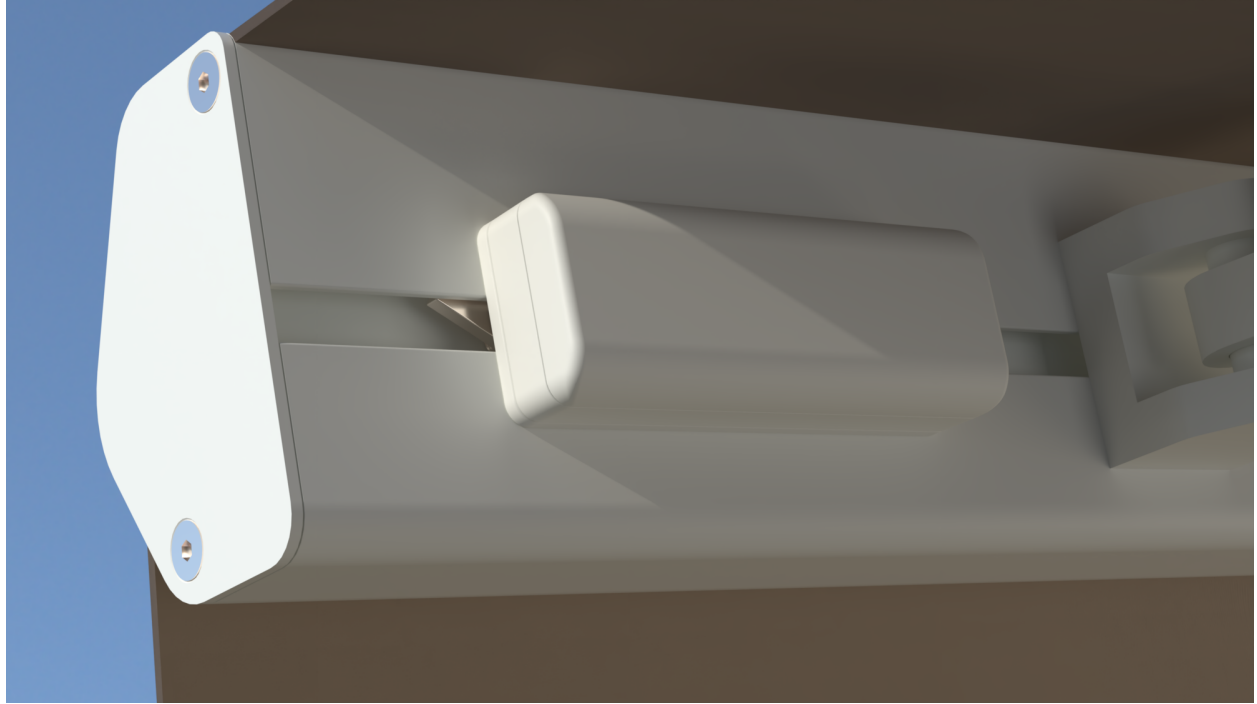




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Product Development of a Housing and Mounting System for a Vibration-Based Awning Sensor

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
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MASTER'S THESIS 2026

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Cover: The final housing and mounting system for the awning sensor developed in this thesis.

Typeset in L^AT_EX

Gothenburg, Sweden 2026

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Abstract

This thesis presents the product development of a housing and mounting system for a vibration-based awning sensor intended to support automatic protection against wind-related damage. The project aimed to improve the reliability of automated awning systems by reducing the risk of weather-related damage, minimizing maintenance costs and enhancing user trust. Existing solutions, stakeholder needs and technical requirements were investigated to guide concept development, detail design, prototype testing and manufacturing adaptation. Following evaluation of different detection principles, the work focused on a vibration-based sensor mounted directly on the awning. The main focus was the physical housing and mounting solution, including protection of internal components, compatibility with different awnings, serviceability, outdoor durability, visual integration and manufacturability.

The final concept consists of a compact sensor housing designed for injection molding, with a two-part construction sealed using a gasket. The concept uses a T-slot mounting solution for attachment to the awning and a bayonet mechanism enabling tool-free removal of the housing. 3D-printed prototypes were manufactured and evaluated regarding sealing performance, mounting compatibility and repeated handling. The results indicated good functionality and suitability for further development. The project concludes that the developed housing and mounting concept has potential to support reliable integration of vibration-based sensing in automated awning systems. Further work should include environmental testing, electronics integration and validation using production-ready components.

Keywords: vibration sensor, awning systems, product development, housing design, mounting system

Acknowledgements

We would especially like to thank our examiner and supervisor, Erik Hulthén at Chalmers, for his guidance, feedback and support throughout the project. Additionally, we would like to thank the collaborating company and our supervisor at the company for their technical expertise, practical insights and support during the project. Their knowledge and experience contributed to the development process. We would also like to thank the installers and interview participants who shared their time, practical experience and insights throughout the project. Their perspectives helped improve our understanding of existing solutions, installation challenges and user-related considerations.

