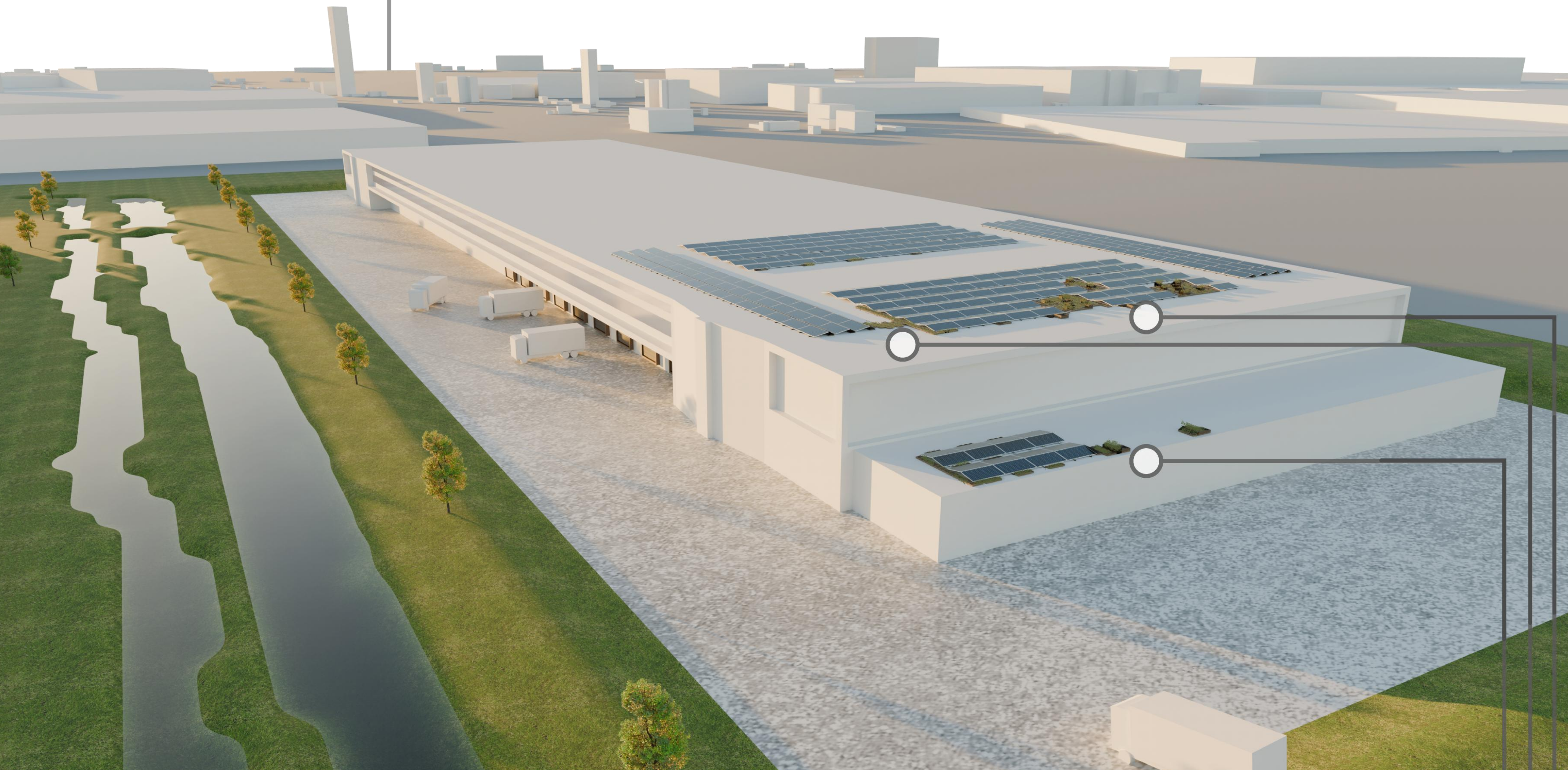
[18] https://sunbeam.solar/calculator/

Here, scenario 3 is visualised. It combines five solar fields in total, all provided with Anemone ballasts, which can replace the current ballast systems.

The Anemone's impact goes beyond being a ballast with 1.2 m^2 of sedum growth (if three tiles are applied). Potential applications beyond the ballast function discussed in Section D are highlighted here and will be elaborated on the following pages.

On the following pages, the terms microclimate and macroclimate will be used. *Microclimate* refers to the local environmental conditions within a single tile, while *macroclimate* describes the broader rooftop environment created by combining multiple tiles and modules.

It should be noted that in the following pages, in addition to Blender and Solidworks Visualise rendering tools, Adobe Photoshop's generative AI was used to illustrate vegetation. This approach was taken because the whole file, including environments, made manually adding the plants in 3D impractical. The visualised plants serve as an indicative representation of where native species or sedum could be placed. The specific plant types shown should not be interpreted as the final or accurate selection.



Stepping stones

Commercial and industrial rooftops often vary in height, typically ranging from 6 to 14 meters. The client in Galileo can already indicate this value. The more elevated a roof is, the more isolated from other environments it is, and the less likely flying insects can reach it.

As discussed in the design recommendations in Chapter B.3, the broader surrounding environment plays a key role in enhancing biodiversity. However, Sunbeams' direct influence lies within the design and application of its system. One way to improve the accessibility of Sunbeam's ABPs for reducers or higher-ranked consumers (indicated in the food pyramid in Chapter B.1) is by managing the maximum height of the installation itself.

This layout draws again inspiration from the Trekvlietzone project in The Hague, which was designed by *Flux Landscape*. Introducing different system heights can create more accessible climates, contributing to richer habitat diversity.

In this configuration, Anemone ballast tiles are also integrated between symmetrical panel rows, serving as ecological "stepping stones." While it forces the field to be functionally split up, it does so without compromising stability due to the added weight. When this is done, ease of installation is reduced, and this should be taken into consideration.

While many design inspiration from current brands uses the “less is more” philosophy, this setup takes a contrasting approach, showing that in the context of biodiversity, more can mean *better*. By increasing the number of tiles, the system creates additional habitat opportunities, enhancing the ecological value of the rooftop.

Additionally, the system shown here includes several additional modules integrated onto the Anemone tile, such as a breeding bird nest, native plant enhancers, and wind deflectors. These features each help create unique microclimates, further supporting a range of species. More information on these modules can be found in Chapter E.3.

South oriented fields

As previously mentioned, south-oriented PV fields are exciting from a design perspective because they require wind deflectors along the northern edge of each panel. Like the current Sunbeam ballast system, these deflectors present an opportunity for a replacement with a dual purpose.

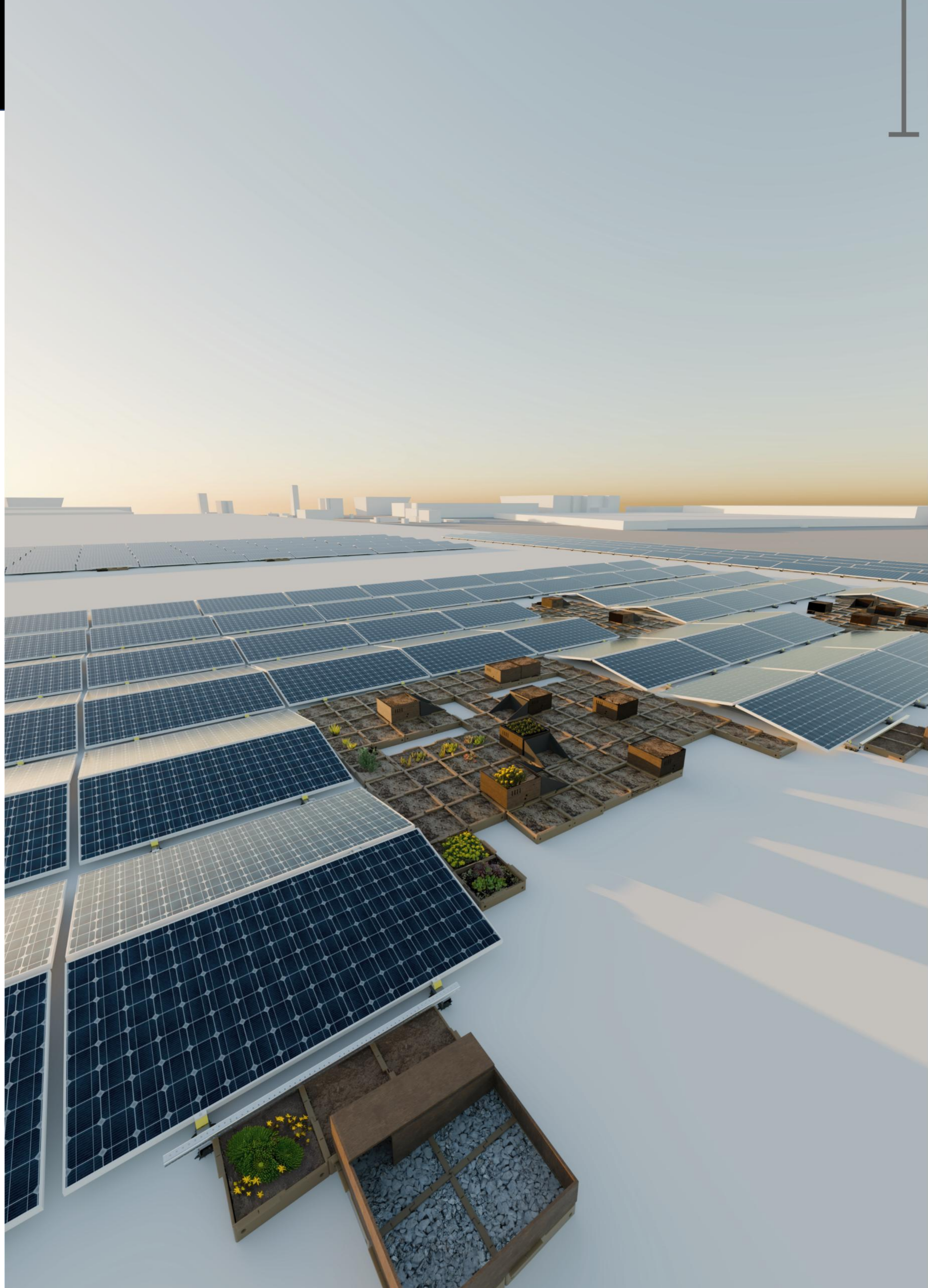
The design and functionality of these wind deflectors are further detailed in the component catalogue.

Intensive/extensive field combinations

Large-scale solar fields often resemble monocultures, offering slight environmental variation, making them unattractive habitats for biodiversity. Adding the ballast tiles that provide 1,2 m^2 of sedum plants will have a limited impact on supporting native ecosystems.

As shown here, larger field sections could incorporate Anemone tiles instead of the minimal additions in the earlier scenarios. These tiles can be used in areas where panels cannot be placed, such as around roof obstructions or where additional anchoring weight is needed.

Various additional modules are applied to further support diversity of plants, including insect housing, native vegetation, and bird nesting features. Additional modules have a different mass, allowing flexible pressure distribution across the roof's surface. This adaptability helps accommodate the structural limitations of different rooftops, making biodiversity enhancements more broadly feasible for different types of roofs.

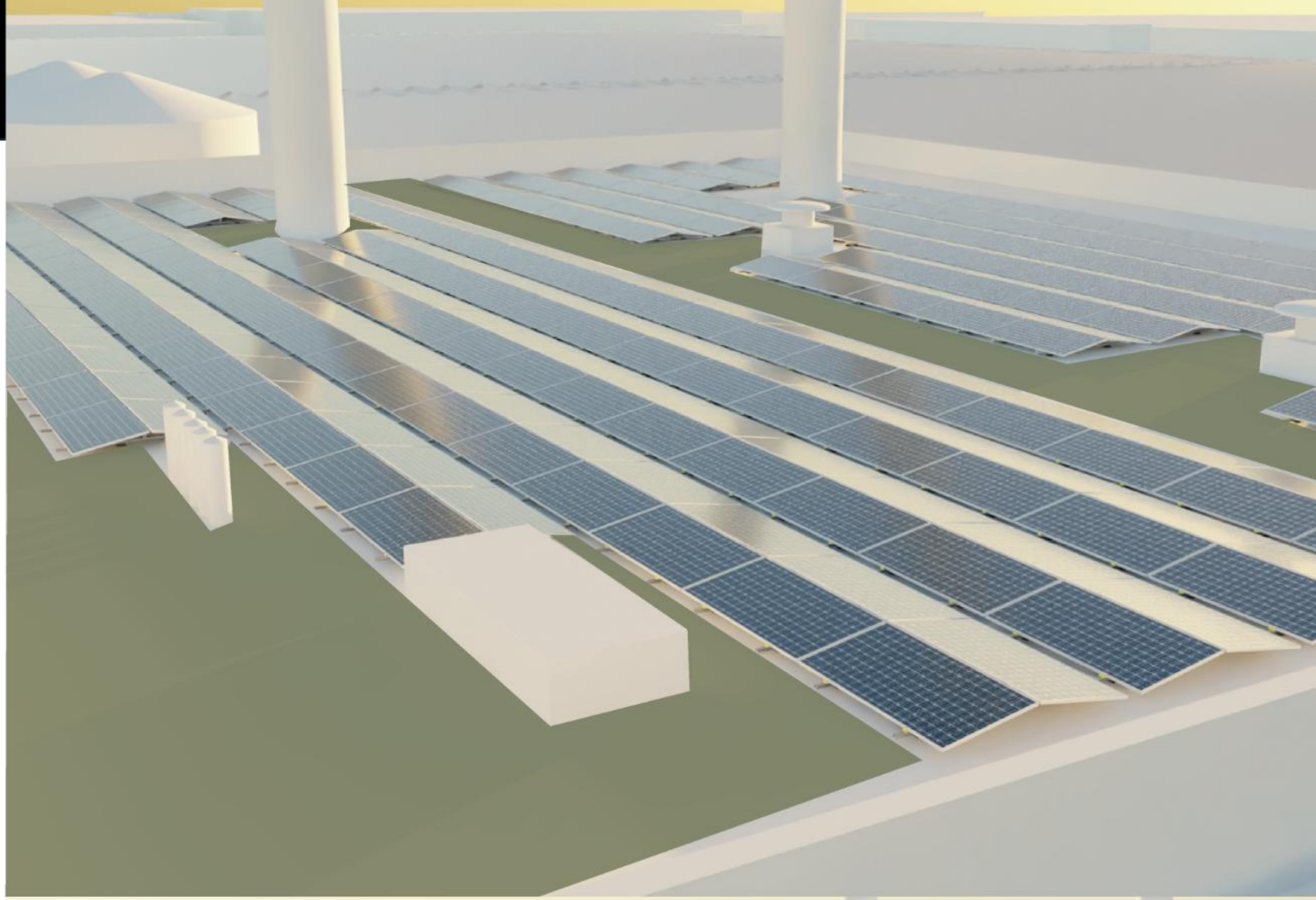


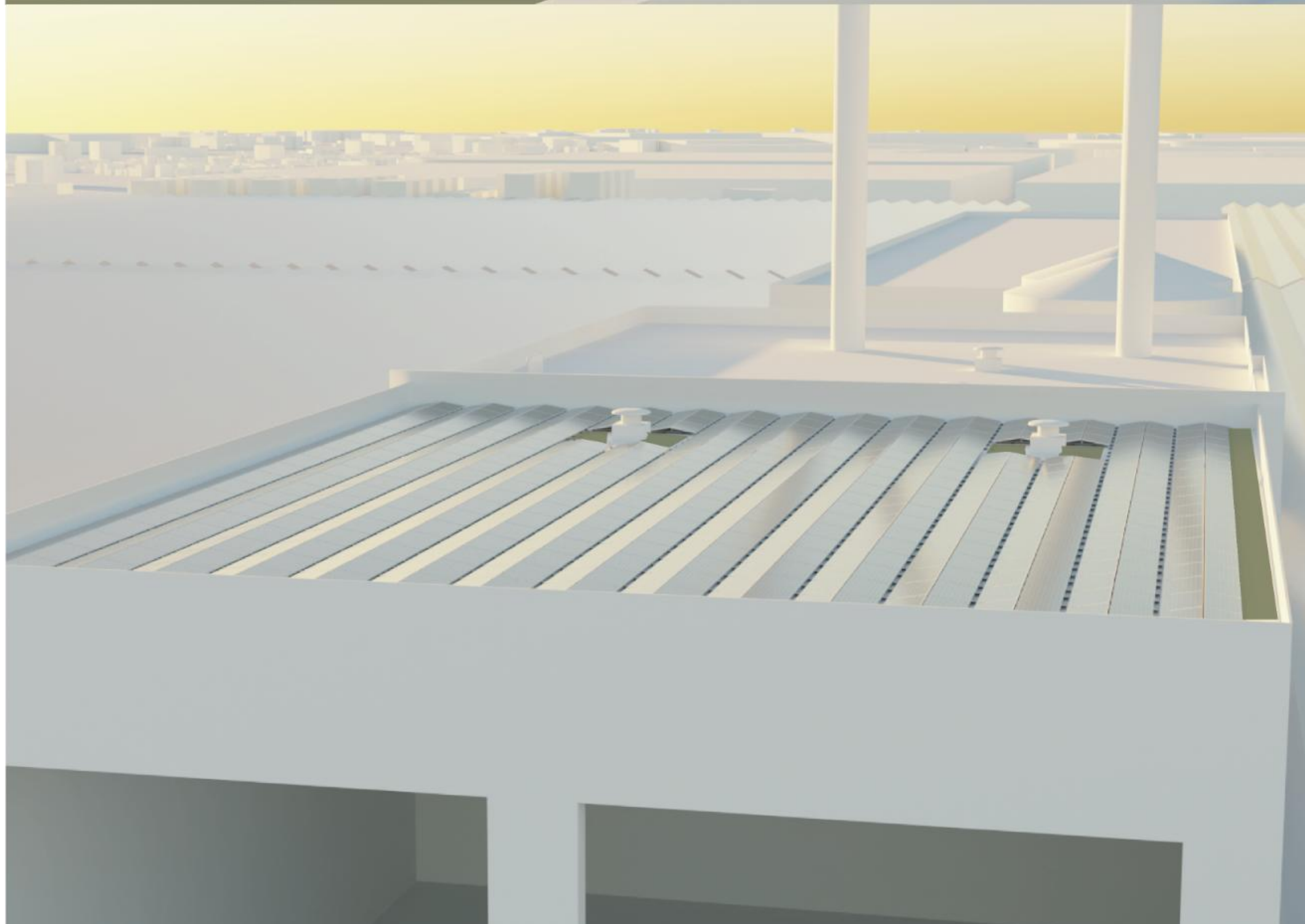
E.2: Current product applications

To show the wider potential of the Anemone system, this chapter explores the Anemones application in a current application of a Sunbeam product. Each typology presents a different context, scale, and ecological function, highlighting the system's adaptive capacity.

In this agricultural setting, there is currently limited space for birds to nest, and the overall environment is relatively barren. However, if the existing gaps on these two rooftops are utilized, it becomes possible to transform the system's current 'dead weight' into a living layer, one that supports thriving plant life, insects, and potentially even bird species.

As shown, this rooftop includes several obstacles that prevent full coverage with solar panels. However, the unused areas can still be utilised by placing Anemone tiles, which replace traditional ballast while adding ecological value.

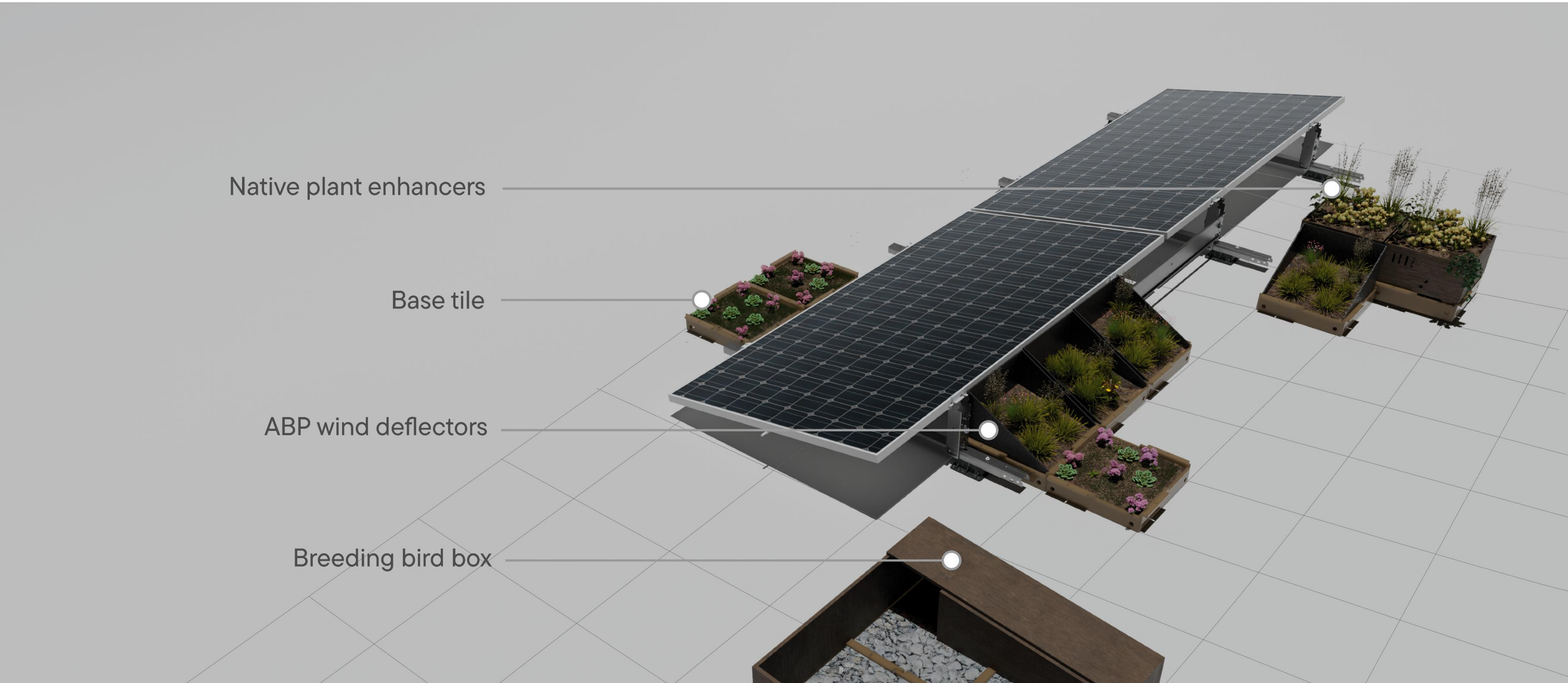




E.3: Component catalogue

This chapter overviews the Anemone system's main components and additional modules. It shows how the system can be adjusted or expanded depending on the specific needs of a project. Each module is briefly described, including its function, estimated cost, mass, and ecological value. Where relevant, links are made to earlier chapters or appendices where these elements were tested or discussed.

An overview of the different modules is given below. The image also shows the measuring grid the Galileo calculator would work with, to estimate values of different configurations.



Base tile

It all starts with the base tile, which is optimally developed in all dimensions to be perfectly suitable for the Supra system of Sunbeam, analysed in section D.

As shown in the design, the tile includes drainage holes at a height of 20 mm. These allow excess water to escape, preventing waterlogging and limiting overall weight. Below the substrate layer, a water retention mat can optionally be placed to retain moisture during dry periods, ensuring a stable water supply to the plants above. In this way, the Anemone tile serves a structural role and helps regulate its own microclimate, contributing to a more balanced macroclimate across the rooftop.

A key difference between the Anemone sedum tiles and conventional sedum mats is that all components of the Anemone system are demountable and separable. While this may require slightly more effort during installation, it offers significant advantages in end-of-life recyclability and sustainability.

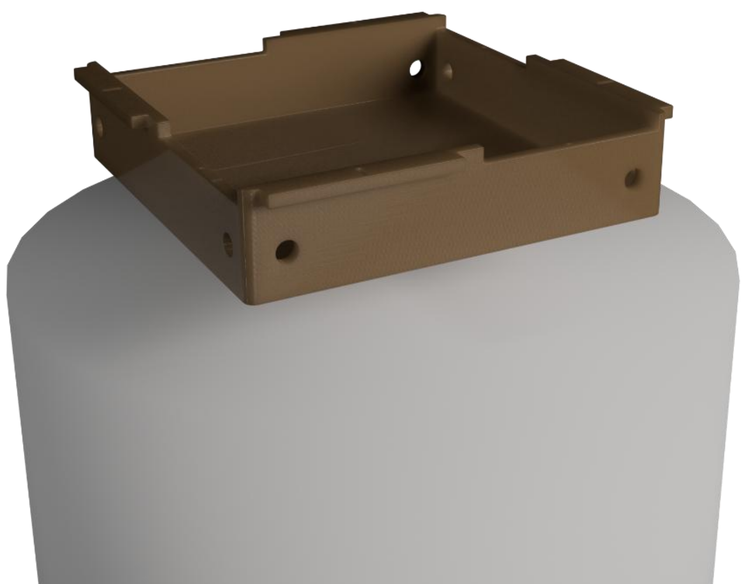
Total mass: 25 kg
Tile: 5kg
Substrate 20kg
Vegetation and water retention mat: 0-2 kg

Expected cost: €24,45
Still an indication, may vary
Base tile: ~€8,-
Vegetation seeds€0,25
Water retention mat: €0,20
Substrate €16,-

To increase market accessibility, it is recommended that cost-efficient materials for the base tile be used and that more affordable substrate alternatives be explored. See the Recommendations section for further discussion.

Species enhancement

Typology suitability



Native plant enhancers

The native plant enhancer is an optional additional component placed on top of the base Anemone tile to support deeper substrate layers, which is ideal for native vegetation. The total height of the enhanced tile reaches approximately 300 mm, aligning with the height of the PV panel's upper edge and Sunbeam's wind deflectors. This compatibility allows wind deflectors to be positioned directly against the plant enhancer, creating a unified, modular system.

The substrate depth can vary between 150 and 300 mm, offering sufficient rooting space for native plant species and making it suitable for rooftops with lower load-bearing capacities. Because this module does not need to bear any structural loads (aside from retaining the soil), it can be manufactured using various low-emission materials. The example shows that it can be made from wooden slats with holes mounted together.

On the sides of the native plant enhancers, openings for butterflies, hoverflies and bees are made in the appropriate size. The research in Section B showed that these were indicated as key reducer species or species that have seen significant declines. Their presence near native flowering plants ensures complete pollination loops, boosting both producer and consumer populations.

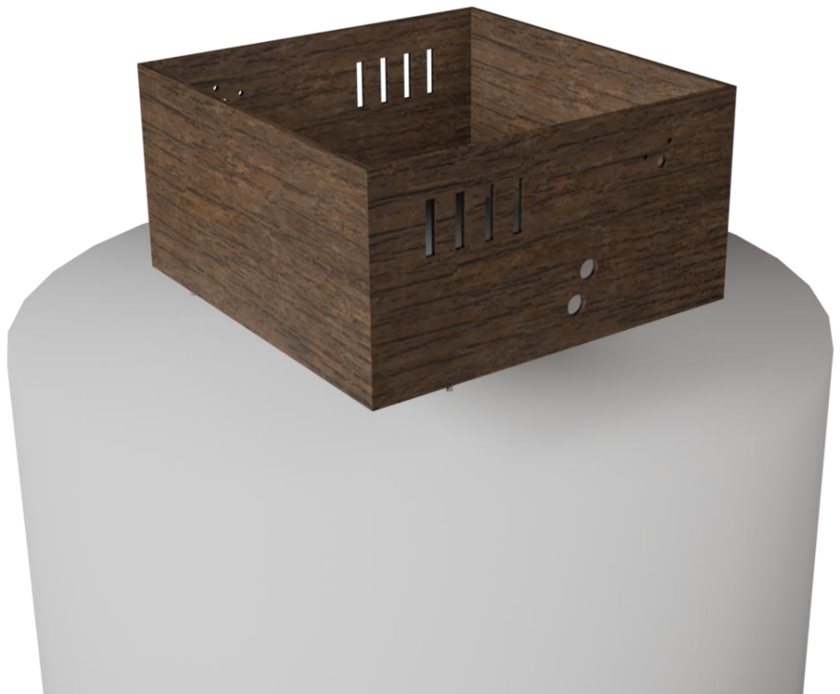
A technical drawing of the additional part can be found in Appendix J.

Total mass: 50-70 kg
(used) wooden slats: 2 kg
Substrate: 40-60 kg.
Potential vegetation 2 kg
Base tile: 6 kg

Expected cost €30-35
Indications may vary
(used) wooden slats: €2,-
Tooling: €1–3,-
Substrate: €20,-
Seeds €1–2
Base tile €8–10,-

Species enhancement

Typology suitability



Wind deflectors

The wind deflector is designed to match the elevated edge of the Supra mounting system, which reaches a height of 300 mm. It slots perfectly into the Anemone tile, remaining securely in place once the water retention mat and substrate are added. The component is envisioned as an HDPE injection-moulded part.

Although the substrate depth remains similar to that of the base tile (approximately 20 kg), the wind deflector introduces a distinct microclimate. Positioned on the north side of the solar panel, it receives little direct sunlight, creating a shaded, cooler environment. This opens up ecological opportunities for shade-tolerant species.

The deflector thus expands the ecological diversity of the system by accommodating plants that would not thrive under full sun exposure. This could let other species thrive like *Festuca rubra (red fescue)* or *Poa nemoralis (wood bluegrass).*

It is important to note that any changes to the geometry or layout of wind deflectors must still meet pressure equalisation and uplift resistance standards. Further simulations or wind tunnel testing are advised to validate performance.

A technical drawing of the additional part can be found in Appendix J.

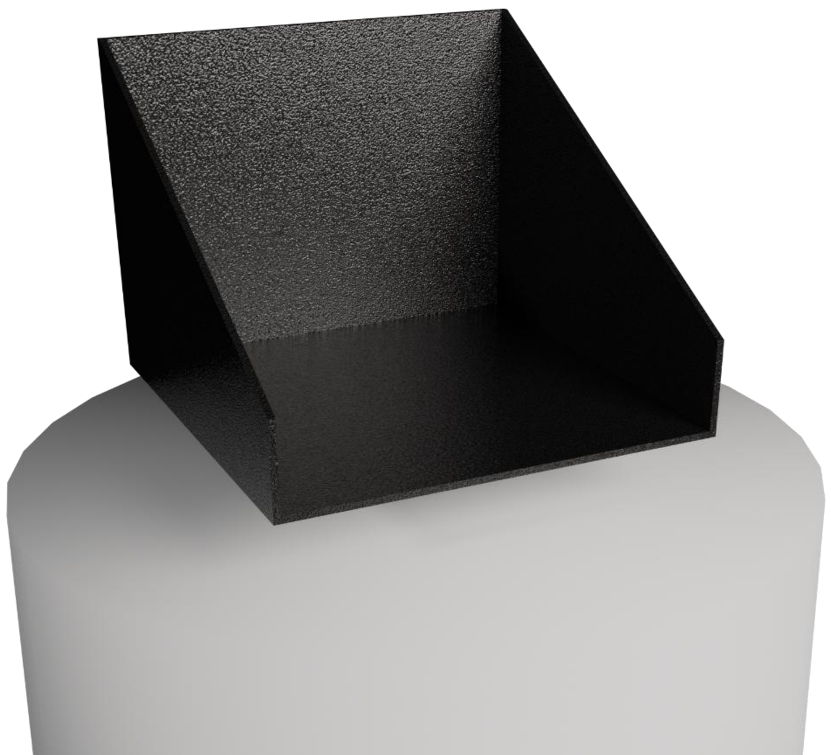
Total mass 27,2 kg
(HD) wind deflector: 2.2 kg
Weight complete base tile: kg

Expected cost €30,-
Indications, may vary.

(HD) PE wind deflector: €3–5,-
Complete cost base tile: €25,-

Species enhancement

Typology suitability



Breeding bird house

Research presented in Section B indicates that breeding bird populations in the Netherlands continue to face significant challenges, primarily due to nesting competition. This issue is particularly relevant for specific rooftop typologies more than others.

The proposed module offers limited flexibility for application beyond the commercial and industrial rooftop typologies, as it is designed as an additional component suited for integration into larger systems. Caution is advised when considering implementation in agricultural contexts (especially at chicken farms) due to the potential risk of disease transmission to livestock.

Literature suggests that oystercatchers frequently choose flat rooftops near photovoltaic (PV) installations as nesting sites, likely to reduce predation risk and secure a safe environment (Vink, Vollaard, & de Zwarte, 2023, p.17). To ensure both a safe environment for the PVs and the birds, it is recommended that an even more suitable nesting site be offered than stimulating the birds to nest beneath the panels. The specific nesting requirements (based on expert interviews) are outlined in Appendix C, expert interviews, and Appendix H, lists of requirements.

Based on specific insights from expert interviews, the birdhouse has been optimised for Oystercatchers. However, it can be adapted in the future to accommodate other breeding bird species as well.

A technical drawing of the additional part can be found in Appendix J.

Mass: 35-60 kg
Wooden slats to create bird housing: 5 kg
4x base tile: 20 kg
Additional mass of some added gravel: 10-25kg

Expected costs: €42,-
Indications, may vary
(used) wooden slats €5,-
Gravel: €5,-
4 base tiles: €32,-

Species enhancement

Typology suitability

Conclusion

This report explored how rooftops with solar infrastructure can serve as an energy source and a platform for enhancing urban biodiversity. The Anemone concept offers a dual-purpose solution grounded in the mutualistic mindset (Section C), which seeks harmony between technical performance and ecological function.

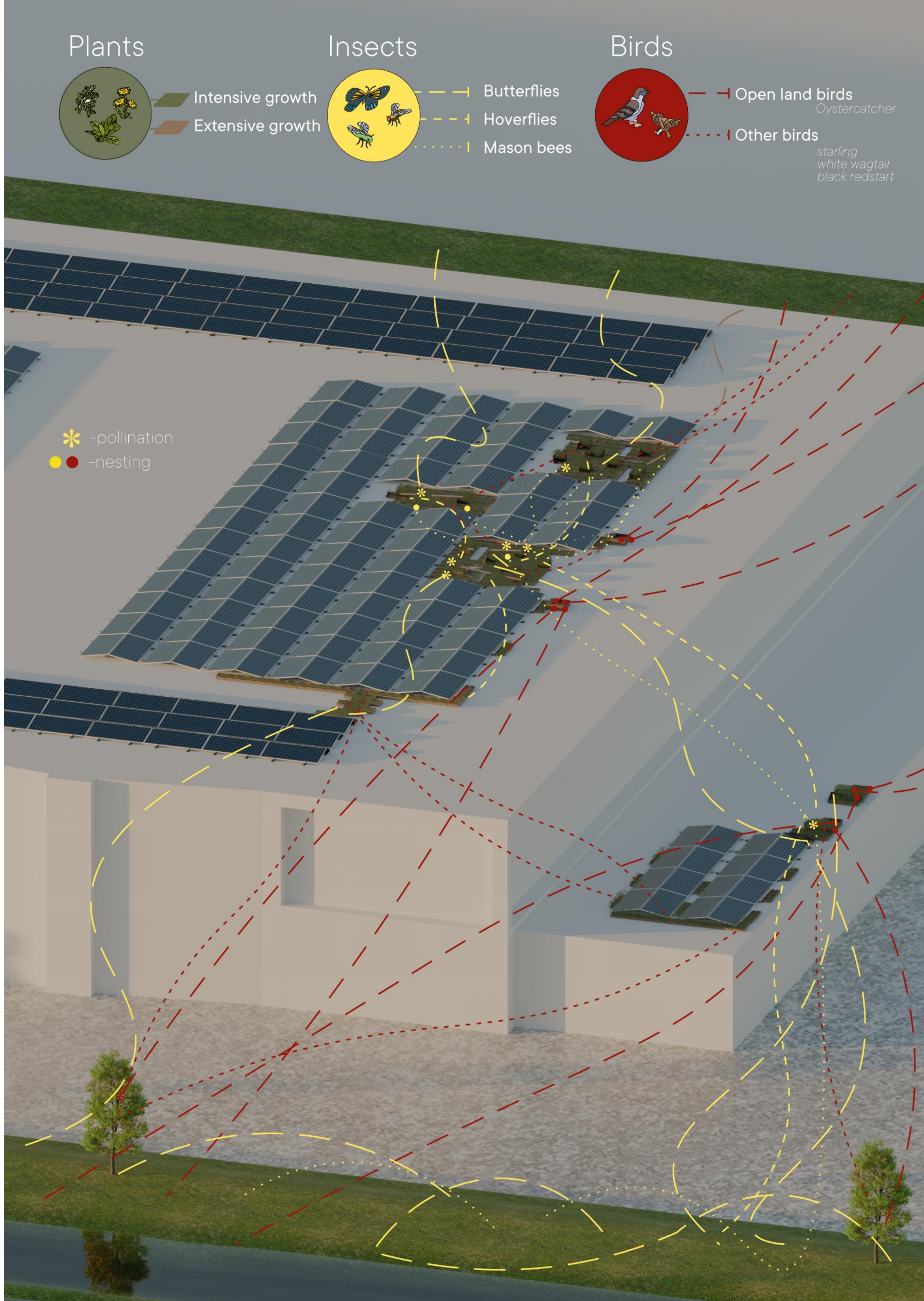
There are constraints to this integration. Adding ecological function introduces additional material, weight, and cost. Considerations such as dirt accumulation and system complexity cannot be ignored. Still, when designed thoughtfully, these trade-offs can be managed.

The Anemone concept offers a biodiversity-enhancing solution that aligns with Sunbeams' core expertise in modular, solar-first systems designed to fit a wide range of flat rooftops. This approach sets it apart from current systems, whose systems start with a full green roof mat, which is less accessible to various roofs due to weight constraints or obstacles. By offering a palette of habitat modules and plant-supporting structures, the system can be tailored to suit these specific rooftop conditions. This environmental variation utilises space for plant, insect and bird diversity, **enhancing different microclimates, ultimately creating a diverse macroclimate.**

It is important to recognise that a single product cannot quickly reverse the decades-long trend of biodiversity loss. However, the Anemone's mutualistic design philosophy can act as a starting point for reimagining the role of industrial and urban surfaces. In the Dutch context, monoculture is deeply embedded across many of the typologies explored in this report. These range from chemically imbalanced agricultural landscapes to heat-intensive flat rooftops on commercial and industrial buildings, and space-constrained residential areas. Within this environment, the Anemone system offers a quiet yet visible form of resistance, and contributes not only as a practical intervention but also as a way to raise awareness of the systemic nature of the issue.

The customer satisfaction research conducted for Sunbeam confirms that this shift in thinking is already underway. Many clients expressed a willingness to adopt biodiversity-enhancing products, often motivated by a belief in the intrinsic value of nature.

Rather than viewing Anemone as just a product, architects, developers, and municipalities should approach it as a design framework: one that encourages layered functions, disrupts spatial monotony, and addresses the growing competition for space in urban settings.



Illustrated examples of potential ecological interactions, including insect-mediated plant pollination and nesting behaviour by a variety of important species

Recommendations

Further research and development

D.1/D.2. Material selection: Investigation into local and sustainable material options is recommended. While the bamboo-fibre composite showed promise, the current material choice is not yet optimised for end-of-life disassembly or low-emission transport. Sunbeam should map out possible supply chains for alternative materials and conduct a complete LCA against the current ballast materials.

D.2: Further testing and optimisation of the assembly process with 1:1 prototypes is recommended. The final prototype revealed that the tile connections are not as easy to assemble as initially expected. While earlier tests using scaled 3D-printed models provided some insights, full-scale prototypes are necessary to evaluate ease of assembly more accurately. Iterating with multiple 1:1 prototypes will help determine whether specific connection geometries and placements work as intended. Exploring key variables includes connection tolerances, alignment features, and overall positioning.

E.3: The current substrate adds approximately 20 kg per tile, which may exceed the load-bearing capacity of some rooftops. It is recommended that Sunbeam explores lighter substrate alternatives, such as lava-based or biochar mixes. Offering a variety of substrates next to the modules would offer more flexibility in ballast distribution. This would make the Anemone system more adaptable to a larger variety of rooftops and applications, just like the variety of modules tries to do now.

E.3: Continued research is needed into water-retaining modules and the potential integration of passive irrigation systems (such as the Acacia concept). Collaborating with experts is advised to validate both feasibility and ecological benefit.

General recommendations

Nature can behave unpredictably, even in controlled environments, as illustrated by the cactus excessively growing. This highlights the need to test the different microclimates within the system using a variety of seed types and substrates to determine which plants can thrive where, without interfering with PVs. The current assumptions about the specific conditions of the modules are still unverified. Full-scale tests should be conducted to evaluate and optimise these microclimates. This should also include monitoring insect and bird activity, particularly in biodiversity-focused modules such as the breeding bird box and nature enhancer, to understand which features most effectively support urban biodiversity, without interfering with the PVs. conflicts between birds and PV panels become too significant, the Acacia concept could be reintroduced into the product line to mitigate these constraints.

The currently selected material focuses on minimising environmental emissions, which remains a well-founded design choice. However, if the Anemone is to be scaled up, it must remain viable for clients at larger volumes, as outlined in Section E. Further client research is needed to determine the additional cost clients are willing to bear. Once this price point is established, a new material study should be conducted to explore more scalable alternatives.

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Appendices

Appendix A: Project brief

Project brief conducted before the start of the thesis.

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Beau Dessens **Student number** 5099064

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title A solution for biodiversity challenges integrated in Sunbeam products.

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Sunbeam is a company making Solar panel frames that is located in Amersfoort, the Netherlands. Sunbeam has a variety of applications for flat and sloping rooftops. They are currently exploring new opportunities to enhance biodiversity through their products, aiming to develop a solution that allows solar panel mounting structures to support local biodiversity. The goal is to create a product that provides habitual opportunities for organisms struggling to find suitable spaces in areas where Sunbeams mounting systems are installed.

So this new product that contributes to restoring and/or sustaining biodiversity in areas of the Netherlands where Sunbeam solar mounting systems are located. (domain). For this initiative, the focus will be on integrating biodiversity-enhancing solutions into Sunbeam's flat rooftop systems, specifically the Supra and Nova models. These systems position solar panels at a slight incline (~12 degrees) to optimize energy capture, creating an open space beneath the panels that could be utilized for this purpose.

When a product is implemented into the systems of Sunbeam, a variety of stakeholders are getting involved, as can be seen in the figure 1 added below. Limitations might occur when still trying to keep all the stakeholders main needs intact.

An additional stakeholder not yet included in Figure 1 is the organisms themselves. Figure 2 illustrates the opportunities and constraints that may arise from a specific collaboration between Sunbeam and a particular organism. The main scope is identifying strategic areas where biodiversity restoration can be integrated into Sunbeam products while fulfilling stakeholder needs (Fig. 1). The project focuses on creating solutions that support both ecological and economic sustainability.