Petter Hemå and Linnéa Johansen, Gothenburg, May 2026

List of Acronyms

AES Acrylonitrile Ethylene Styrene. 37, 38

ASA Acrylonitrile Styrene Acrylate. 37, 38, 47, 59, XXVII, XXIX, XXX

CAD Computer-Aided Design. 3, 6, 18, 21–24, XX, XXXI

DFE Design for Environment. 4, 6

EPDM Ethylene Propylene Diene Monomer. 38, 39, 41, 43, 48, 59, XXX

IoT Internet of Things. 1

IP Ingress Protection. 43, 55

LCP Liquid Crystal Polymer. 37

PCB Printed Circuit Board. 42, 45, 61, XXXIII

SWOT Strengths, Weaknesses, Opportunities and Threats. 11, 12

TPU Thermoplastic Polyurethane. 43, 59

UV Ultraviolet. 1, 7, 36, 38, 56, XXIX

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1

Introduction

This chapter introduces the project background, purpose, objectives, scope and limitations.

1.1 Background

This project was conducted in collaboration with a company developing Internet of Things (IoT) products for residential and commercial environments. The company has an existing system for controlling awnings and other shading products. Within this context, the project focused on developing a sensor housing and mounting solution for a sensor intended to support automatic protection during unsuitable weather conditions. These sensors can detect conditions such as wind or rain. This enables the system to react, by preventing operation of the awning and retracting it when necessary. Smart home automation, solar shading products and the environmental challenges associated with exterior awnings provide the contextual foundation for the project. Particular focus was placed on outdoor exposure, mounting compatibility and the need for reliable integration with awning systems.

1.1.1 Smart Home Systems and Automation

The increasing availability of low-power embedded electronics and wireless communication has enabled large-scale deployment of connected devices in residential and commercial environments. Smart home systems often integrate multiple devices and sensors using event-driven control logic, allowing automated control without continuous user input. The home automation sector has seen increased innovation activity recently, reflected by the increasing number of patent filings within the IoT domain (Maghsoudi et al., 2026). Since smart home technologies rely on underlying IoT capabilities, these trends may indicate continued technological development and future growth of smart home products and systems.

1.1.2 Sunshading Products

As smart home ecosystems continue to expand, new product categories with smart functionality are being introduced, including sunshading systems. Several products are used to block sunlight, such as blinds, curtains and awnings. Unlike interior sunshading products, exterior awnings are directly exposed to environmental conditions including wind, rain, temperature variations and Ultraviolet (UV) radiation. Many systems are electrically controlled and may automatically extend based on lighting conditions. Since exterior sunshading systems operate under demanding conditions, protective functionality is required to prevent damage during harsh weather.

1.1.3 Preventing Damage to Awnings

Awnings, such as the terrace awning shown in Figure 1.1, are available in a wide range of dimensions and are typically designed to be compact when retracted. Larger awnings can extend several meters from the wall, meaning relatively small forces at the outer edge can create high torques near the mounting point.