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introduction (continued): space for images

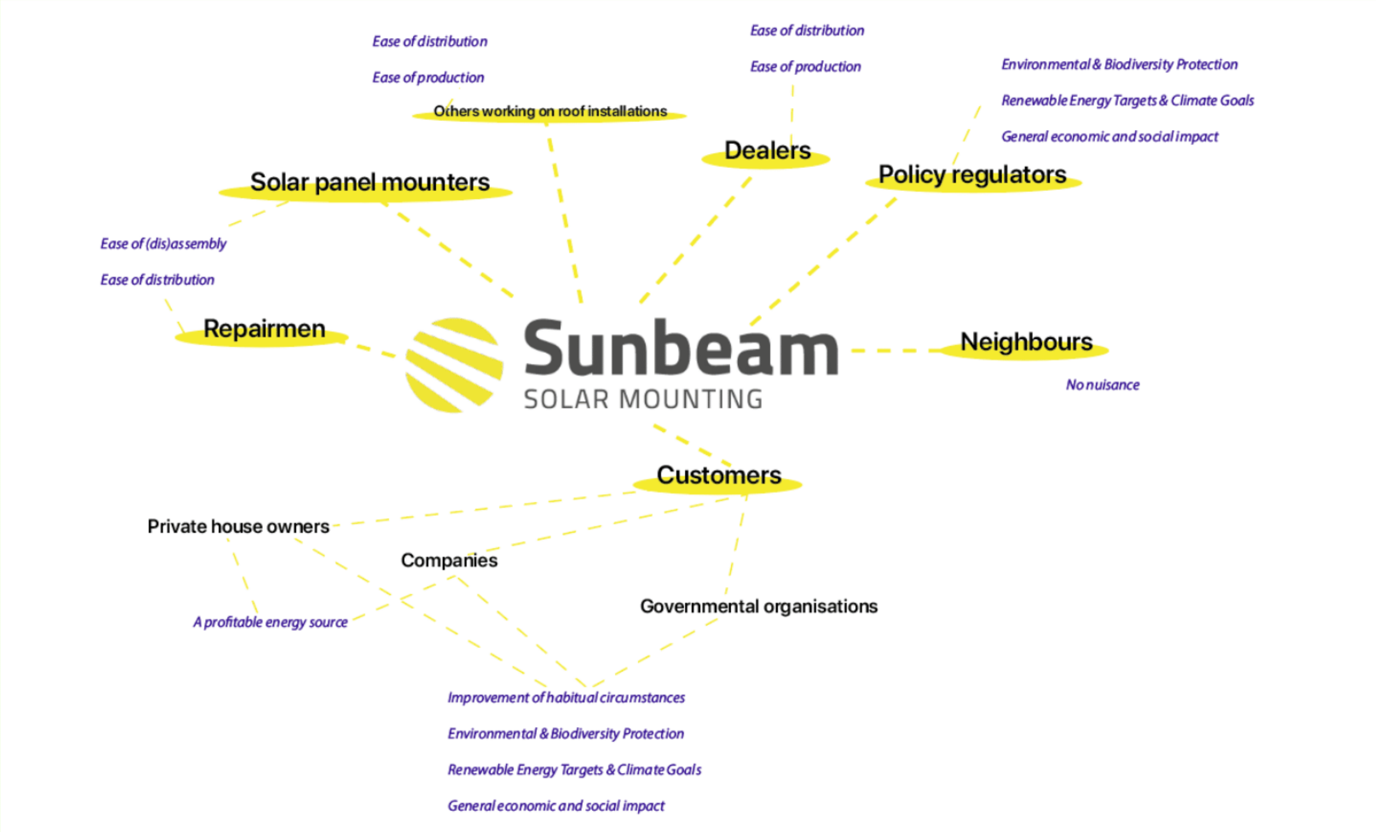

image / figure 1: Stakeholder map

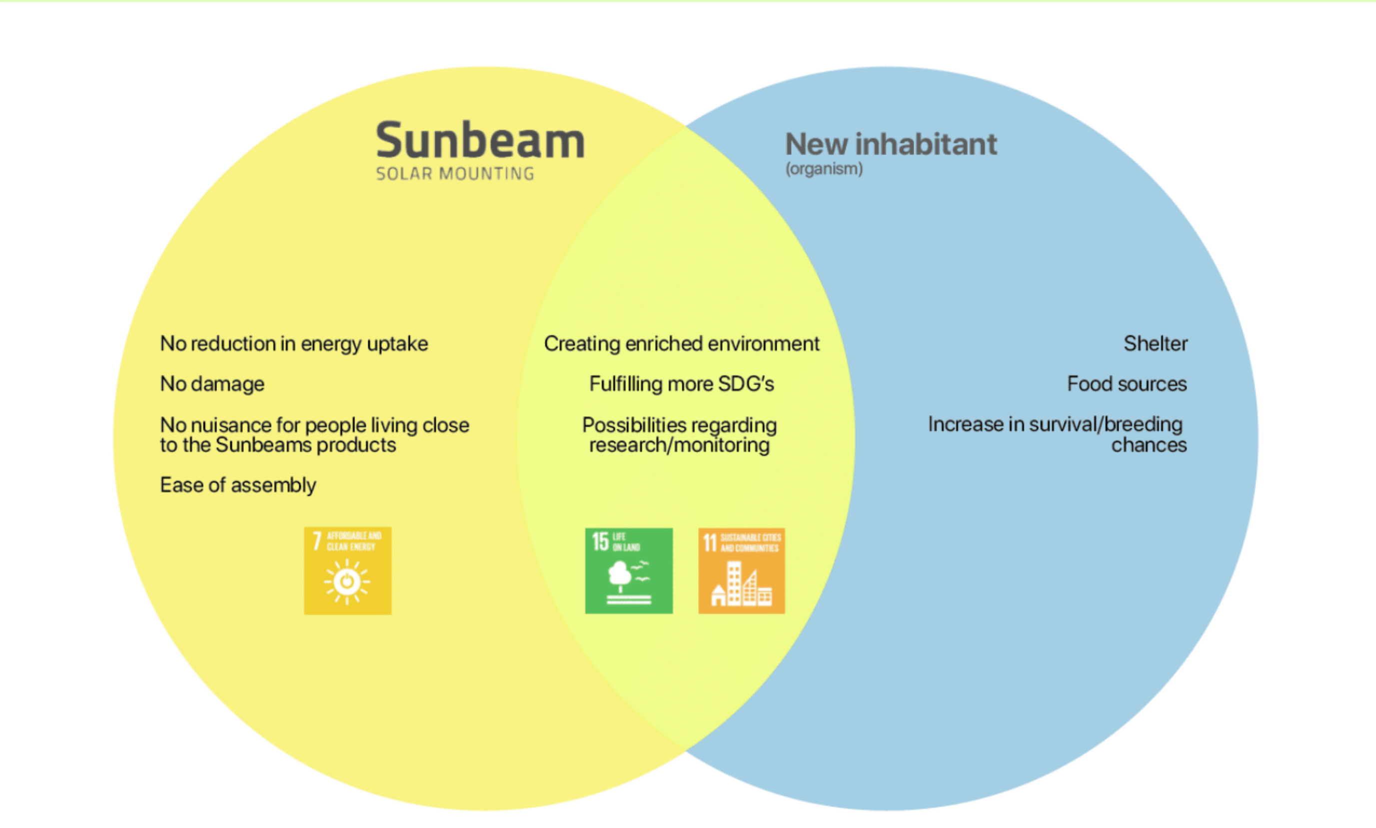

image / figure 2: Main two stakeholders with their main needs and added values

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The added value, as previously described, is Sunbeam's achievement of multiple Sustainable Development Goals [1] to also encompass contributions to SDG 11 (sustainable cities and communities) and SDG 15 (life on land). By integrating these sustainability goals, Sunbeam strengthens its long-term vision, ensuring a broader and more sustainable future for the company.

This also aligns with IDEs main vision regarding Design for our Future.

The goal of enhancing biodiversity must be approached strategically to ensure that the needs of all stakeholders, as outlined above, are met as effectively as possible. This requires targeted research to develop a concept line and product that supports biodiversity where it is most needed in the Netherlands, without significantly compromising the efficiency of the solar panels or the quality of life for nearby residents.

[1] https://sdgs.un.org/goals

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a product to validate a habitat solution for organisms that restores/sustains biodiversity in the Netherlands – specifically in areas where Sunbeam products are (or will be) located – while limiting the negative impacts on other stakeholders.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

Week 7 ('midterm'):

1. **Market/product Research**: Analyze Sunbeam's market, product locations, and client base. Assess existing products for biodiversity integration opportunities and constraints. *Possible research methods: Trend analysis(mapping)/Ansoff growth matrix/SWOT/C-boxes (or other matrixes).*

2. **Biodiversity Research**: Investigate biodiversity challenges in the Netherlands, identifying species that would benefit most and are in greatest need. Possible research methods: Trend analysis(mapping)/

3. **Start concept ideation**: Develop first initial concepts: conclude which organisms are best suited for a possible product. *Possible research methods: List of requirements/storyboards*

External sources: SolarNRG, Sunbeam, Groendak, Paviljoen 3, TU Delft projects, Wageningen University—current biodiversity rooftop solutions.

Week 12: Concept development done. Decide between: 1. A specific product tailored to a particular organism. OR 2. A concept line with one chosen concept that goes into further development.

Week 16 (Green Light): Develop substantiated product idea. (If multiple concepts exist, one undergoes deeper prototyping for quality assurance.) Prototypes tested within Sunbeams systems, testing should determine the value for a variety of two main stakeholders: Sunbeam and organism. (If organism is not possible, further ease of assembly can developed as well) *Think of: habitant for organism, fitting in Sunbeam product (wind/mechanical testing/connection testing).*

Week 20: Finalize a functional, tested prototype, (validated for feasibility with multiple stakeholders) Secure pricing with suppliers via Sunbeam.
Possible research methods: Fatigue or tensile testing/connection testing/FEM's/cost price estimation methods.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting 25 Feb 2025

Mid-term evaluation 11 April 2025

Green light meeting 13 Jun 2025

Graduation ceremony 11 Jul 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments: *Remote the week of 7 april.*

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

This project motivates me as it allows me to apply my conceptual design skills to a solution that positively impacts the future while aligning with one of my key interests—nature. As a child, I was always fascinated by discovering new animals and plants while playing outdoors, and that curiosity continues to inspire me today.

Personal Learning Goals:

- Develop a product that creates a positive impact on the world and its future.
- Do a quite **specified research** that will lead to a niche expertise regarding the topic.
- Possibly **improve my prototyping skills**.
- Gain experience in embodiment product design by working together with the client and exploring **new product testing methods** later in the project.
- **Engage with manufacturers** to refine product ideas, test them with existing Sunbeam products, and optimize my design process.

Appendix B: Examples of typologies

Here some practical examples of Sunbeam projects suiting the described typologies are listed.

Agriculture

Commercial and Industrial

Flats

Spacious houses

Dense houses

Municipal

Sources images: Sunbeam.nl, Wikimedi.org.

Appendix C: Main takeaways from interviews

Several interviews have been conducted with various experts in from different universities, ecological consultancy firms, and companies involved in ecology-related work. The main insights from these interviews are listed here.

Friso van der Zee – Wageningen University

Online Teams Call
Affiliation: Wageningen Environmental Research – Biodiversity and Policy
Date: 13 March 2025

Key Insights

- Fewer opportunities for species like house sparrows and bats due to improved insulation and sealing of buildings.
- Oystercatchers prefer gravel substrates for nesting, close to PVs.
- Sparrows are likely to be found under roof tiles.
- The nitrogen crisis is a significant ecological issue, especially in solar parks studied by Van der Zee. It leads to nutrient-poor conditions, which negatively affect biodiversity.
- Solar parks are currently not very suitable for birds, particularly meadow birds, which prefer open, unobstructed landscapes.
- Invasive species such as Japanese knotweed and the American crayfish also pose threats to Dutch biodiversity.
- The heat generated by solar panels may have potential relevance for certain species like butterflies.

Ecologist at an Engineering Consultancy

Interviewee preferred to remain anonymous
Date: 14 March 2025

Key Insights

- Biodiversity in the Netherlands is in serious decline.
- Urban structures can offer benefits to certain species, such as house sparrows, starlings, and bats.
- Bats need to drop from their roosts to begin flying, making flat roofs generally unsuitable for them.
- Swift nesting boxes are increasingly installed; these birds typically nest under roof tiles but may also use south-facing roofs.
- Butterflies can potentially reach heights of up to 40 meters, but insects generally prefer lower altitudes, closer to the ground.
- Insects are highlighted as one of the most vulnerable groups in the current ecosystem crisis.
- The habitat of the black-tailed godwit (grutto) is rapidly disappearing.

Ir. Evelien van Doorn – Ecologist at Bureau Stadsnatuur Rotterdam

In-person meeting at the Natural History Museum Rotterdam
Date: 17 March 2025

Key Insights

- Species commonly observed on flat rooftops include the black redstart (*Zwarte roodstaart*, *Phoenicurus ochruros*), gulls (*Meeuwen*, *Laridae*), and the white wagtail (*Witte kwikstaart*, *Motacilla alba*).
- Migration patterns of the herring gull (*Zilvermeeuw*, *Larus argentatus*), lesser black-backed gull (*Kleine mantelmeeuw*, *Larus fuscus*), and the oystercatcher (*Scholekster*, *Haematopus ostralegus*) require further research.
- A study in England showed that a square meter of gravel beneath solar panels served as an ideal hiding and nesting spot for the magpie (*Ekster*, *Pica pica*), making it an optimal breeding location.
- Bird breeding seasons require further investigation to inform rooftop biodiversity design.
- Other urban-dwelling species currently facing challenges include the red mason bee (*Metselbij*, *Osmia bicornis*), hedgehog (*Egel*, *Erinaceus europaeus*), and marten (*Marter*, *Martes* spp.).

Mathijs Verwij – Ecologist at Kwinfra

Online meeting via Teams
Kwinfra is an Environmental & Civil Engineering Consultancy
Date: 19 March 2025

Key Insights

- The nitrogen crisis affects more than just isolated species; it disrupts the overall chemical balance in ecosystems. For example, low calcium and high nitrogen levels lead to plant imbalance, which cascades to insects (*Insecten, Insecta*) and eventually to birds (*Vogels, Aves*), possibly even weakening eggshells.
- A distinction must be made between protected and threatened species. Some animals are protected due to policy decisions, even if not officially endangered.
- Bats (*Vleermuizen, Chiroptera*) may suffer from changing rooftop microclimates caused by solar panels. The company Apodemus produces heated bat boxes to mitigate this.
- Under Natura 2000, all native birds are protected.
- In addition to the oystercatcher (*Scholekster, Haematopus ostralegus*), several other species are known to breed or dwell on flat rooftops:
  - Common tern (*Visdief, Sterna hirundo*) – in worse condition than the oystercatcher
  - Lapwing (*Kievit, Vanellus vanellus*) – chicks need to forage independently after hatching
  - Black redstart (*Zwarte roodstaart, Phoenicurus ochruros*)
  - Starling (*Spreeuw, Sturnus vulgaris*)
  - House sparrow (*Huismus, Passer domesticus*)
  - Swift (*Gierzwaluw, Apus apus*)
  - Peregrine falcon (*Slechtvalk, Falco peregrinus*)
- Interspecies conflict can occur, with some birds displacing others:
  - Woodpecker (*Specht, Picidae*) vs. ring-necked parakeet (*Halsbandparkiet, Psittacula krameri*)
  - Great tit (*Koolmees, Parus major*) vs. bats
  - Spoonbill (*Lepelaar, Platalea leucorodia*) vs. herons (*Reigers, Ardea* spp.)
  - Crow (*Kraai, Corvus corone*) vs. magpie (*Ekster, Pica pica*)
  - Owl (*Uil, Strigiformes*) – various species that compete with other raptors
- Notable existing products and organisations:
  - Apodemus – heated bat shelters
  - Faunest – supplier and consultant for nature-inclusive design

BirdBlocker – Informal Call

Date: 19 March 2025

Key Insights

- The three main types of animal-related nuisance around buildings are:
  - Around solar panels on pitched roofs: Most damage is caused by jackdaws (*Kauw, Coloeus monedula*) and pigeons (*Duif, Columba livia domestica*), which can damage panel wiring and components.
  - On flat roofs: The biggest issue is bird droppings, particularly from gulls (*Meeuwen, Laridae*) near waste processing facilities. No effective solution currently exists for this.
  - On industrial rooftops: Pine martens (*Steenmarter, Martes martes*) can chew through cables, causing electrical damage.
  - In agricultural settings: Migratory birds (*Trekvogels*, various species) pose a risk of transmitting diseases to poultry, especially on chicken farms.
- BirdBlocker focuses mainly on pitched roofs, as solar panels here are mounted close to the roof surface, making the area underneath more vulnerable to animal intrusion and damage. This is generally not a concern on flat roofs, where there is more space and less access beneath the panels.

Erik Broer – Zoogdiervereniging

Online Teams call with Erik Broer, Project Lead Bats at Zoogdiervereniging
Date: 11 April 2025

Key Insights

- There are 18 bat species present in the Netherlands. While the overall population trend is currently increasing, populations declined significantly before 1990 and have yet to fully recover.
- In urban environments, bats are commonly found in built structures, including roof surfaces (*Dakvlak*), cavity walls (*Spouwmuren*), and fascia boards (*Boeiboorden*).
- In addition to the common pipistrelle (*Dwergvleermuis, Pipistrellus pipistrellus*), other key bat species include:
  - Pond bat (*Meervleermuis, Myotis dasycneme*): The Netherlands is home to around 30% of the European population. However, its population has halved since 2023.
  - Parti-coloured bat (*Tweekleurige vleermuis, Vespertilio murinus*): Another species of interest for rooftop biodiversity design.
- Managing the microclimate within buildings is essential - particularly during the maternity period, as bats require stable humidity and thermal conditions.
- Research by TNO provides relevant insights into the microclimatic effects of tilted roofs, both with and without solar panels.
- A permit is required for any monitoring or research at sites where bats are known to be present.
- Bats in the Netherlands can be monitored through NEM (*Netwerk Ecologische Monitoring*), a national ecological monitoring network.

Marie José – Vogelbescherming (ScholeksterOpHetDak.nl Initiative)

Online Teams call to discuss early design concepts
Date: 9 April 2024

Key Insights

- There is a growing need for biodiversity-friendly rooftops, particularly in urban environments.
- Green roofs can improve the microclimate for both flora and fauna by retaining moisture and reducing rooftop overheating.
- Nesting birds on rooftops require protection from predators and harsh environmental conditions, such as intense sunlight and heat.
- Water availability is essential on rooftops; a small water basin is recommended to support birds.
- Monitoring species presence is key to validating whether rooftop biodiversity interventions are successful.

The call with Marie José was particularly valuable to retain feedback on concept 4:

- This concept is considered highly relevant, as the species involved already nest on flat rooftops in urban settings.
- Key design requirements for rooftop-nesting birds such as the oystercatcher (*Scholekster, Haematopus ostralegus*):
    - Minimum gravel area of 5x5 meters is preferred (though smaller is acceptable).
    - Provide shade and shelter for chicks to protect them from heat and predators.
    - Include an elevated roof edge (20–50 cm) to prevent chicks from falling off the roof.
    - Ensure unobstructed views and open flight paths for parent birds.
    - Integrate a water source on the roof, especially for dry periods.
    - Use gravel or shell substrate for nesting - light-colored gravel is preferred as it supports better chick movement.

Gert Jan Kampschmidt - Groendakspecialist

*Online Teams call. Final concepts are presented to the owner of Groendakspecialist, Gert Jan Kampschmidt. Gert Jan Kampschmidt is an expert in Design, construction and maintenance of green roofs and roof gardens, which contribute to biodiversity, water management and insulation.*Date:

Date: 20 May 2025

Key insights

- Anemone: Generally, very positive about concept, main point of research is how much is dry weight vs saturated weight. Type of earth can be picked if you want a high/low saturated weight.
    - 'Perlite is a Material that is used often for lightweight green roofs. Lava underwater stone.
    - Epiphyte: Temperature regulation also done greatly with water potentially. Regarding plant growth: Have to be aware that plants are in Northern direction, so will be less warm and can have consequences.
- Acacia: Every green roof in the Netherlands MUST have something with water. The Netherlands has never been as drought as it is now, and if you want to do something for biodiversity on rooftops, you need water. The earlier concepts have to have something like acacia installed
    - Watering can be done by:
        - Sprinkler system: more pressure needed.
        - Drip tube: No high pressure needed. Garden tap is fine.
    - The more complex of a watering system, the more it goes wrong in practice.
    - Adding something with water can also do a lot for the cooling of the panels.
- EAN norms: Water storage.
- Certificates: GPR and Green could be important.

Gabriëlle Jager – Cruydt Hoeck

Online Teams call. Final concepts and dimensioning of soil and water retention are presented to an ecological advisor of Cruydt Hoeck, Gabrielle Jager. Cruydt Hoeck is a plant nursery for native Dutch plants to stimulate other biodiversity as butterflies and other insects.

Date: 21-5-2025

Key insights

- Big fields are often ecological deserts. Biodiversity potential is currently very low. Real impact you need to sacrifice some panels.
- Acacia: Direct tap water supply is less ecological; consider rainwater harvesting (e.g. barrels, underground layers).
- Minimum desired ground layers:
    - 15 cm minimum for native species. Cruyd Hoeck offers D2 seed package that is suitable to this. Se-dum can survive without irrigation, but native plants require a minimum of 15 cm soil depth (10 cm with water retention might be possible).
    - Otherwise sedum, with 6 cm layer. Less great for Dutch biodiversity. Not really hosts for butterflies and bees.
- Other plant advises:
    - Avoid plants that seed or spread too easily to prevent debris on panels.
    - Current option at Cruyd Hoeck: Use the D2-mix: a blend of low-growing native plants suited for dry, shallow, windy rooftop environments.
- Larger tiles (surface area) are ofcourse better for biodiversity as well.

Appendix D: Challenging factors for biodiversity

Here challenging factors, mentioned in Chapter B.1 are more elaborately described.. The challenges are retrieved from the expert interviews and additional desktop research.

In ecology a distinction is made between biotic and abiotic factors. Biotic factors is life itself, while abiotic factors concern the non-living parts of an environment.

Both biotic and abiotic factors can limit or constrain biodiversity in the Netherlands.

These factors have been based mainly on interviews with experts in this field, and is complemented by desktop research.

Biotic factors

- Invasive species: Invasive species can cause challenges for species originating from the Netherlands, and causing major disruptions in ecosystems. Experts suggest that it not advised to introduce more of these invasive species to the Dutch biome. Examples of these invasive species that cause significant problems are:
    - Japanese Knotweed (*Japanse Duizendknoop, Fallopia japonica*) – outcompetes native plants.
    - Signal Crayfish / Red Swamp Crayfish (*Rivierkreeft, Pacifastacus leniusculus* or *Procambarus clarkii*) - disrupting aquatic ecosystems by damaging banks and reducing biodiversity.
    - Pacific Oyster (Japanse Oester, *Magallana gigas* or *Crassostrea gigas*) – Dominates in intertidal zones.

Abiotic factors

The challenge of biodiversity can be briefly formulated by Friso van der Zee (Project manager at Wageningen environmental research):

Nature has a hard time in the Netherlands since it has to compete a lot. It has to compete a because of acidification (nitrogen) and by competing with built environments.

According to other experts this problem of competition can be more described as sparseness.

Acidification

According to experts acidification of soil might be the biggest cause of biodiversity reduction in the Netherlands. Note the species with the biggest drop in LPI are butterflies, also an essential species also serving as pollinator for a lot of (wild) plants .This trend can be directly linked to increasing Nitrogen deposition. This occurs because the increase of Nitrogen makes certain plants grow faster, resulting in plant species diversity reduction, which leads to lower food quality for butterfly larvae (Feest et al., 2014).

It's clear that acidification has its main effects in the agricultural landscapes, as farmlands and open landscapes have the biggest regression in LPI trends.

Acidification of nitrogen also influences Natura 2000 areas, as 60% of natura 2000 areas are currently over their Nitrogen threshold, which causes similar implications (Van Dobben et al., 2025).

Acidification

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Competition because of built environments

Even though less researched, built environments also influence the original habitat of organisms, and alter biodiversity. It is understandable that not all forms of nature are always desirable, especially when certain biodiversity is located close to people, in urban/built environments. This topic is further discussed in Chapter B.2, which addresses biodiversity that is often avoided or excluded in built environments.

Altered water flows

Changes in water flow, such as dam constructions and drainage for agriculture, can impact ecosystems. The Netherlands of course is know for it's revolutionizing way of doing this, and this can actually have some positive effects on the Dutch ecosystem as well,

A positive example the "Room for river" program has demonstrated positive outcomes ("Rijkswaterstaat," 2025).

A negative example is altered water flows which may lead to further acidification, in case of the coastal peatlands, which can release CO2 when flooded by water. (Aben et al., 2024)

Appendix E: Biodiversity trends

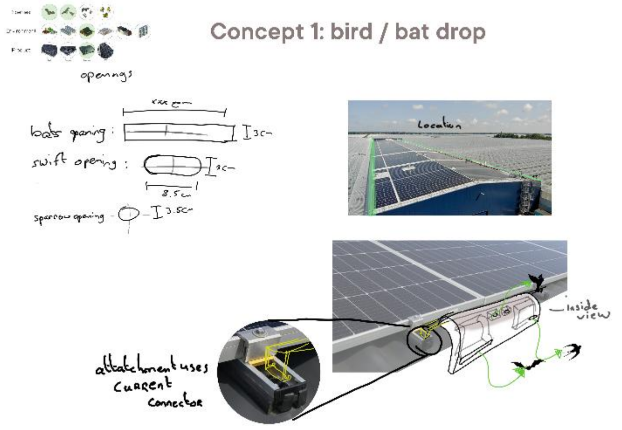
Argumentation of the assigned biodiversity trends from Chapter B.1 and B.2 are shown, and will give argumentation and sources per taxonomic group.

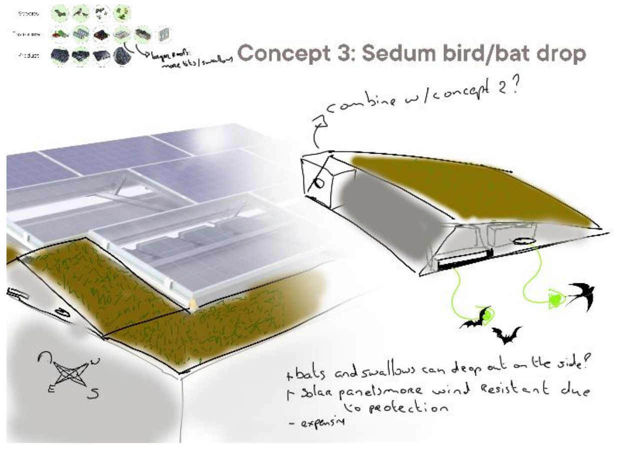
Taxonomic group	LPI (or similar geometric mean) trend (1990 – 2020+)
Birds	Total: moderate increase on total picture: 18.3% in LPI. 2025 even above 25%
Farmland (agricultural/open landscape) birds	General decrease (40% decrease) ("CLO: Farmland Bird Indicator, 1915-2023," 2024)
Forest birds	Stable / moderate growth 2022: 110% in 2020 (Sovon Dutch Centre for Field Ornithology, 2023)
Wetlands birds	Stable / moderate growth 120% in 2020 (Sovon Dutch Centre for Field Ornithology, 2023)
Mammals	Total view in LPI: More than 100% increase. Data still incomplete since in total around 60% of the mammals is covered.
Chiroptera (Bats, 18 species)	Overall trends of a variety of bats (La Haye & van der Meij, 2022) – General increase: 100-160% ; But showed an overall decrease of 80% from 1970 until 1980 (Zoological Society of London (ZSL, 2023).
Rodentia (rodents, 10-12 species)	No specific data found for the Netherlands. Worldwide trend indicates generally stable (Zoological Society of London (ZSL, 2023)
Carnivora -10 species and eulipotyphla (insectivores) - 8 species in the Netherlands	No specific data found in the Netherlands. Worldwide trend indicates The global Living Planet Index for Carnivora shows a decline. Using 1990 as the baseline (100), population levels dropped to just 17% by 2010, and further to less than 1% by 2020 (ZSL, 2023).
Other mamals (even toed and lagomorpha (deers and rabbits) – very few species)	No specific data found for in the Netherlands. Worldwide trend seems to be quite stable, but seems to be very species and habitat specific, due to diseases. (ZSL, 2023).
Reptiles	78%, significant, but wide confidence interval. Small group (CLO: Trend of reptiles, 2024)
Amfibians	+5,4% Slight, not significant increase (CLO: Trend of amphibians, 2024)
Invertebrates	Not that much information about invertebrates, has to do with the fact that LPI is in theory a term that is usually used for vertebras. For most insect groups, such standardized and sustained monitoring is still lacking at the global and national scale (WWF, 2023). The number used in the graph is sourced from standardised monitoring schemes (for butterflies and dragonflies, also highlighted in the figure), is and opportunistic citizen science records, which show a small regression of 7,2% (insignificant) (Van Strien et al., 2016). Broader studies in Europe indicate an even bigger decline: A 75% decline in flying insect biomass over 27 years in Germany, which is considered representative of broader trends in Western Europe. (Scheper et al., 2017)
Butterflies	General decrease (60%) – like said above not vertebras, still an LPI value can be found here (Alkemade et al., 2019).
Dragonflies	General increase (50%) – like said above not vertebras, still an LPI can be found here (Van Strien et al., 2016).
Flora	No specific data around indexes for flora, Some general articles can be found however to give an estimation: Decline in farmland flora: Since 35% reduction in plant species characteristic of arable fields, with the most pronounced declines after 1950. (CBS: Decline in farmland flora and fauna as of 1900, 2020) Notable is that this decline is linked a lot to declines in specialist pollinators (Hooper et al., 2012) This indicates the further relevance of the relation between plants and insects.

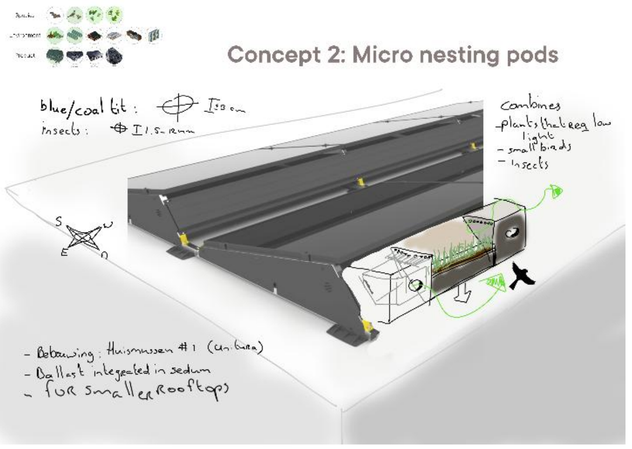
Appendix F: Initial concepts

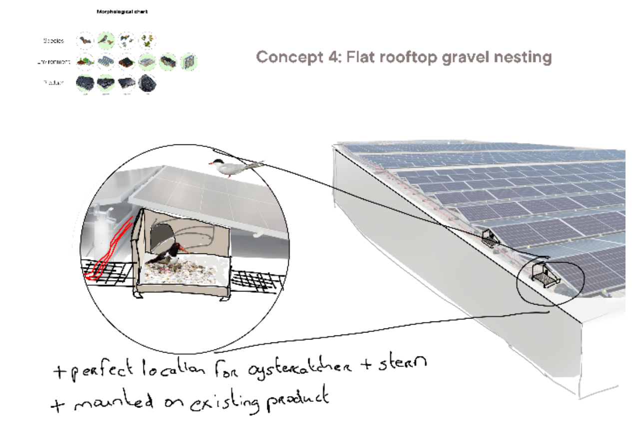
The next pages guide the reader through the conceptual design phase that was going throughout the whole graduation project. The concept sketches shown were used to communicate ideas to experts both in the biodiversity and solar energy field, in order to gather feedback from both a product development perspective and an ecological perspective. Significant feedback points that might have changed the trajectory of the design direction are listed.

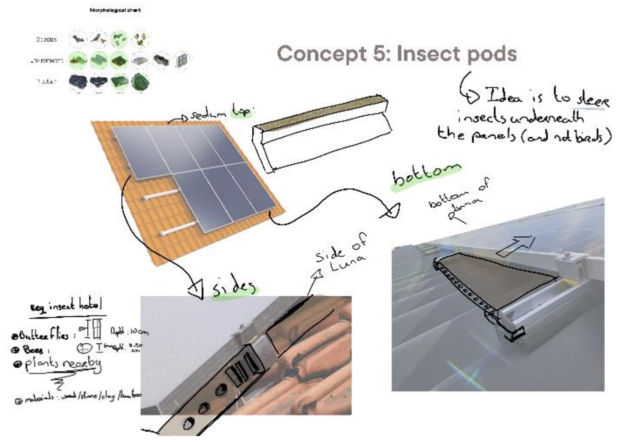
There are 12 initial concepts made, which were presented before and just after the midterm report to this variety of experts. After these 12 concepts, a variety of new versions were made *(listed as i.e. concept 5.1, 5.2, etc)*. These newer versions were made to adjust to feedback and to further shape the final three concepts that can be seen in Chapter C.3.

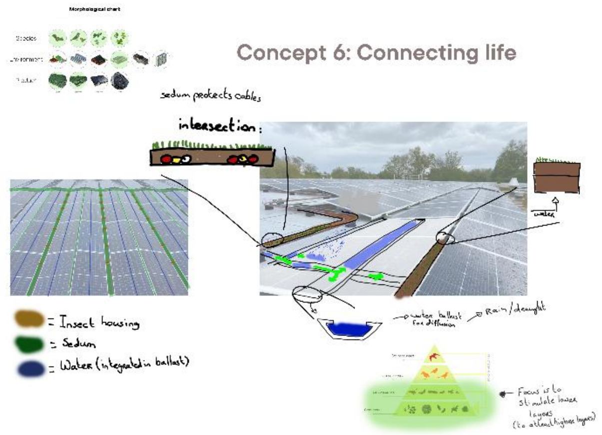


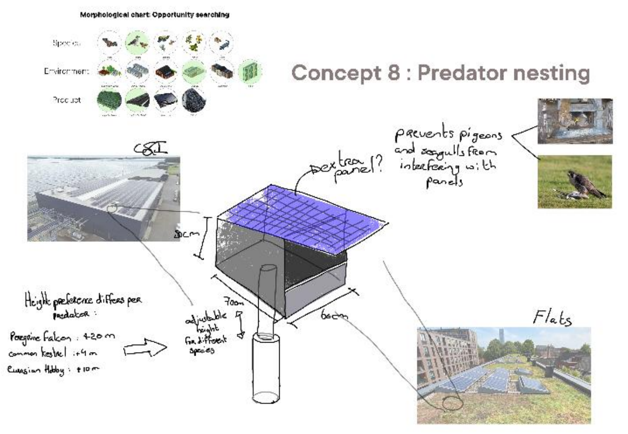


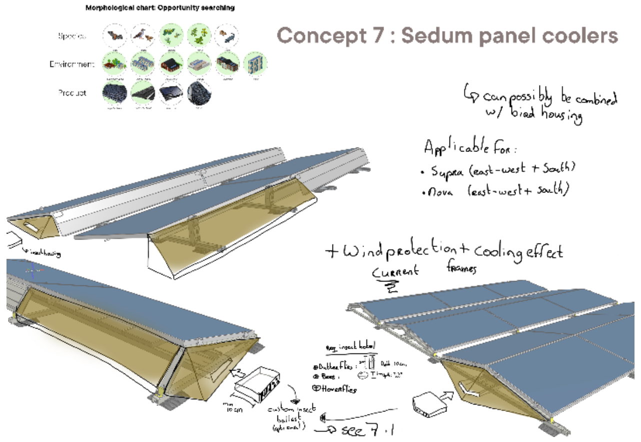


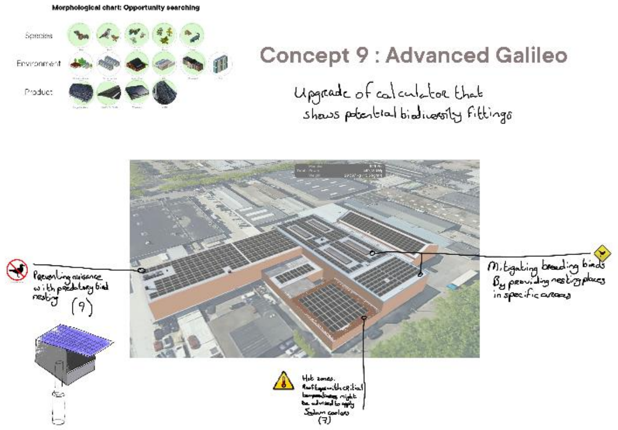


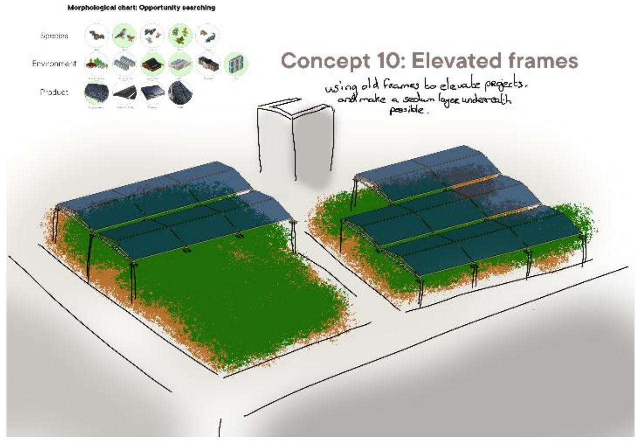


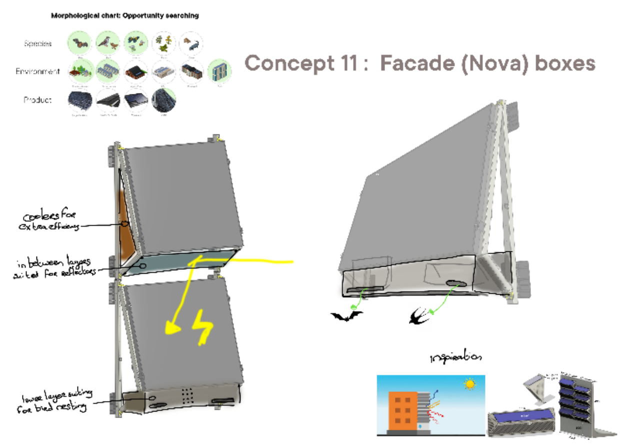


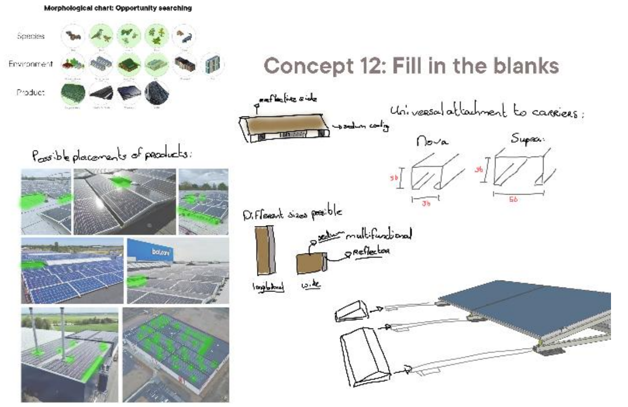












Further feedback on these concepts will be shown on the next page. After, the further developed concepts, and a clustering of the concepts is shown.

Some of the feedback that was collected on the initial concepts that lead to further development:

Feedback concept 1: Bird/bat drop

Sunbeam:

- Problems with sun and heat? This could always be in the sunny side. – climate moderation might be a big issue.
- Keep nests separated from cables. Watch out for overheating. Suggestion to use fire-retardant materials
- Combination with bird blocker pins, to steer birds.
- Think about drainage and dirt accumulation.

Erik Broer (Bats expert working for the zoogdierenvereniging)

- Isolation: Bats are animals that need different climates, possible solution is brought up with different isolations, but then it might be really heavy.
- Note that bats need a vertical drop, not sure if this inner shape works.

Feedback concept 2: Micro nesting pods

Sunbeam:

- Question whether nesting boxes alone are attractive on hot flat roofs (without greenery). Like the ideas to combine with concrete structures for cost-saving + added ballast function.
- Suggestion: Simplicity is key, Integrated, lightweight, foldable options suggested.
- Keep 40 cm distance from side of the roof in mind.
- Adjust flight routes of the birds. Avoid crows, they can drop rocks on PV's.

Feedback concept 3: Sedum bird/bat drop

Sunbeam:

- Like the idea of integrating sedum with a wind protection function.
- More energy efficiency because of Sedum?
- Suggested for larger roofs or specific design zones (especially where full PV coverage isn't possible).
- Needs smart wind and temperature management to avoid heat buildup.

Feedback concept 4: Flat rooftop gravel nesting

Sunbeam:

- Combine this with cable protection elements.
- Gravel might have to be part of the product, since it's not that often that there is already gravel on the rooftop. Gravel as a ballast?
- Could be integrated into Supra's side deflectors.

Marie-José (Scholeksterophetdak.nl)

- Need for gravel/shells, how much is probably less than 1m^2.
- Hiding spot: Required for heat and predators.
- The young birds fall of the rooftop sometimes, 20-50 cm barrier, so they can only hop off when they can already fly.
- Some additional water for cooling would also be nice, but not mandatory when we look at current nesting spots.

Feedback concept 5: Insect pods

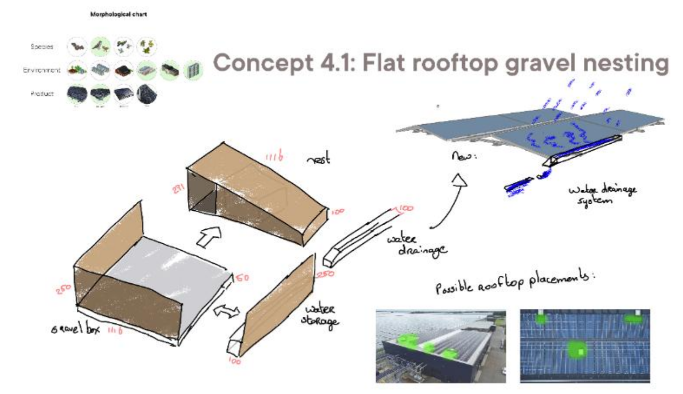
Sunbeam:

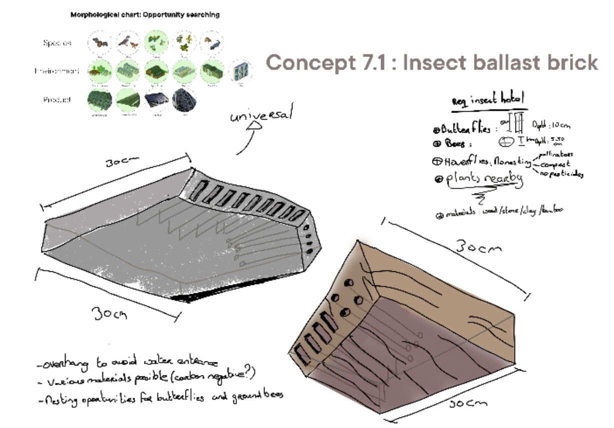
- Sedum or plants require consideration of moisture availability.
- Try to avoid wasps.
- Is it realistic to make insect pods on the roof? Will they really get there?
- Green roof on tilted roof is also expensive and difficult.
- Top coverage not possible, opening needed for cooling. lower part shouldn't pile up water.

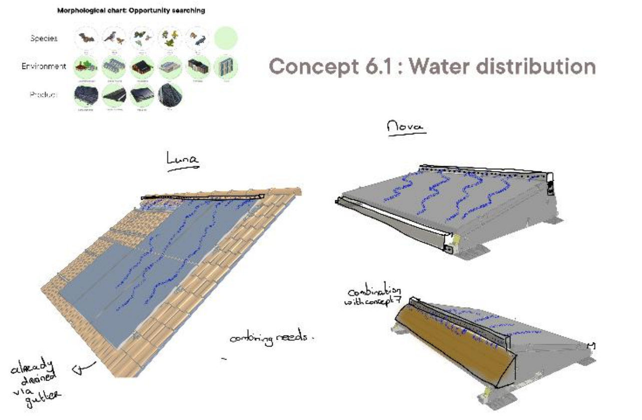
Feedback concept 6: Connecting life

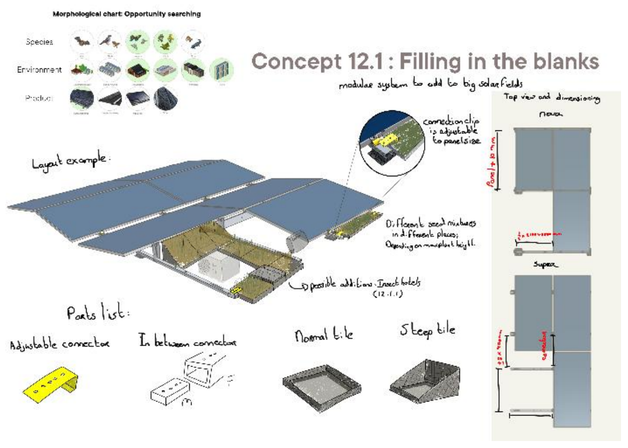
Sunbeam:

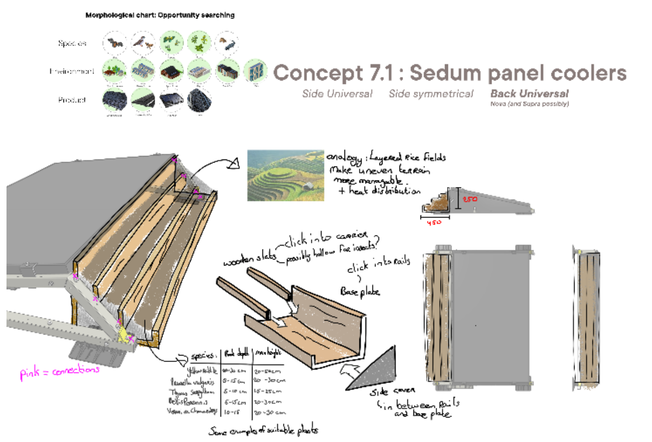
- Possibility to combine cleaning the solar panels with water, with Sedum underneath?
- Feedback: explore as future strategy, not immediate product.
- Leave ballast and cables without other function – separate products.
- Water as a ballast is impossible, due to small slopes.

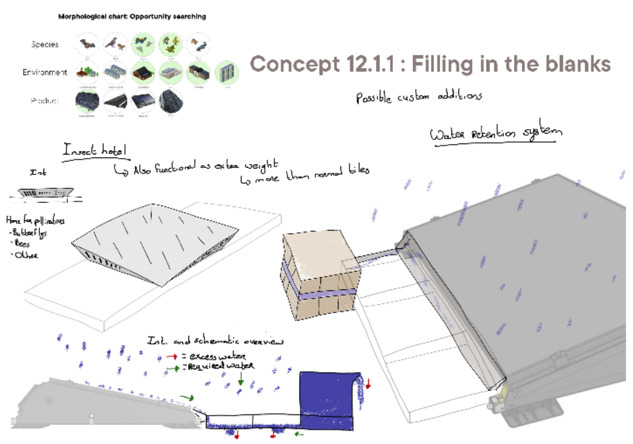


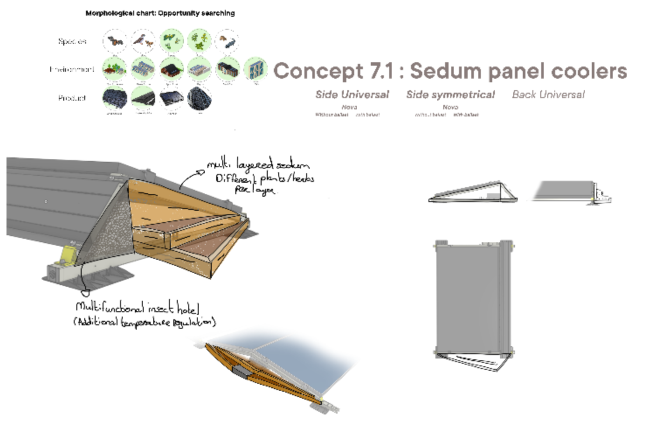






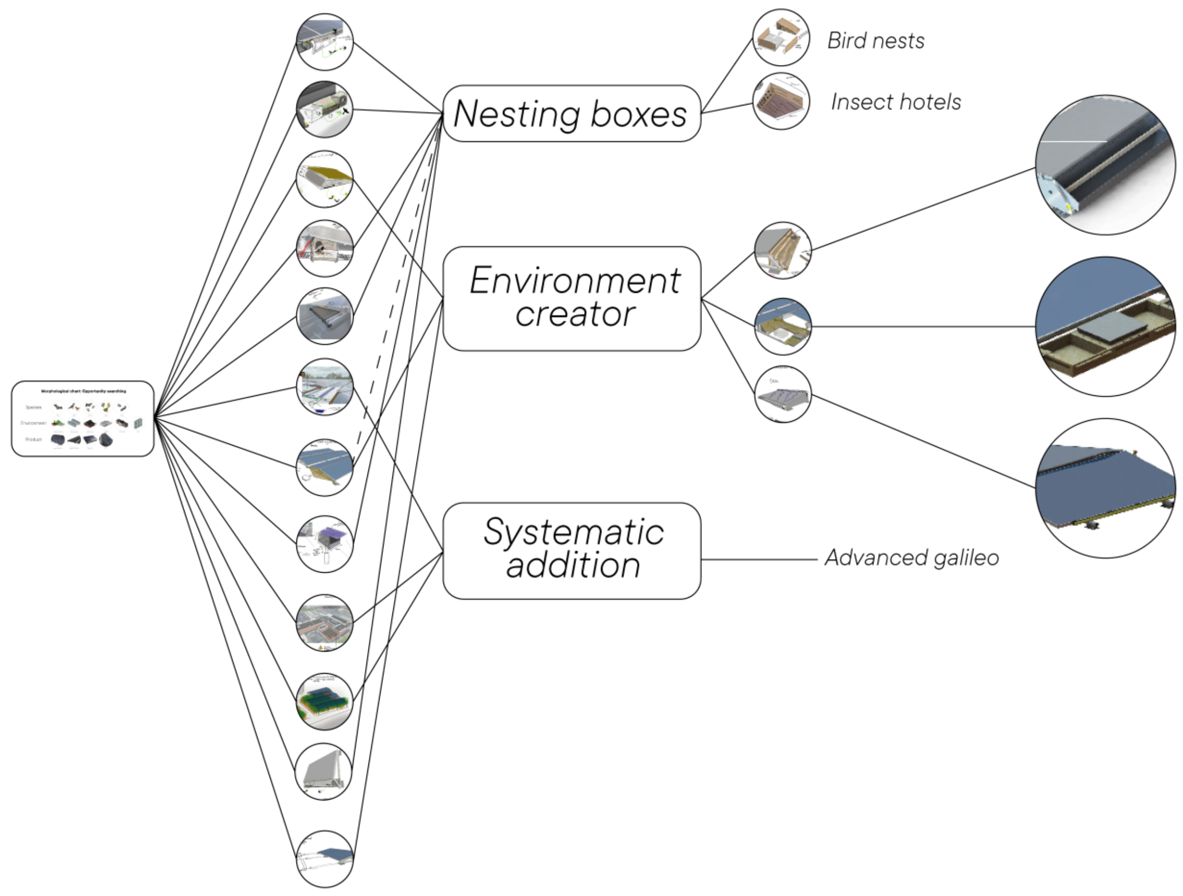






These concepts were further iterations after the initial feedback sessions on the last page.

A further schematic overview of the total concept development can be illustrated as the Fish trap model, also shown summarised in Figure C.1.1.



Appendix G: List of relevant regulations, certificates and inspections

Below, an overview is shown from potential regulations in the Netherlands regarding potential ABPs in solar mounting systems, sorted on building and nature regulations, with its relevancy and source.

Requirement	Relevance	Source
Building regulations		
SDE ++	ABP should not interfere with subsidy for sustainable energy	
Technical Dutch regulations	Design according to NEN-regulations, maintenance friendly.	NEN 1010 (elektra), NEN 2767 (conditiemeting), NEN 6060 (brandveiligheid).
ARBO regulations	Safety for maintenance and installers.	Rijksoverheid.nl
Nature regulations		
Natura 2000 protected area	Cannot build here	https://www.natura2000.nl/gebieden
Omgevingswet	Making sure that new product is suiting to the 'omgevingswet.' General regulations surrounding building new environments and preventing nature losses	https://www.rijksoverheid.nl/onderwerpen/omgevingswet
'Vogelrichtlijn'	Stick to 'vogelrichtlijn' regulations from the Netherlands, protecting bird species	Richtlijn 2009/147/EG
		https://www.nederlandsesoorten.nl/vogelrichtlijn
		https://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?from=NL&uri=CELEX%3A32009L0147&utm_
Nature conservation act	Variety of regulations of protection of nature, biodiversity and specific species and habitats.	
Specific local regulations		Stadsnatuurprogrammes per local authorities
VBB-FLL norm	To ensure the quality of building greening, it is important that projects are approached in a uniform manner.	https://www.bouwwerkbegroeners.nl/vbb-fll-norm/
	Every organization involved in greening a roof, façade, or building interior is expected to use the VBB FLL as the standard.	
NTA 8292	Green roofs - Terms, definitions and characteristics - Resistance to actions by wind, water retaining capacity and external fire exposure	https://www.nen.nl/nta-8292-2016-nl-225872
Certificates		
GPR ('Gemeentelijke Praktijk Richtlijn")	Certifications and methods to indicate quality and sustainability of buildings. Could strengthen future products.	https://gprsoftware.nl/certificaat-aanvragen/
Inspections		
SCIOS Scope 12: Perodic inspection, around every five years.	Inspection that checks electrical safety and fire hazards of the installation.	Various parties, not mandatory however, might be for some insurers.
NEN 1010	Mandatory inspection for electrical installation, when installing mounting systems	NEN 1010
NEN 3140	Periodic inspection of existing low-voltage installations, performed every 3-5 years.	NEN 3140

Appendix H: Lists of requirements

The list of requirements is divided into three categories: species-related, product-related, and follows up with general wishes. Together, they outline the key constraints (and indicate potential opportunities) when designing with biodiversity in mind for Sunbeam. When matched with Sunbeam's product requirements, they help determine how feasible and impactful specific solutions can be.

The **'list of requirements: species'** developed offers general insights that can support biodiversity-focused design beyond this specific context. It is developed by combining the feedback of ecologists with supplementary desktop research done where needed. Important to note is that this list, developed, offers general insights that can support biodiversity-focused design beyond this specific context.

In addition, a set of **'product-specific requirements'** has been developed to quantify the reasoning behind the design of a PV mounting system. These requirements also account for relevant regulations, both for the mounting system and for the integration of ABPs.

Lastly, a **'list of wishes'** is also presented. Besides the lists of requirements that zoom in on many details of the biodiversity and product side, this list summarises the earlier research from Sections A and B into measurable points. The eventual concepts presented in chapter C.3 will be measured alongside these concluding wishes, while following the earlier two lists of requirements.

Important to note is that these requirement lists will also extend beyond the conceptual phase, serving as essential tools during development and testing in an iterative design process.

List of requirements: Species.

Below a summary of requirements for interesting taxonomy groups is listed.

	Bats	Breeding Birds	Insects	Wild plants
Opening Requirements	*Small, elongated cavities* *No vegetation obstructing entry* *Free vertical space for 'drop-out' behaviour*	*Species-specific cavity sizes* *Height adjusted to species* *Min. 0.5 m from windows* *Prefer N, NE, E orientation* *South-facing only if shaded*	*Entry sizes 1.5–12 mm, rear closed* *Orientation: South, SE, SW for sun exposure*	*N/A*
Interior Requirements	*Rough surfaces to enable climbing*	*Species specific*	*Tunnel depth: 60–100 mm* *Materials: wood, clay, bamboo, or stone*	*Some particular species: 40–70 mm substrate* *Most need: 80+ mm substrate*
Water & Humidity	*Require both dry and humid conditions* *Water sources nearby* *Roosts should vary in humidity levels*	*Water must be nearby* *Some nests protected from rain*	*Moderate to high humidity* *Avoid fungus development*	*Water needed for growth + to avoid dry out* *Water retention to a certain extent*
Temperature	*Winter: 0–15°C* *Summer: >7°C*	*Constant incubation temperature*	*Winter: 0–15°C* *Summer: >15°C*	*Species-dependent*
Light Conditions	*Prefer dark conditions during emergence* *Shelter interior must remain dark*	*Orientation and light access determined by opening requirements*	*Entry exposed to sunlight preferred*	*Requires a range of sunlight intensities*
Other Nearby Demands	*Insect presence nearby for feeding* *Wind shielding* *Roosts change every ±12 days (hibernation, maternity, mating)*	*Vegetation with food sources* *Sand/gravel for dry baths* *Dead trees preferred for breeding*	*Native vegetation* *Avoid pesticides* *Organic material for hibernation/eggs* *Nearby insects as food source*	

List of requirements: Product

To make the reader have a general understanding of the product requirements, the general categories of the product requirements are listed below. To keep it understandable, specific technical values are kept mostly out of this list. These could be applicable for the current mounting system or for an ABP.

Category	Requirement
Inclination	*Need to put PV at preferred angle, flat roofs between 10-13 degrees*
	Prevent potential cast shadow by ABP's
Interconnection	*PV system can be interconnected via the carriers*
Rooftop matching	*Anchoring is required if ballast requirements cannot be met*
	Regulations regarding maximum load for specific roof is not exceeded
Clamping requirements	*Stay under the maximum clamping force*
	The panel size should be variable, as much as it is now
	The size of the clamp does not exceed 50 mm × 10 mm
	Max clamping force of 420 Pa
Cables	*Cables should be bundled from the floor*
	Cables can transfer their heat away
	Cables are fire-resistant/safe
	Organisms are limited by their ability to access the cables
	ABPs are compatible with a variety of cable clips/gutters.
Mounting	*Minimum distance off the side of the roof is less than the structure's maximum height.*
Ballast	*ABPs are mounted the rest of the construction*
	Ballast needs to protect the PV from moving because of wind (or other external loads)
	Ballast can provide up to a certain flexibility in weight safely
	Ballast will pass the bending test
	Prevent sharp edges that can damage the rooftop
Wind effects	*Wind deflectors should be able to withstand wind forces and improve aerodynamics of the product*

Category	Requirement
Weather circumstances	*The integration of additional ABPs should allow sufficient airflow beneath the solar panels to avoid excessive heat buildup.*
	Drainage will be not piling underneath the structure (due to addition of ABPs)
	All parts of the product should be UV resistant
	All parts of the product should be corrosion resistant
Maintenance and placement	*Existing products and ABPs should remain easily understandable.*
	No lifting of heavy parts above 20kg
	Free space of 10 mm between panels
Store and transport	*All products can be easily nested together for transport (including possible variety of ABPs)*
	Transport should have centre of mass in lower half of container
ABP specific requirements	*ABPs should guide species' behaviour in a way that prevents damage to the system*
Recycling	*All non-organic parts should be able to last 25-30 years*
	Parts must allow for easy disassembly
Costs	*ABP costs should be scalable alongside with the current mounting system*
Materials	*Everything from the frame and ABPs should be produceable in Europe*
Remanufacturing	*Specific repair/replacement services possible*

Wishes

As seen in the table, a variety of wishes is derived from the earlier done research in sections A and B.

Further, in the next chapter, C.3, specific opportunities and challenges are identified. These form the basis of some of the main wishes that a design would have to fulfil. The final concept should address these objectives as fully as possible in order to represent the most effective and well-adapted design.

The importance of each wish is also indicated and is determined in discussion with the client. More fundamental workings are primarily seen as more important. Below a short description will be given of the wishes indicated importance.

In chapter A.1 products and typologies were identified and showed a variety of products and typologies. In Table A.1.1 Sunbeams' different products and their placements have been analysed, and are clustered as typologies. For an ABP it would be advantageous to fit a variety of typologies so that it can be implemented widely. This would also increase when an ABP would be implementable into multiple types of products, but since the product line of Sunbeams' sales are quite dominant towards flat rooftop installations, its importance may be reduced if the concept is already tailored to the flat roof installations.

A.2 gives us an indication in the possible motivations of Sunbeam clients. If a product is more attractive for a larger variety of clients, the possibility of implication on a larger scale increases as well, thus the effect of the ABPs.

Chapter A.3 introduces the possibility of using carbon-negative materials. While not a core requirement, this aligns with Sunbeam's positioning as a provider of climate-neutral constructions. Future regulations are becoming more precise with those term which makes it not possible anymore to fully compensate your CO_2 production emissions. Incorporating such materials into the ABP could strengthen alignment with the company's broader sustainability goals and brand identity.

Chapter B.3 outlines general biodiversity-related design considerations and links them to the previously discussed rooftop typologies. One of the key wishes is for the ABP to contribute meaningfully to ecological systems and support long-term regeneration. This can be done by prioritising native species, though evidence suggests that restoring habitat and underlying ecological conditions is even more effective.

The main point of combining the two roof systems is because it is beneficial for both, which will be further technically validated in chapter D.2 for the final idea, and that it is feasible to test in the given time of this project.

Section	Description	Importance
A.1	ABP is desireable and implementable in a variety of **typologies**	Moderate/high
A.1	ABP is implementable in a variety of **products** of Sunbeam, without having to have a variety of product sizes	Low/moderate
A.2	ABP is implementable for a variety of **clients**; utility, residental and intrinsically or extrinsically motivated	Moderate
A.3	**Material Possibilities**: Possibilities to imply carbon negative materials.	Low/moderate
B.3	ABP offers the owner or user a convenient way to support specific **native species**, while minimizing the risk of attracting invasive or other possible problematic species, like pigeons or seagulls	Low/moderate
B.3	ABP helps ecosystem in a **sufficient** way and helps **foundation** of ecosystem	Very high
C.3	Estimated **cost calculation** relative to other concepts: Total additional cost of ABP	Moderate
C.3	ABP is benificial for biodiversity **and** mounting system	Very high
D	Feasibility in testing possibilities: Experimental steps requi-red are feasible to execute in the time span of the project	High

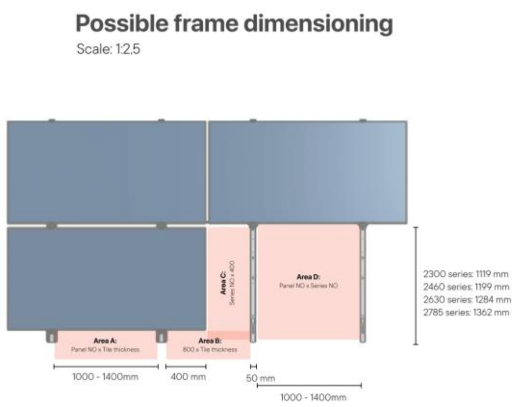
Appendix I: Tile size calculation (Maple file)

Below is an overview of the Maple script. The code was developed with support from ChatGPT.

The final pages are shown larger.

```
> restart;
> with(plots) :
```

Optimal tile configuration in areas A, B, C and D.



#Here the Tile width is not calculated, so areas A and B are seen as one dimensional, and C and D are measured by their surface area.

```
> results := [ ] : # to store tileLen, used_area, possible_area, score, tiles
```

Possible tile sizes & general values

```
> tileWidths := [seq(i, i=200..500, 50)];
  tileLengths := [seq(i, i=200..1000, 50)];
                tileWidths := [200, 250, 300, 350, 400, 450, 500]
tileLengths := [200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900,      (1.1)
    950, 1000]
># Total weight factors for coverage vs fewer tiles.
  alpha := 0.5 : # importance of coverage
  beta := 0.5 :
      # importance of fewer tiles - the weights are put variable if we decide later to change that.
```

Surface possibilities A & B

```
#Surface and weight factor(1 dimensional)
> surfaces_AB := [
    [1000, 0.3], # A1
    [1050, 0.4], # A2
    [1100, 0.5], # A3
    [1150, 0.5], # A4
    [1200, 0.9], # A5
    [1250, 0.5], # A6
    [1300, 0.5], # A7
    [1350, 0.5], # A8
    [1400, 0.9], # A9
    [400, 1.0], # B1
    [800, 1.0]  # B2
  ]:
>
#Code made with help of chatGPT, top score /5 (app)
> for tileLen in tileLengths do
    total_score := 0 :
    total_tiles := 0 :

    for s in surfaces_AB do
      len_surf := s[1] :
      weight := s[2] :

      n_tiles := floor(len_surf / tileLen) :
      if n_tiles = 0 then next end if: # skip if tile too big

      coverage := (tileLen * n_tiles) / len_surf :
      surface_score := weight * (alpha * coverage + beta * (1/n_tiles)) :

      total_score := total_score + surface_score :
      total_tiles := total_tiles + n_tiles :
    end do:

    print("Tile length:", tileLen, "→ Score:", total_score, "Tiles used:", total_tiles) :
  end do:
        "Tile length:", 200, "→ Score:", 4.187417389, "Tiles used:", 57
        "Tile length:", 250, "→ Score:", 4.296708699, "Tiles used:", 44
        "Tile length:", 300, "→ Score:", 4.431165272, "Tiles used:", 35
        "Tile length:", 350, "→ Score:", 4.667848088, "Tiles used:", 30
        "Tile length:", 400, "→ Score:", 4.881817917, "Tiles used:", 26
        "Tile length:", 450, "→ Score:", 3.995715027, "Tiles used:", 21
        "Tile length:", 500, "→ Score:", 4.121561670, "Tiles used:", 19
        "Tile length:", 550, "→ Score:", 4.346455935, "Tiles used:", 17
        "Tile length:", 600, "→ Score:", 4.549789872, "Tiles used:", 15
        "Tile length:", 650, "→ Score:", 4.723939028, "Tiles used:", 13
        "Tile length:", 700, "→ Score:", 4.878843170, "Tiles used:", 11
        "Tile length:", 750, "→ Score:", 5.013046253, "Tiles used:", 10
        "Tile length:", 800, "→ Score:", 5.147249337, "Tiles used:", 10
        "Tile length:", 850, "→ Score:", 4.250202420, "Tiles used:", 9
        "Tile length:", 900, "→ Score:", 4.353155504, "Tiles used:", 9
        "Tile length:", 950, "→ Score:", 4.456108588, "Tiles used:", 9
        "Tile length:", 1000, "→ Score:", 4.559061670, "Tiles used:", 9        (2.1)
```

Surface possibilities C & D

```
>
> surfaces_CD := [
    [400, 1119, 1.0], # C1
    [400, 1199, 1.0], # C2
    [400, 1284, 1.0], # C3
    [400, 1362, 1.0], # C4
    [1000, 1119, 0.3], # D1.1
    [1050, 1119, 0.4], # D1.2
    [1100, 1119, 0.5], # D1.3
    [1150, 1119, 0.5], # D1.4
    [1200, 1119, 0.9], # D1.5
    [1250, 1119, 0.5], # D1.6
    [1300, 1119, 0.5], # D1.7
    [1350, 1119, 0.5], # D1.8
    [1400, 1119, 0.9], # D1.9
    [1000, 1199, 0.3], # D2.1
    [1050, 1199, 0.4], # D2.2
    [1100, 1199, 0.5], # D2.3
    [1150, 1199, 0.5], # D2.4
    [1200, 1199, 0.9], # D2.5
    [1250, 1199, 0.5], # D2.6
    [1300, 1199, 0.5], # D2.7
    [1350, 1199, 0.5], # D2.8
    [1400, 1199, 0.9], # D2.9
    [1000, 1284, 0.3], # D3.1
    [1050, 1284, 0.4], # D3.2
    [1100, 1284, 0.5], # D3.3
    [1150, 1284, 0.5], # D3.4
    [1200, 1284, 0.9], # D3.5
    [1250, 1284, 0.5], # D3.6
    [1300, 1284, 0.5], # D3.7
    [1350, 1284, 0.5], # D3.8
    [1400, 1284, 0.9], # D3.9
    [1000, 1362, 0.3], # D4.1
    [1050, 1362, 0.4], # D4.2
    [1100, 1362, 0.5], # D4.3
    [1150, 1362, 0.5], # D4.4
    [1200, 1362, 0.9], # D4.5
    [1250, 1362, 0.5], # D4.6
    [1300, 1362, 0.5], # D4.7
    [1350, 1362, 0.5], # D4.8
    [1400, 1362, 0.9]  # D4.9
  ];
surfaces_CD := [[400, 1119, 1.0], [400, 1199, 1.0], [400, 1284, 1.0], [400, 1362, 1.0],      (3.1)
    [1000, 1119, 0.3], [1050, 1119, 0.4], [1100, 1119, 0.5], [1150, 1119, 0.5], [1200, 1119,
    0.9], [1250, 1119, 0.5], [1300, 1119, 0.5], [1350, 1119, 0.5], [1400, 1119, 0.9], [1000,
    1199, 0.3], [1050, 1199, 0.4], [1100, 1199, 0.5], [1150, 1199, 0.5], [1200, 1199, 0.9],
    [1250, 1199, 0.5], [1300, 1199, 0.5], [1350, 1199, 0.5], [1400, 1199, 0.9], [1000, 1284,
    0.3], [1050, 1284, 0.4], [1100, 1284, 0.5], [1150, 1284, 0.5], [1200, 1284, 0.9], [1250,
    1284, 0.5], [1300, 1284, 0.5], [1350, 1284, 0.5], [1400, 1284, 0.9], [1000, 1362, 0.3],
    [1050, 1362, 0.4], [1100, 1362, 0.5], [1150, 1362, 0.5], [1200, 1362, 0.9], [1250, 1362,
    0.5], [1300, 1362, 0.5], [1350, 1362, 0.5], [1400, 1362, 0.9]]
> results_CD := [ ] : # Stores [tileLen_CD, used_area, total_area, score, total_tiles]
> for tileLen_CD in tileLengths do
    for tileWid_CD in tileWidths do
      total_score_CD := 0;
      total_tiles_CD := 0;

      for s in surfaces_CD do
        len_CD := s[1];
        wid_CD := s[2];
        weight_CD := s[3];

        n_tiles_len := floor(len_CD / tileLen_CD);
        n_tiles_wid := floor(wid_CD / tileWid_CD);
        n_tiles := n_tiles_len * n_tiles_wid;

        if n_tiles = 0 then
          next;
        end if;

        coverage := (tileLen_CD * tileWid_CD * n_tiles) / (len_CD * wid_CD);
        surface_score := weight_CD * (alpha * coverage + beta / n_tiles);
        total_score_CD := total_score_CD + surface_score;
        total_tiles_CD := total_tiles_CD + n_tiles;
      end do;

      printf("Tile: %4d x %-4d mm  Score: %.3f  Tiles: %d\n",
        tileLen_CD, tileWid_CD, evalf(total_score_CD), total_tiles_CD);
    end do;
  end do;
Tile:  200 x 200  mm  Score: 10.700  Tiles: 1166
Tile:  200 x 250  mm  Score: 11.032  Tiles: 954
Tile:  200 x 300  mm  Score: 10.499  Tiles: 742
Tile:  200 x 350  mm  Score: 10.706  Tiles: 636
Tile:  200 x 400  mm  Score: 10.344  Tiles: 530
Tile:  200 x 450  mm  Score: 10.600  Tiles: 477
Tile:  200 x 500  mm  Score: 10.696  Tiles: 424
Tile:  250 x 200  mm  Score: 9.980  Tiles: 902
Tile:  250 x 250  mm  Score: 10.354  Tiles: 738
Tile:  250 x 300  mm  Score: 9.993  Tiles: 574
Tile:  250 x 350  mm  Score: 10.255  Tiles: 492
Tile:  250 x 400  mm  Score: 10.077  Tiles: 410
Tile:  250 x 450  mm  Score: 10.383  Tiles: 369
Tile:  250 x 500  mm  Score: 10.544  Tiles: 328
Tile:  300 x 200  mm  Score: 10.126  Tiles: 726
Tile:  300 x 250  mm  Score: 10.523  Tiles: 594
Tile:  300 x 300  mm  Score: 10.193  Tiles: 462
Tile:  300 x 350  mm  Score: 10.477  Tiles: 396
Tile:  300 x 400  mm  Score: 10.340  Tiles: 330
Tile:  300 x 450  mm  Score: 10.668  Tiles: 297
Tile:  300 x 500  mm  Score: 10.851  Tiles: 264
Tile:  350 x 200  mm  Score: 10.392  Tiles: 616
Tile:  350 x 250  mm  Score: 10.813  Tiles: 504
Tile:  350 x 300  mm  Score: 10.505  Tiles: 392
Tile:  350 x 350  mm  Score: 10.811  Tiles: 336
Tile:  350 x 400  mm  Score: 10.706  Tiles: 280
Tile:  350 x 450  mm  Score: 11.057  Tiles: 252
Tile:  350 x 500  mm  Score: 11.260  Tiles: 224
Tile:  400 x 200  mm  Score: 10.496  Tiles: 528
Tile:  400 x 250  mm  Score: 10.942  Tiles: 432
Tile:  400 x 300  mm  Score: 10.676  Tiles: 336
Tile:  400 x 350  mm  Score: 11.007  Tiles: 288
Tile:  400 x 400  mm  Score: 10.954  Tiles: 240
Tile:  400 x 450  mm  Score: 11.331  Tiles: 216
Tile:  400 x 500  mm  Score: 11.560  Tiles: 192
Tile:  450 x 200  mm  Score: 8.205  Tiles: 440
Tile:  450 x 250  mm  Score: 8.552  Tiles: 360
Tile:  450 x 300  mm  Score: 8.337  Tiles: 280
Tile:  450 x 350  mm  Score: 8.593  Tiles: 240
Tile:  450 x 400  mm  Score: 8.544  Tiles: 200
Tile:  450 x 450  mm  Score: 8.835  Tiles: 180
Tile:  450 x 500  mm  Score: 9.011  Tiles: 160
Tile:  500 x 200  mm  Score: 8.213  Tiles: 396
Tile:  500 x 250  mm  Score: 8.577  Tiles: 324
Tile:  500 x 300  mm  Score: 8.399  Tiles: 252
Tile:  500 x 350  mm  Score: 8.673  Tiles: 216
Tile:  500 x 400  mm  Score: 8.668  Tiles: 180
Tile:  500 x 450  mm  Score: 8.978  Tiles: 162
Tile:  500 x 500  mm  Score: 9.173  Tiles: 144
Tile:  550 x 200  mm  Score: 8.407  Tiles: 352
Tile:  550 x 250  mm  Score: 8.802  Tiles: 288
Tile:  550 x 300  mm  Score: 8.666  Tiles: 224
Tile:  550 x 350  mm  Score: 8.970  Tiles: 192
Tile:  550 x 400  mm  Score: 9.019  Tiles: 160
Tile:  550 x 450  mm  Score: 9.359  Tiles: 144
Tile:  550 x 500  mm  Score: 9.583  Tiles: 128
Tile:  600 x 200  mm  Score: 8.314  Tiles: 308
Tile:  600 x 250  mm  Score: 8.745  Tiles: 252
Tile:  600 x 300  mm  Score: 8.695  Tiles: 196
Tile:  600 x 350  mm  Score: 9.038  Tiles: 168
Tile:  600 x 400  mm  Score: 9.187  Tiles: 140
Tile:  600 x 450  mm  Score: 9.564  Tiles: 126
Tile:  600 x 500  mm  Score: 9.831  Tiles: 112
Tile:  650 x 200  mm  Score: 7.837  Tiles: 264
Tile:  650 x 250  mm  Score: 8.310  Tiles: 216
Tile:  650 x 300  mm  Score: 8.405  Tiles: 168
Tile:  650 x 350  mm  Score: 8.800  Tiles: 144
Tile:  650 x 400  mm  Score: 9.108  Tiles: 120
Tile:  650 x 450  mm  Score: 9.533  Tiles: 108
Tile:  650 x 500  mm  Score: 9.860  Tiles: 96
Tile:  700 x 200  mm  Score: 7.573  Tiles: 220
Tile:  700 x 250  mm  Score: 8.078  Tiles: 180
Tile:  700 x 300  mm  Score: 8.271  Tiles: 140
Tile:  700 x 350  mm  Score: 8.703  Tiles: 120
Tile:  700 x 400  mm  Score: 9.120  Tiles: 100
Tile:  700 x 450  mm  Score: 9.582  Tiles: 90
Tile:  700 x 500  mm  Score: 9.950  Tiles: 80
Tile:  750 x 200  mm  Score: 7.305  Tiles: 198
Tile:  750 x 250  mm  Score: 7.839  Tiles: 162
Tile:  750 x 300  mm  Score: 8.122  Tiles: 126
Tile:  750 x 350  mm  Score: 8.588  Tiles: 108
Tile:  750 x 400  mm  Score: 9.105  Tiles: 90
Tile:  750 x 450  mm  Score: 9.598  Tiles: 81
Tile:  750 x 500  mm  Score: 10.005  Tiles: 72
Tile:  800 x 200  mm  Score: 7.670  Tiles: 198
Tile:  800 x 250  mm  Score: 8.211  Tiles: 162
Tile:  800 x 300  mm  Score: 8.469  Tiles: 126
Tile:  800 x 350  mm  Score: 8.939  Tiles: 108
Tile:  800 x 400  mm  Score: 9.434  Tiles: 90
Tile:  800 x 450  mm  Score: 9.932  Tiles: 81
Tile:  800 x 500  mm  Score: 10.338  Tiles: 72
Tile:  850 x 200  mm  Score: 8.035  Tiles: 198
Tile:  850 x 250  mm  Score: 8.584  Tiles: 162
Tile:  850 x 300  mm  Score: 8.816  Tiles: 126
Tile:  850 x 350  mm  Score: 9.289  Tiles: 108
Tile:  850 x 400  mm  Score: 9.763  Tiles: 90
Tile:  850 x 450  mm  Score: 10.266  Tiles: 81
Tile:  850 x 500  mm  Score: 10.672  Tiles: 72
Tile:  900 x 200  mm  Score: 8.400  Tiles: 198
Tile:  900 x 250  mm  Score: 8.957  Tiles: 162
Tile:  900 x 300  mm  Score: 9.163  Tiles: 126
Tile:  900 x 350  mm  Score: 9.639  Tiles: 108
Tile:  900 x 400  mm  Score: 10.093  Tiles: 90
Tile:  900 x 450  mm  Score: 10.601  Tiles: 81
Tile:  900 x 500  mm  Score: 11.006  Tiles: 72
Tile:  950 x 200  mm  Score: 8.764  Tiles: 198
Tile:  950 x 250  mm  Score: 9.329  Tiles: 162
Tile:  950 x 300  mm  Score: 9.510  Tiles: 126
Tile:  950 x 350  mm  Score: 9.989  Tiles: 108
Tile:  950 x 400  mm  Score: 10.422  Tiles: 90
Tile:  950 x 450  mm  Score: 10.935  Tiles: 81
Tile:  950 x 500  mm  Score: 11.339  Tiles: 72
Tile: 1000 x 200  mm  Score: 9.129  Tiles: 198
Tile: 1000 x 250  mm  Score: 9.702  Tiles: 162
Tile: 1000 x 300  mm  Score: 9.857  Tiles: 126
Tile: 1000 x 350  mm  Score: 10.340  Tiles: 108
Tile: 1000 x 400  mm  Score: 10.751  Tiles: 90
Tile: 1000 x 450  mm  Score: 11.269  Tiles: 81
Tile: 1000 x 500  mm  Score: 11.673  Tiles: 72
>
```

Best tile configuration outcomes (top 10) # Pre-calculate total weight

```
total_weight_AB := add(s[2], s in surfaces_AB);
total_weight_CD := add(s[3], s in surfaces_CD);

# Create a list to store results
final_results := [ ];

># Pre-calculate total weight
  total_weight_AB := add(s[2], s in surfaces_AB);
  total_weight_CD := add(s[3], s in surfaces_CD);

  # Create a list to store results
  final_results := [ ];

  # Loop over tile combinations
  for tileLen in tileLengths do
    for tileWid in tileWidths do

      # ---- AB evaluation ----
      total_score_AB := 0;
      total_tiles_AB := 0;

      for s in surfaces_AB do
        len_AB := s[1];
        weight_AB := s[2];
        n_tiles_AB := floor(len_AB / tileLen);

        if n_tiles_AB = 0 then
          next;
        end if;

        coverage_AB := tileLen * n_tiles_AB / len_AB;
        score_AB := weight_AB * (alpha * coverage_AB + beta / n_tiles_AB);
        total_score_AB := total_score_AB + score_AB;
        total_tiles_AB := total_tiles_AB + n_tiles_AB;
      end do;
```

```
    normalized_AB := total_score_AB / total_weight_AB;

    # ---- CD evaluation ----
    total_score_CD := 0;
    total_tiles_CD := 0;

    for s in surfaces_CD do
      len_CD := s[1];
      wid_CD := s[2];
      weight_CD := s[3];

      n_tiles_len := floor(len_CD / tileLen);
      n_tiles_wid := floor(wid_CD / tileWid);
      n_tiles_CD := n_tiles_len * n_tiles_wid;

      if n_tiles_CD = 0 then
        next;
      end if;

      coverage_CD := (tileLen * tileWid * n_tiles_CD) / (len_CD * wid_CD);
      score_CD := weight_CD * (alpha * coverage_CD + beta / n_tiles_CD);
      total_score_CD := total_score_CD + score_CD;
      total_tiles_CD := total_tiles_CD + n_tiles_CD;
    end do;

    normalized_CD := total_score_CD / total_weight_CD;

    # ---- Combine scores ----
    final_score := evalf(normalized_AB + normalized_CD);
    total_tiles := total_tiles_AB + total_tiles_CD;

    # Store results
    final_results := [op(final_results), [tileLen, tileWid, final_score, total_tiles]];
  end do;
end do;

# ---- Sort and display top 10 ----
sorted_results := sort(final_results, (a, b) → a[3] > b[3]);

printf("\nTop 10 Tile Configurations:\n");
for i to min(10, nops(sorted_results)) do
  r := sorted_results[i];
  printf("%2d. Tile: %4d x %-4d mm  Score: %.3f  Tiles: %d\n",
 i, r[1], r[2], r[3], r[4]);
end do;
```

total_weight_AB := 7.0
total_weight_CD := 24.0

final_results := [ ]

sorted_results := [[400, 500, 1.179068685, 218], [400, 450, 1.169525820, 242], [800, 500, 1.166082333, 82], [400, 350, 1.156033935, 314], [400, 400, 1.153830129, 266], [400, 250, 1.153337922, 458], [800, 450, 1.149155346, 91], [400, 300, 1.142226546, 362], [1000, 500, 1.137662440, 81], [350, 500, 1.136018498, 254], [400, 200, 1.134720186, 554], [750, 500, 1.133008735, 82], [800, 400, 1.128413555, 100], [350, 450, 1.127546946, 282], [1000, 450, 1.120843984, 90], [350, 250, 1.117396211, 534], [350, 350, 1.117284363, 366], [750, 450, 1.116054615, 91], [350, 400, 1.112916321, 310], [700, 500, 1.111566830, 91], [950, 500, 1.109053128, 81], [800, 350, 1.107759272, 118], [350, 300, 1.104543957, 422], [350, 200, 1.099840576, 646], [1000, 400, 1.099257023, 99], [700, 450, 1.096207376, 101], [750, 400, 1.095524116, 100], [950, 450, 1.092207539, 90], [800, 300, 1.088188244, 136], [650, 500, 1.085664784, 109], [300, 500, 1.085148856, 299], [1000, 350, 1.082119725, 117], [900, 500, 1.080443815, 81], [300, 450, 1.077532398, 332], [800, 250, 1.077460861, 172], [700, 400, 1.076988898, 111], [750, 350, 1.073990587, 118], [650, 450, 1.072074738, 121], [300, 250, 1.071480580, 629], [950, 400, 1.070831870, 99], [300, 350, 1.069554888, 431], [300, 400, 1.063870768, 365], [900, 450, 1.063571094, 90], [1000, 300, 1.061996217, 135], [700, 350, 1.059622681, 131], [600, 500, 1.059584441, 127], [200, 250, 1.057858070, 1011], [300, 300, 1.057748520, 497], [1000, 250, 1.055531433, 171], [300, 200, 1.054948032, 761], [800, 200, 1.054907377, 208], [750, 300, 1.054557679, 136], [650, 400, 1.054333069, 133], [250, 500, 1.053142192, 372], [950, 350, 1.052815326, 117], [850, 500, 1.051834502, 81], [600, 450, 1.048479531, 141], [250, 450, 1.046430598, 413], [250, 250, 1.045249163, 782], [200, 350, 1.044283427, 693], [200, 200, 1.044033792, 1223], [200, 500, 1.043859694, 481], [750, 250, 1.042764646, 172], [900, 400, 1.042406717, 99], [700, 300, 1.041588537, 151], [650, 350, 1.041518101, 157], [250, 350, 1.041087692, 536], [200, 450, 1.039866226, 534], [200, 300, 1.035670199, 799], [850, 450, 1.034934648, 90], [250, 400, 1.033706347, 454], [700, 250, 1.033558791, 191], [950, 300, 1.032829938, 135], [600, 400, 1.032743381, 155], [1000, 200, 1.031679856, 207], [250, 300, 1.030208725, 618], [250, 200, 1.029669436, 946], [200, 400, 1.029207400, 587], [600, 350, 1.026558220, 183], [950, 250, 1.025299504, 171], [650, 300, 1.025050565, 181], [900, 350, 1.023510927, 117], [650, 250, 1.021106381, 229], [750, 200, 1.020535686, 208], [550, 500, 1.020224389, 145], [600, 250, 1.014331767, 267], [850, 400, 1.013981565, 99], [700, 200, 1.012507621, 231], [600, 300, 1.012243397, 211], [550, 450, 1.010876124, 161], [900, 300, 1.003663659, 135], [950, 200, 1.001772451, 207], [650, 200, 1.001393061, 277], [550, 400, 0.9967161768, 177], [600, 200, 0.9963961905, 323], [900, 250, 0.9950675751, 171], [550, 350, 0.9946686610, 209], [850, 350, 0.9942065280, 117], [550, 250, 0.9876580620, 305], [550, 300, 0.9819854188, 241], [850, 300, 0.9744973801, 135], [900, 200, 0.9718650453, 207], [550, 200, 0.9712129941, 369], [500, 500, 0.9709957733, 163], [850, 250, 0.9648356463, 171], [500, 450, 0.9628578727, 181], [500, 350, 0.9501752802, 235], [500, 400, 0.9499514673, 199], [450, 500, 0.9462755689, 181], [500, 250, 0.9461564326, 343], [850, 200, 0.9419576397, 207], [450, 450, 0.9389536702, 201], [500, 300, 0.9387323284, 271], [500, 200, 0.9309854119, 415], [450, 350, 0.9288448221, 261], [450, 250, 0.9271312902, 381], [450, 400, 0.9268121550, 221], [450, 300, 0.9181824467, 301], [450, 200, 0.9127008867, 461]]

```
Top 10 Tile Configurations:
```

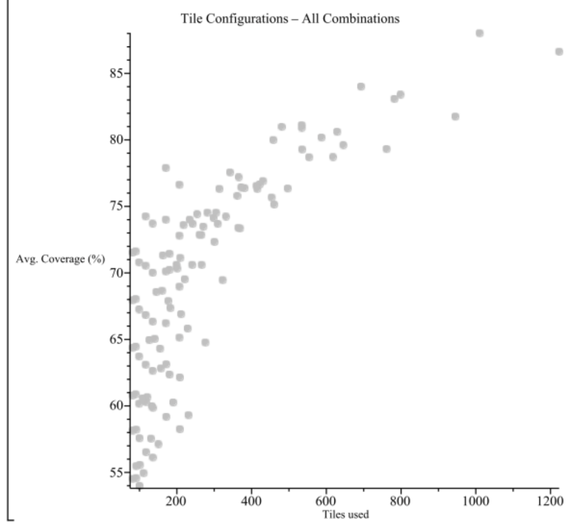
r := [400, 500, 1.179068685, 218]
```
 1. Tile:  400 x 500  mm  Score: 1.179  Tiles: 218
```
r := [400, 450, 1.169525820, 242]
```
 2. Tile:  400 x 450  mm  Score: 1.170  Tiles: 242
```
r := [800, 500, 1.166082333, 82]
```
 3. Tile:  800 x 500  mm  Score: 1.166  Tiles: 82
```
r := [400, 350, 1.156033935, 314]
```
 4. Tile:  400 x 350  mm  Score: 1.156  Tiles: 314
```
r := [400, 400, 1.153830129, 266]
```
 5. Tile:  400 x 400  mm  Score: 1.154  Tiles: 266
```
r := [400, 250, 1.153337922, 458]
```
 6. Tile:  400 x 250  mm  Score: 1.153  Tiles: 458
```
r := [800, 450, 1.149155346, 91]
```
 7. Tile:  800 x 450  mm  Score: 1.149  Tiles: 91
```
r := [400, 300, 1.142226546, 362]
```
 8. Tile:  400 x 300  mm  Score: 1.142  Tiles: 362
```
r := [1000, 500, 1.137662440, 81]
```
 9. Tile: 1000 x 500  mm  Score: 1.138  Tiles: 81
```
r := [350, 500, 1.136018498, 254]
```
10. Tile:  350 x 500  mm  Score: 1.136  Tiles: 254
```

```
> top10_set := convert([seq(sorted_results[i], i=1..10)], set);
```

top10_set := {[350, 500, 1.136018498, 254], [400, 250, 1.153337922, 458], [400, 300, 1.142226546, 362], [400, 350, 1.156033935, 314], [400, 400, 1.153830129, 266], [400, 450, 1.169525820, 242], [400, 500, 1.179068685, 218], [800, 450, 1.149155346, 91], [800, 500, 1.166082333, 82], [1000, 500, 1.137662440, 81]} **(4.1)**

Visualisation possibilities

```
> all_pts := [ ]:
for i to nops(final_results) do
  r := final_results[i];
  tileLen := r[1];
  tileWid := r[2];
  total_tiles := r[4];

  # Calculate total coverage
  total_coverage_AB := 0;
  surface_count_AB := 0;
  for s in surfaces_AB do
    len := s[1];
    n_tiles := floor(len / tileLen);
    if n_tiles = 0 then
      next;
    end if;
    total_coverage_AB := total_coverage_AB + tileLen * n_tiles / len;
    surface_count_AB := surface_count_AB + 1;
  end do;

  total_coverage_CD := 0;
  surface_count_CD := 0;
  for s in surfaces_CD do
    len := s[1];
    wid := s[2];
    n_tiles_len := floor(len / tileLen);
    n_tiles_wid := floor(wid / tileWid);
    n_tiles := n_tiles_len * n_tiles_wid;
    if n_tiles = 0 then
      next;
    end if;
    total_coverage_CD := total_coverage_CD + tileLen * tileWid * n_tiles / (len * wid);
    surface_count_CD := surface_count_CD + 1;
  end do;

  total_coverage := total_coverage_AB + total_coverage_CD;
  total_surfaces := surface_count_AB + surface_count_CD;
  avg_coverage := evalf(100 * total_coverage / total_surfaces);

  pt := [total_tiles, avg_coverage];
  all_pts := [op(all_pts), pt];
end do:
#Plot all the values
with(plots) :
display(
  pointplot(all_pts, symbol = solidcircle, symbolsize = 10, color = grey),
  labels = ["Tiles used", "Avg. Coverage (%)"],
  title = "Tile Configurations – All Combinations"
);
```



Indicating most interesting values

#initialize variables to store the best candidates

```
> max_coverage := −infinity :
  max_efficiency := −infinity :
  max_score := −infinity :
  max_square_score := −infinity :

  best_coverage_tile := NULL :
  best_efficiency_tile := NULL :
  best_score_tile := NULL :
  best_square_tile := NULL :

for r in final_results do
  tileLen := r[1] :
  tileWid := r[2] :
  score := r[3] :
  total_tiles := r[4] :

  # Calculate average coverage
  total_coverage_AB := 0 :
  surface_count_AB := 0 :
  for s in surfaces_AB do
    len := s[1] :
    n_tiles := floor(len / tileLen) :
    if n_tiles = 0 then next: end if:
    total_coverage_AB := total_coverage_AB + tileLen * n_tiles / len :
    surface_count_AB := surface_count_AB + 1 :
  end do:

  total_coverage_CD := 0 :
  surface_count_CD := 0 :
  for s in surfaces_CD do
    len := s[1] :
    wid := s[2] :
    n_tiles_len := floor(len / tileLen) :
    n_tiles_wid := floor(wid / tileWid) :
    n_tiles := n_tiles_len * n_tiles_wid :
    if n_tiles = 0 then next: end if:
    total_coverage_CD := total_coverage_CD + tileLen * tileWid * n_tiles / (len * wid) :
    surface_count_CD := surface_count_CD + 1 :
  end do:

  total_coverage := total_coverage_AB + total_coverage_CD :
  total_surfaces := surface_count_AB + surface_count_CD :
  avg_coverage := evalf(100 * total_coverage / total_surfaces) :
  efficiency := avg_coverage / total_tiles :

 if max_coverage < avg_coverage then
  max_coverage := avg_coverage;
  best_coverage_tile := [tileLen, tileWid, avg_coverage, total_tiles];
end if;

  if efficiency > max_efficiency then
    max_efficiency := efficiency :
    best_efficiency_tile := [tileLen, tileWid, efficiency, avg_coverage, total_tiles] :
  end if:

 if score > max_score then
  max_score := score :
```



```
for r in final_results do
  tileLen := r[1] :
  tileWid := r[2] :
  score := r[3] :
  total_tiles := r[4] :

  # Calculate average coverage
  total_coverage_AB := 0 :
  surface_count_AB := 0 :
  for s in surfaces_AB do
    len := s[1] :
    n_tiles := floor(len / tileLen) :
    if n_tiles = 0 then next: end if:
    total_coverage_AB := total_coverage_AB + tileLen * n_tiles / len :
    surface_count_AB := surface_count_AB + 1 :
  end do:

  total_coverage_CD := 0 :
  surface_count_CD := 0 :
  for s in surfaces_CD do
    len := s[1] :
    wid := s[2] :
    n_tiles_len := floor(len / tileLen) :
    n_tiles_wid := floor(wid / tileWid) :
    n_tiles := n_tiles_len * n_tiles_wid :
    if n_tiles = 0 then next: end if:
    total_coverage_CD := total_coverage_CD + tileLen * tileWid * n_tiles / (len * wid) :
    surface_count_CD := surface_count_CD + 1 :
  end do:

  total_coverage := total_coverage_AB + total_coverage_CD :
  total_surfaces := surface_count_AB + surface_count_CD :
  avg_coverage := evalf(100 * total_coverage / total_surfaces) :
  efficiency := avg_coverage / total_tiles :

 if max_coverage < avg_coverage then
  max_coverage := avg_coverage;
  best_coverage_tile := [tileLen, tileWid, avg_coverage, total_tiles];
end if;

  if efficiency > max_efficiency then
    max_efficiency := efficiency :
    best_efficiency_tile := [tileLen, tileWid, efficiency, avg_coverage, total_tiles] :
  end if:

 if score > max_score then
  max_score := score :
```



```
  best_score_tile := [tileLen, tileWid, score, total_tiles, avg_coverage] :
 end if:

 if tileLen = tileWid and score > max_square_score then
  max_square_score := score :
  best_square_tile := [tileLen, tileWid, score, total_tiles, avg_coverage] :
 end if:
 end do:

 # Display results
 printf("1. Highest Coverage Tile: %dx%d --- %.2f%%\n", best_coverage_tile[1],
    best_coverage_tile[2], best_coverage_tile[3]);
 printf("2. Highest Efficiency Tile: %dx%d --- %.4f (eff), %.2f%% coverage, %d tiles\n",
    best_efficiency_tile[1], best_efficiency_tile[2], best_efficiency_tile[3], best_efficiency_tile[4],
    best_efficiency_tile[5]);
 printf("3. Best Square Tile: %dx%d --- Score: %.3f\n", best_square_tile[1], best_square_tile[2],
    best_square_tile[3]);
 printf("4. Best Overall Score Tile: %dx%d --- Score: %.3f\n", best_score_tile[1],
    best_score_tile[2], best_score_tile[3]);
```

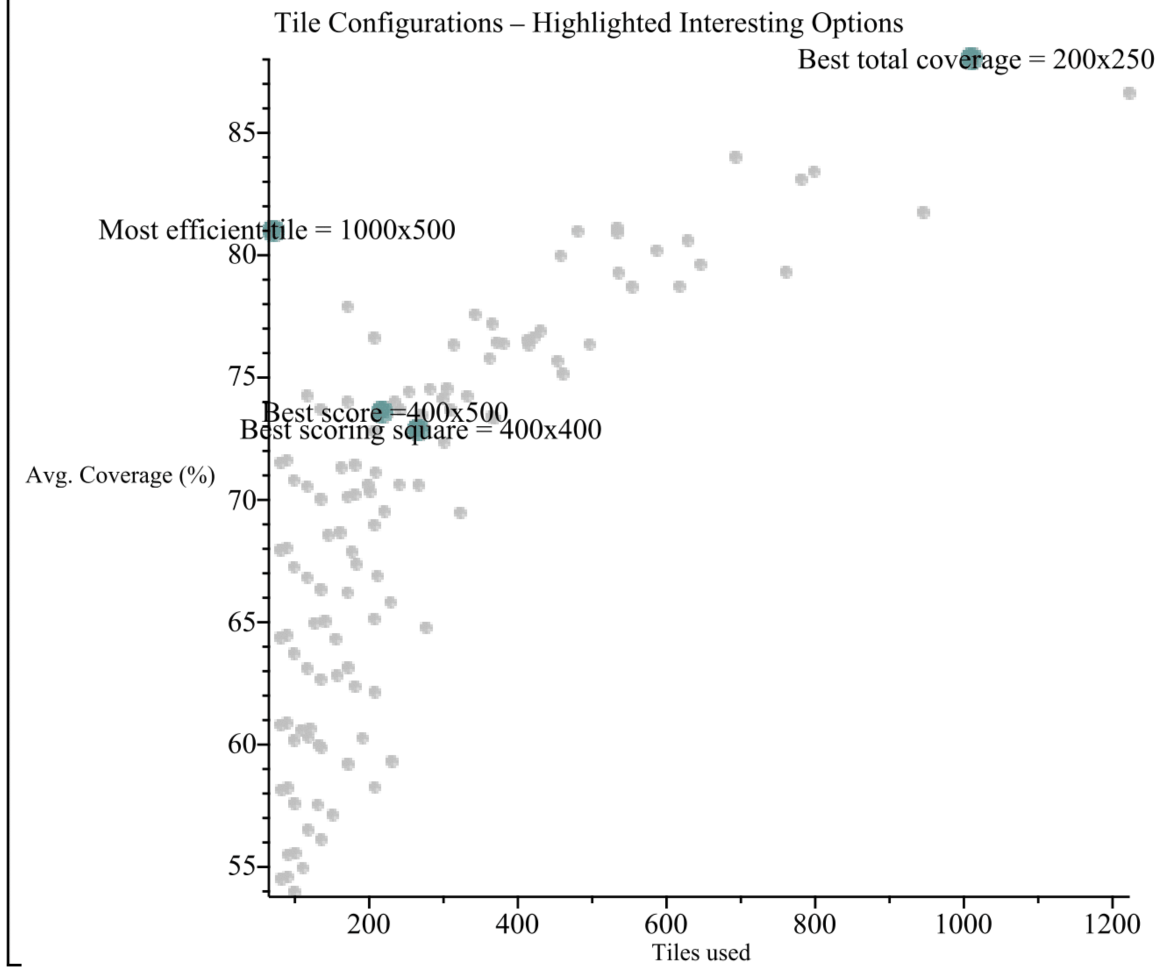
```
1. Highest Coverage Tile: 200x250 --- 88.03%
2. Highest Efficiency Tile: 1000x500 --- 0.8829 (eff), 71.51%
coverage, 81 tiles
3. Best Square Tile: 400x400 --- Score: 1.154
4. Best Overall Score Tile: 400x500 --- Score: 1.179
```

```
> with(plots) :

 gold_pts := [ ] :
 gold_tags := [ ] :

 # Add best_coverage_tile
 if assigned(best_coverage_tile) and nops(best_coverage_tile) ≥ 4 then
  gold_pts := [op(gold_pts), [best_coverage_tile[4], best_coverage_tile[3]]] :
  gold_tags := [op(gold_tags), textplot([best_coverage_tile[4] + 5, best_coverage_tile[3],
    cat("Best total coverage = ", best_coverage_tile[1], "x", best_coverage_tile[2])])] :
 end if:

 # Add best_efficiency_tile
 if assigned(best_efficiency_tile) and nops(best_efficiency_tile) ≥ 5 then
  gold_pts := [op(gold_pts), [best_efficiency_tile[4], best_efficiency_tile[5]]] :
  gold_tags := [op(gold_tags), textplot([best_efficiency_tile[4] + 5, best_efficiency_tile[5],
    cat("Most efficient tile = ", best_efficiency_tile[1], "x", best_efficiency_tile[2])])] :
 end if:

 # Add best_square_tile
 if assigned(best_square_tile) and nops(best_square_tile) ≥ 5 then
  gold_pts := [op(gold_pts), [best_square_tile[4], best_square_tile[5]]] :
```

```
    best_score_tile := [tileLen, tileWid, score, total_tiles, avg_coverage] :
  end if:

  if tileLen = tileWid and score > max_square_score then
    max_square_score := score :
    best_square_tile := [tileLen, tileWid, score, total_tiles, avg_coverage] :
  end if:
  end do:

  # Display results
  printf("1. Highest Coverage Tile: %dx%d --- %.2f%%\n", best_coverage_tile[1],
      best_coverage_tile[2], best_coverage_tile[3]);
  printf("2. Highest Efficiency Tile: %dx%d --- %.4f (eff), %.2f%% coverage, %d tiles\n",
      best_efficiency_tile[1], best_efficiency_tile[2], best_efficiency_tile[3], best_efficiency_tile[4],
      best_efficiency_tile[5]);
  printf("3. Best Square Tile: %dx%d --- Score: %.3f\n", best_square_tile[1], best_square_tile[2],
      best_square_tile[3]);
  printf("4. Best Overall Score Tile: %dx%d --- Score: %.3f\n", best_score_tile[1],
      best_score_tile[2], best_score_tile[3]);
```

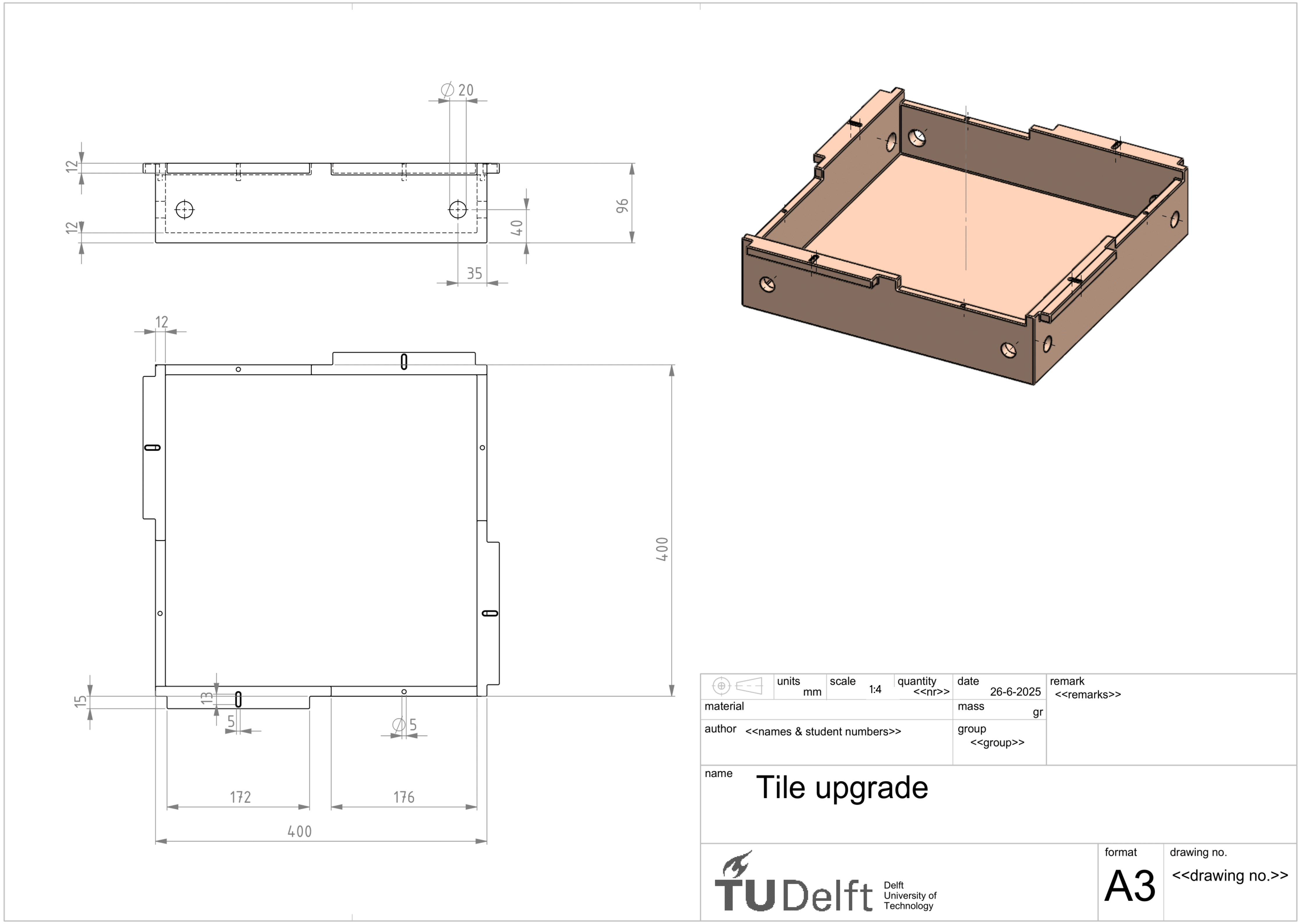
```
1. Highest Coverage Tile: 200x250 --- 88.03%
2. Highest Efficiency Tile: 1000x500 --- 0.8829 (eff), 71.51%
coverage, 81 tiles
3. Best Square Tile: 400x400 --- Score: 1.154
4. Best Overall Score Tile: 400x500 --- Score: 1.179
```

```
> with(plots) :

  gold_pts := [ ] :
  gold_tags := [ ] :

  # Add best_coverage_tile
  if assigned(best_coverage_tile) and nops(best_coverage_tile) ≥ 4 then
    gold_pts := [op(gold_pts), [best_coverage_tile[4], best_coverage_tile[3]]] :
    gold_tags := [op(gold_tags), textplot([best_coverage_tile[4] + 5, best_coverage_tile[3],
        cat("Best total coverage = ", best_coverage_tile[1], "x", best_coverage_tile[2])])] :
  end if:

  # Add best_efficiency_tile
  if assigned(best_efficiency_tile) and nops(best_efficiency_tile) ≥ 5 then
    gold_pts := [op(gold_pts), [best_efficiency_tile[4], best_efficiency_tile[5]]] :
    gold_tags := [op(gold_tags), textplot([best_efficiency_tile[4] + 5, best_efficiency_tile[5],
        cat("Most efficient tile = ", best_efficiency_tile[1], "x", best_efficiency_tile[2])])] :
  end if:

  # Add best_square_tile
  if assigned(best_square_tile) and nops(best_square_tile) ≥ 5 then
    gold_pts := [op(gold_pts), [best_square_tile[4], best_square_tile[5]]] :
    gold_tags := [op(gold_tags), textplot([best_square_tile[4] + 5, best_square_tile[5],
        cat("Best scoring square = ", best_square_tile[1], "x", best_square_tile[2])])] :
  end if:

  # Add best_score_tile
  if assigned(best_score_tile) and nops(best_score_tile) ≥ 5 then
    gold_pts := [op(gold_pts), [best_score_tile[4], best_score_tile[5]]] :
    gold_tags := [op(gold_tags), textplot([best_score_tile[4] + 5, best_score_tile[5],
        cat("Best score =", best_score_tile[1], "x", best_score_tile[2])])] :
  end if:

  # Now display the final plot with highlights
  display(
    pointplot(all_pts, symbol = solidcircle, symbolsize = 10, color = grey),
    pointplot(gold_pts, symbol = solidcircle, symbolsize = 14, color = "#669999"),
    op(gold_tags),
    labels = ["Tiles used", "Avg. Coverage (%)"],
    title = "Tile Configurations – Highlighted Interesting Options"
  );
```



Appendix J: Technical drawings

Below technical drawings can be found of the base tile (excluding draft angle), sigma profile, Uconnector, wind deflector, native enhancer and bird house.



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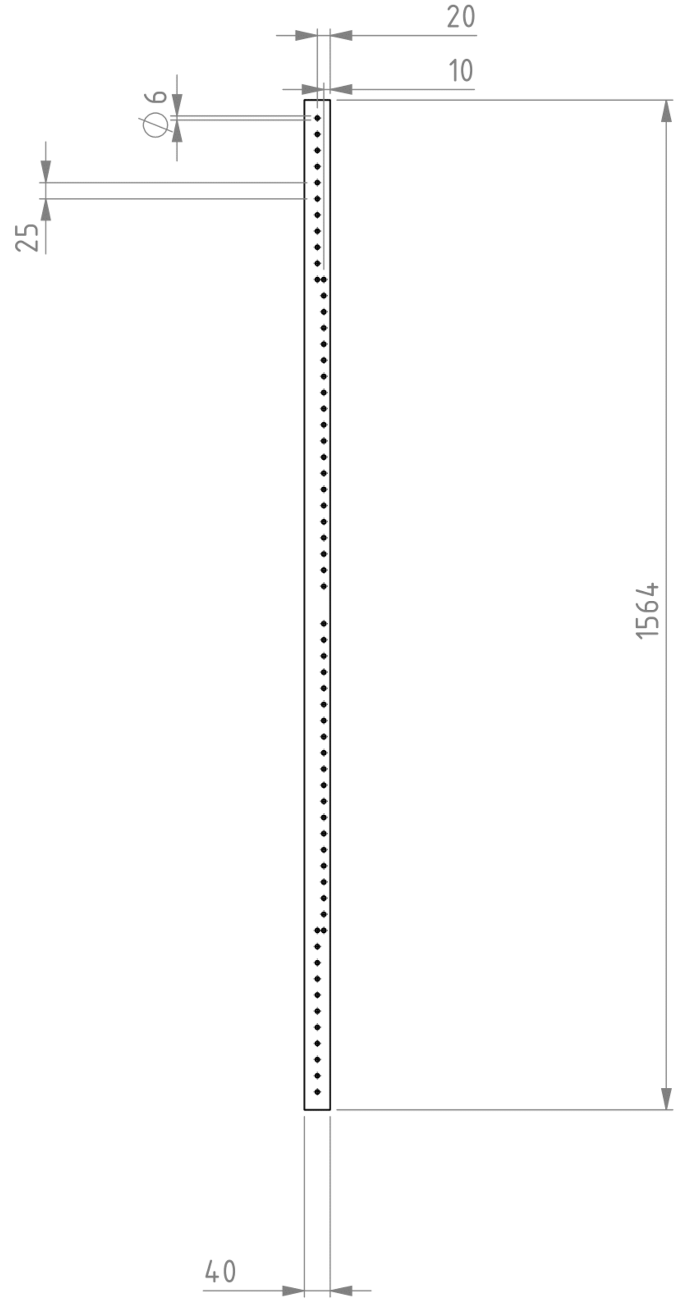
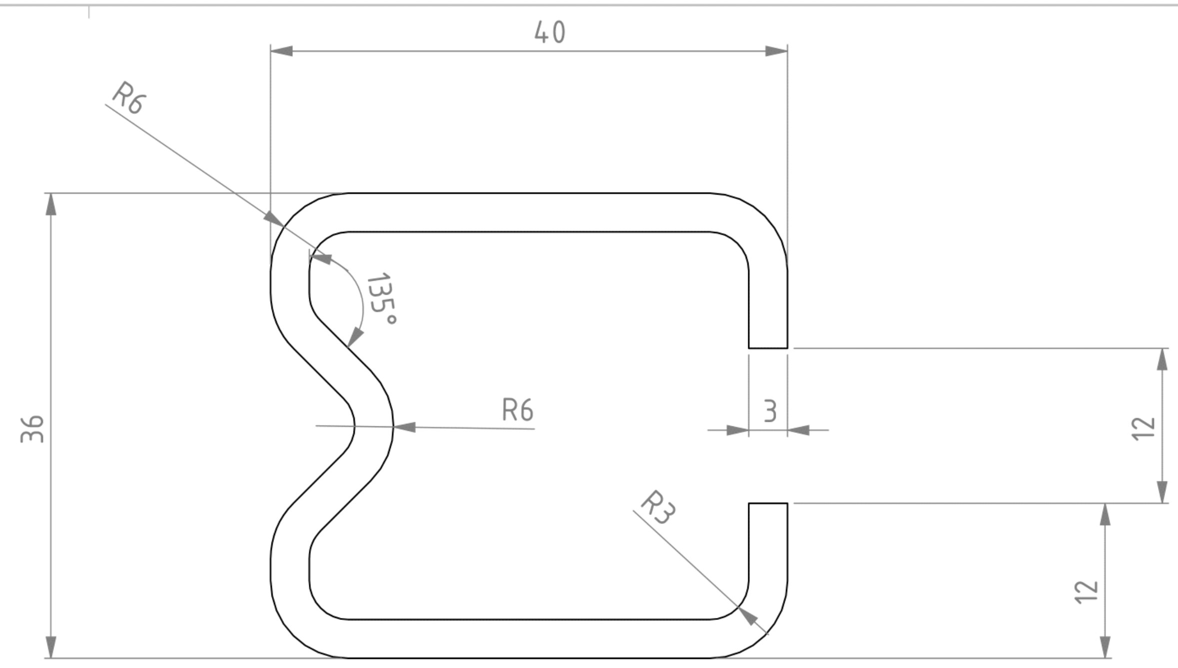
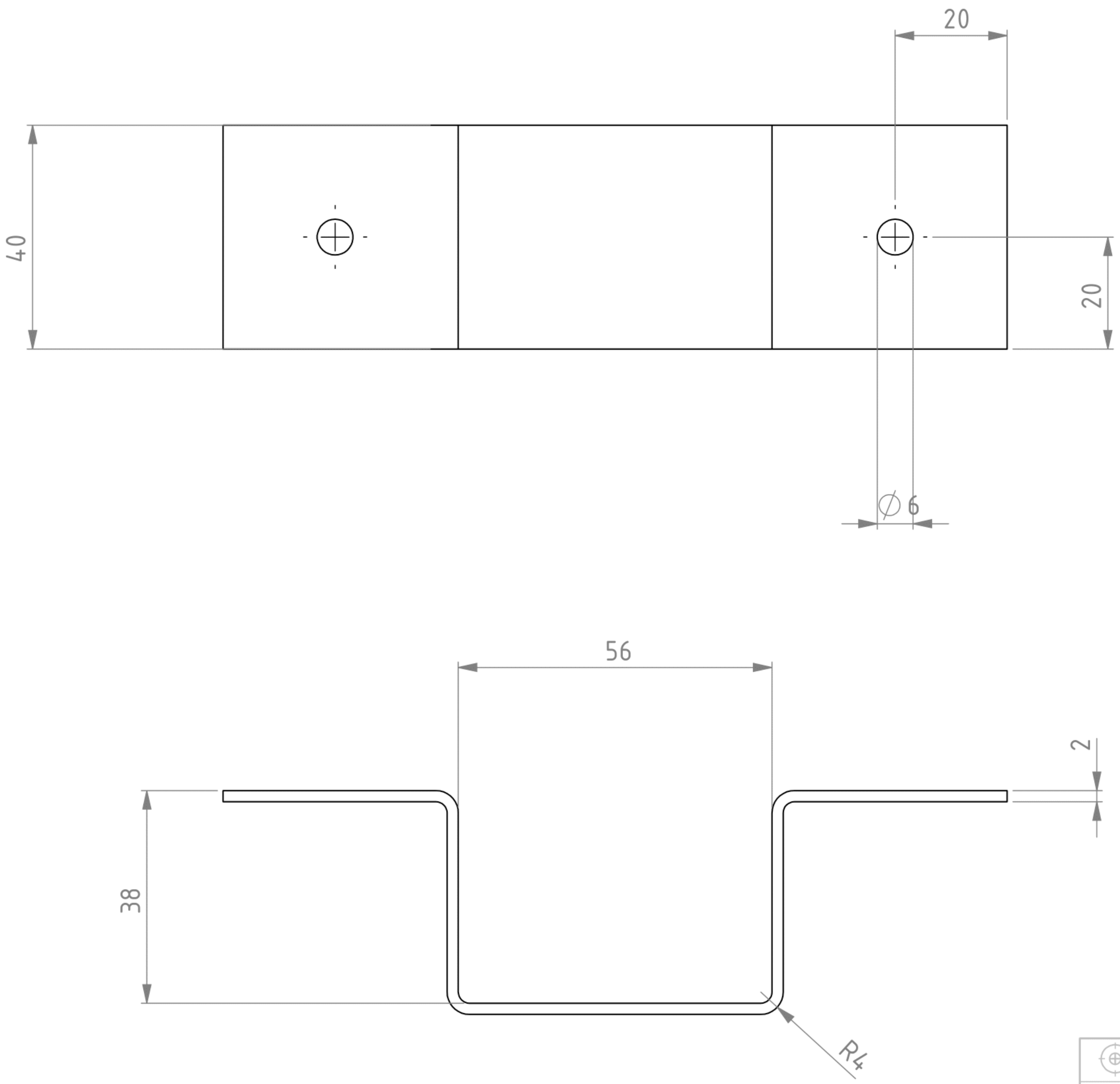




units: mm	scale: 1:10	quantity: <<nr>>	date: 4-7-2025	remark: <<remarks>>
material: AISI 1020 Steel, Cold Rolled			mass: 4517.76gr	
author: <<names & student numbers>>			group: <<group>>	
name: Sigma profile				
TU Delft, Delft University of Technology			format: A3	drawing no.: <<drawing no.>>



units mm | scale 1:1 | quantity <<nr>> | date 4-7-2025 | remark <<remarks>>

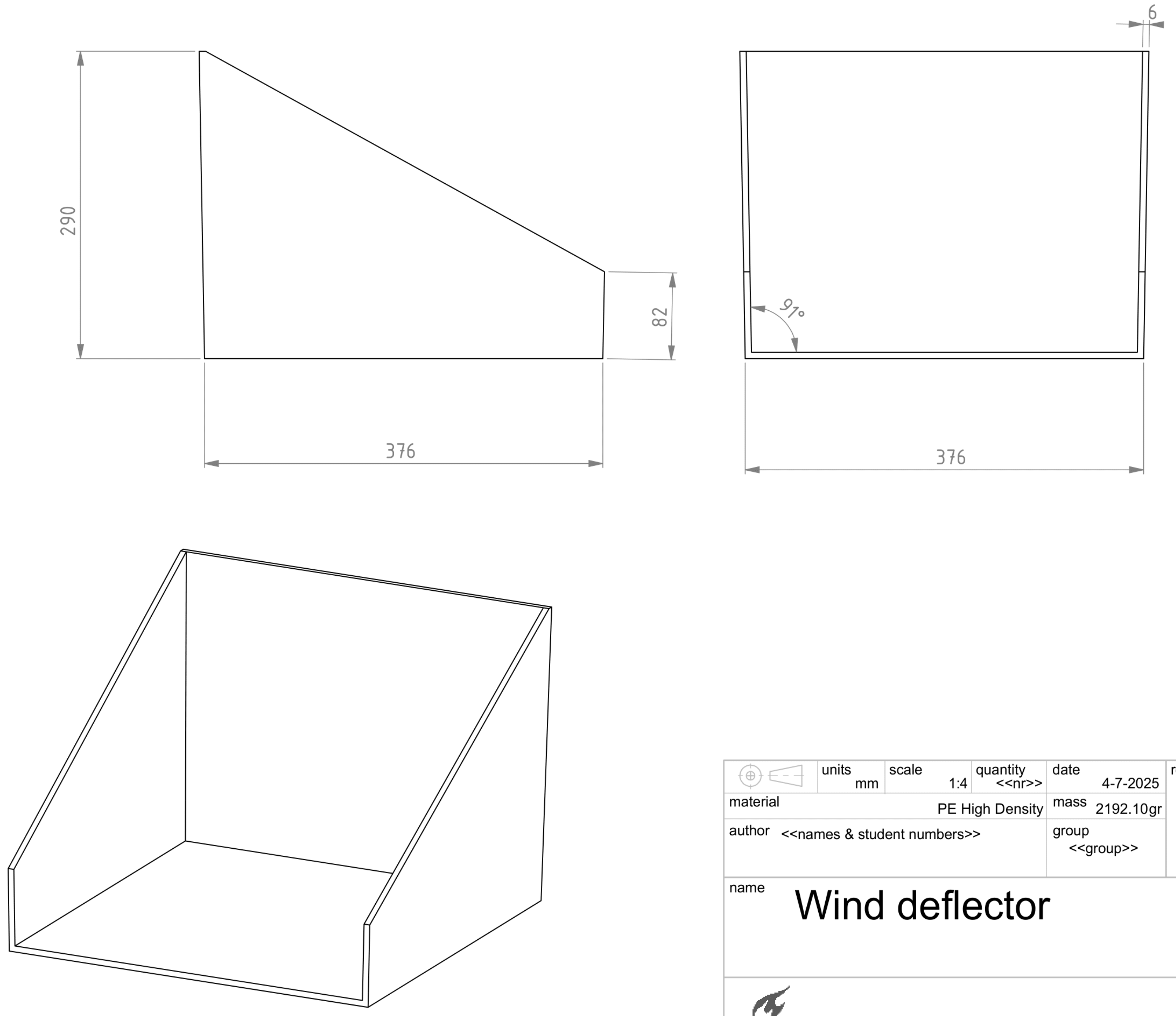
material AISI 1015 Steel, Cold Drawn (SS) | mass 131.74gr

author <<names & student numbers>> | group <<group>>

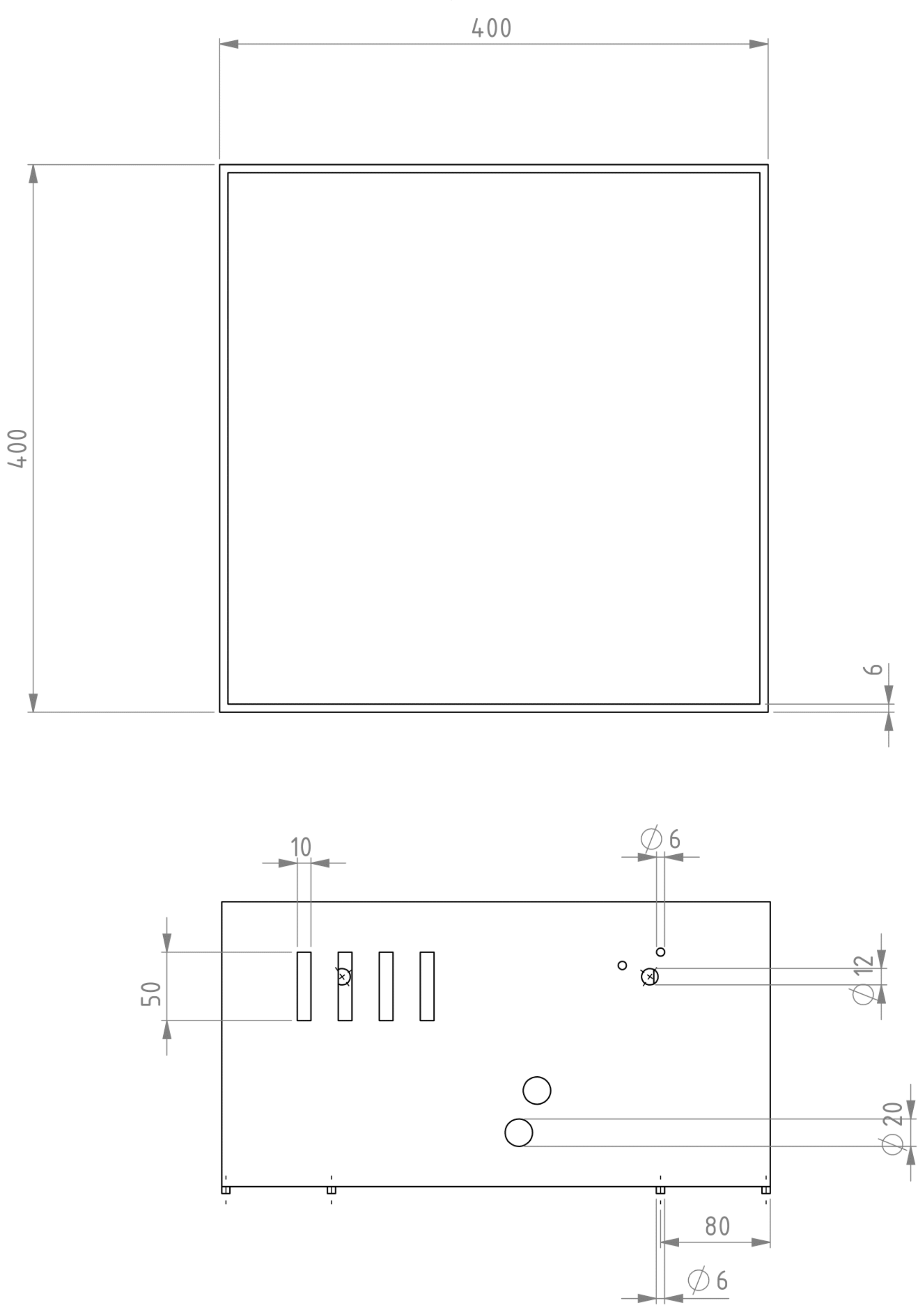
name **U profile connector**

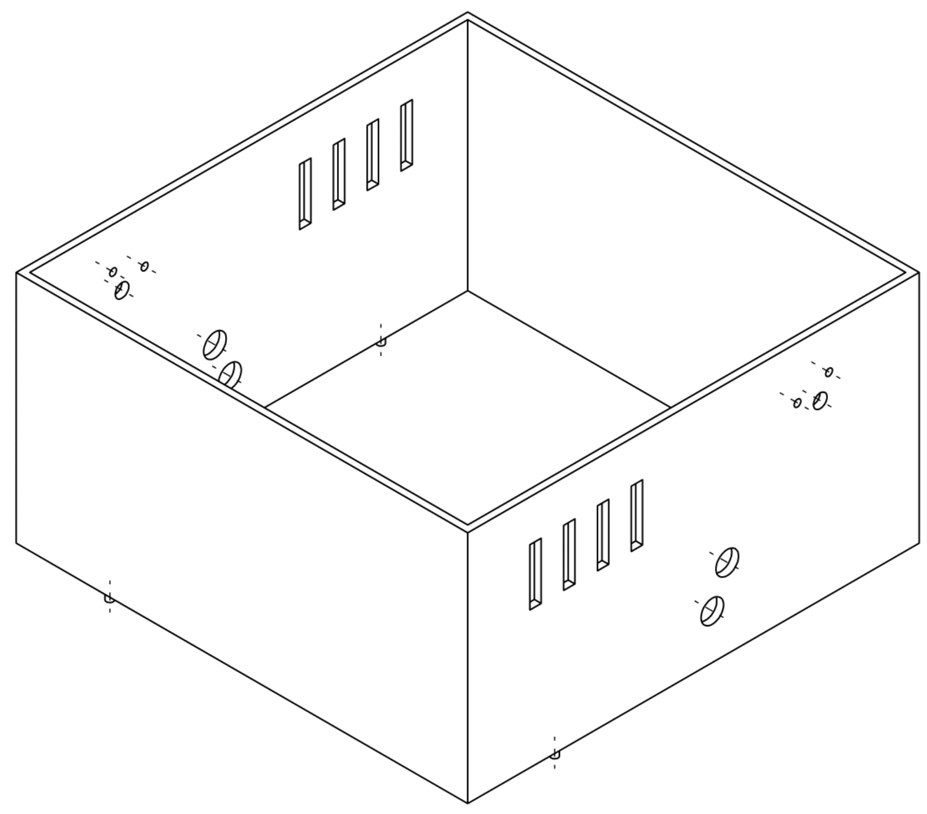
TU Delft — Delft University of Technology

format A3 | drawing no. <<drawing no.>>



units mm	scale 1:4	quantity <<nr>>	date 4-7-2025	remark <<remarks>>
material PE High Density			mass 2192.10gr	
author <<names & student numbers>>			group <<group>>	
name **Wind deflector**				
Delft University of Technology			format A3	drawing no. <<drawing no.>>





	units	scale	quantity	date	remark
	mm	1:4	<<nr>>	4-7-2025	<<remarks>>
material				mass gr	
author <<names & student numbers>>				group <<group>>	

name

Bio enhancer

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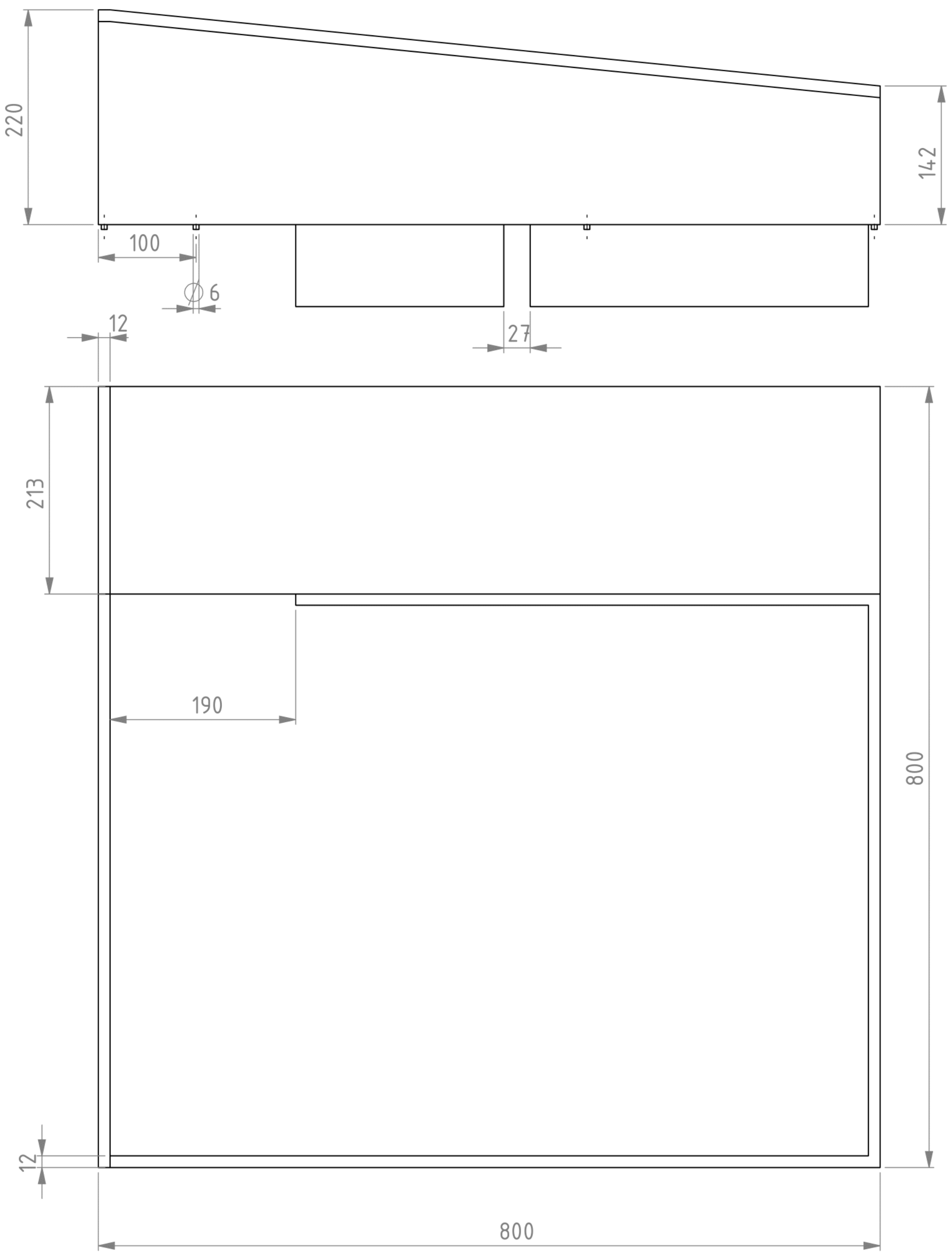
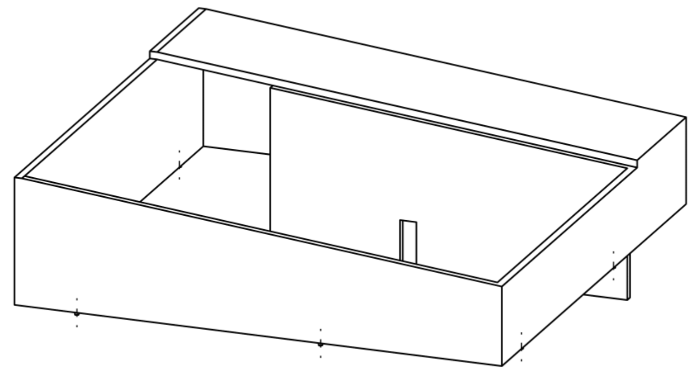
format: A3

drawing no.: <<drawing no.>>





units mm	scale 1:5	quantity <<nr>>	date 4-7-2025	remark <<remarks>>
material			mass gr	
author <<names & student numbers>>			group <<group>>	

name **Bird house**

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format A3

drawing no. <<drawing no.>>

Appendix K: Costs: emissions and expenses

Further calculations of the total emissions and expenses are listed here, indicated with sources.

Emissions

Emissions prevented

Below estimated values are given for the estimated emission values from a current ballast system with a mass of approximately 78.3 kg, derived from Environment Product Declarations (EPD's) of Sunbeam products, or Environmental Product Declarations of outsourced products.

Current concrete ballast (max): Made by various outsourced concrete manufacturers. Studies show total CO_2 emissions of $4 * \frac{96.8}{1000} = 0.3872$ kg per tile. (Lindh, 2020). Which means a total of 19 * 0.3872 = 7.36. kg CO_2 eq-.

Current Supra foot (2): Made from HDPE (UV-stabilised): 0.3 kg CO_2 eq- * 2 = 0.6 CO_2 eq-.

Current ballast plate (max 1): 2,66 kg CO2eq /kg * 2,46 kg* 2 = 13,4 kg CO_2eq-.

Total = **21,36 CO_2 eq-** for the material and manufacturing processes for the current parts that can be replaced by one Anemone ballast.

Additional emissions

Final tiles: As earlier described the bamboo fibre composite is chosen as a material since it has a potential to be carbon negative, since bamboo takes up CO_2 when growing. It has to be noted that before actual production new sources/ research shall be done to see the actual emissions for this relatively novel material, but current research can give us an indication for its potential.

Anemone tile: 3*0.01 = 0.03 kg CO_2 eq. (Gu et al. , 2019), (Ghasemi et al., 2020)

*30% volume of bamboo fibre: (267kg CO2m3*0.00341m3*0,3) = 0.27 kg CO_2 eq. 70% volume of soy bio resin: (0,4kg CO2eq- * 0.7) =0,28 kg CO_2 eq-*

Sigma connector to frame: Cold rolled, just as the current ballast plate. Gives us material and manufacturing emissions of: (2,66 kg CO2eq- * 4,5 (weight of the frame) = 12,00 kg CO_2 eq.

Clamping connections: Volume = 16739.28 cubic millimetres of rolled steel, 1,25 kg CO_2eq.

Substrate per tile: 20kg of sedum substrate can be carbon negative in a variety of ways. 20 kg soil in a 0.16 m^2 tile, 0.20 kg CO_2eq- (Getter & Rowe, 2009)

Vegetation: Vegetation can potentially take up 0.3 until 0.6 kg CO_2eq /yr (Whittinghill et al. ,2014)

Total = **5,07 CO_2 eq in 20 years.**

Expenses

Expenses prevented

Below estimated values are given for cost prices of the following total of parts, provided by Sunbeam.

Current ballast plate (2): 2 * €4,7676 = €9,54

Current concrete ballast brick[17]: 0,54*19 =€10,26

Current Supra foot (2): 2 * €0,259 = €0,518

Total = €20,32

Additional expenses

3 Anemone tiles: Hard to make an accurate estimation of the costs, but if when looking at similar products, costs could be between around €5-15 for material costs alone (Martijanti et al., 2021).

Clamping connectors: Prefab part €0,50 cents per piece.[18]

Sedum substrate: €40,- per m^2 * 0,4 = 16 per tile, so €48,- per total ballast unit.[19]

Sedum vegetation: €0,25 for seeds.[20]

Sigma frame (prefabricated estimation): €11,- [21]

Total = ~€85,-

[19] https://www.gamma.nl/assortiment/klinker-beton-grijs-21x10-5x8-cm-360-klinkers-7-94-m2/p/B610489

[20] https://www.aluminium-profile.co.uk/

[21] https://www.covergreen.nl/en/toepassing/green-roof/

[22] https://www.graszaadselect.nl/en/sedum-green-roofs-16-kg-20-m2.html

[23] https://www.voestalpine.com/sadef/

Appendix L: 1:1 Prototype

Various 3D prints have been made to test assembling, as well as a final 1:1 model, which is shown below.