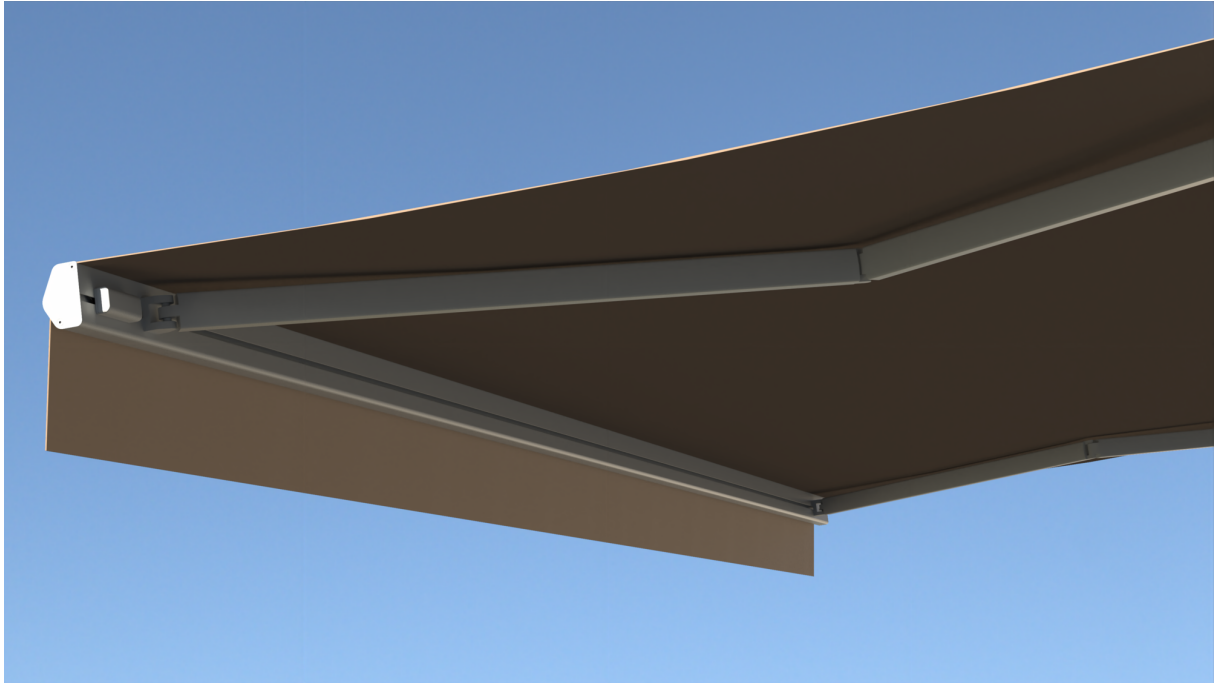


Figure 1.1: Example of a terrace awning in its extended position.

Since awnings are often designed with aesthetics in mind, they are generally not intended to withstand high wind speeds or other severe weather conditions. If adverse weather is not detected in time, the awning may remain extended and be exposed to loads that can cause structural damage. Since awnings can represent a significant investment, avoiding unnecessary damage is important.

Sensors can be used to detect conditions where retraction is necessary. Two common approaches can be identified: monitoring environmental conditions directly or monitoring the state of the awning itself. Environmental monitoring may protect multiple nearby awnings, while monitoring the individual awning can detect forces acting directly on the structure that may not be captured through environmental measurements alone. This project therefore focused on developing a product that monitors the state of an individual awning system. In addition to preventing physical damage, reliable protection may also influence user behavior. If users perceive the system as capable of protecting itself during damaging conditions, they may be more willing to leave the awning extended during everyday use, increasing its practical utility.

1.2 Purpose

The purpose of the project is to increase the reliability of an existing awning control system in order to reduce the risk of weather-related damage, unexpected maintenance costs and reduced user trust in the system.

1.2.1 Objectives

The project aimed to investigate and develop a sensor concept intended to improve the reliability of automated awning systems by enabling detection of environmental conditions that may cause damage.

- Explore current solutions to identify relevant design principles and opportunities for improvement.
- Investigate and select a suitable detection technology for identifying environmental conditions that may cause damage to awnings.
- Identify compatibility requirements to support integration with a wide range of existing awnings.
- Design a mechanical housing that is functional, visually integrated, suitable for outdoor environments, and easy to install and service.
- Manufacture and test prototypes to evaluate selected aspects of the design.

1.3 Scope and Limitations

Scope

The project was conducted over a 20-week period during the spring of 2026 and focused on the development of an awning-integrated sensor concept intended to support the reliability of an existing awning control system. The work included competitor benchmarking, requirement identification, evaluation of detection technologies, concept development, Computer-Aided Design (CAD), material selection, prototype manufacturing and testing, as well as considerations related to manufacturability and sustainability. Following evaluation of suitable detection technologies, the continued development focused on a vibration-based sensor mounted on the awning itself. The main focus was the housing and mounting solution for compatibility with different awning systems, including protection of internal components, sealing, visual integration and manufacturability. A preliminary internal component layout was also developed to support physical integration of the sensor design.

Limitations

While manufacturability and large-scale production considerations were included during development, creation of a fully market-ready product was outside the scope of the project. The project did not include development of electronics, circuit board design, embedded

software, communication protocols, power saving strategies or mobile applications. The prototype was therefore used to evaluate the physical design rather than complete sensor functionality. Long-term durability, environmental exposure and certification testing were outside the scope of the project. Detailed tolerance analysis was also outside the scope of the project.

1.4 Research Questions

The project was guided by a set of research questions that identify the main design challenges. The following research questions were addressed:

- How can the housing and mounting system be designed for compatibility with different awning profiles without interfering with awning operation?
- How can the sensor housing protect internal components from outdoor environmental exposure while remaining serviceable?
- How can the design balance manufacturability, cost, usability and visual integration?

1.5 Societal, Ethical and Ecological Considerations

In addition to technical and functional requirements, the development of the sunshade product involves societal, ethical and ecological considerations. Since the project explores sensor-based control systems and product design, it is important to consider how these solutions may affect users, society and the environment. From a societal perspective, the system may influence user safety, accessibility and trust. If the system reacts in the wrong way, it could cause problems for the user or even damage the awning. Therefore, the control logic needs to be predictable and easy to understand. Compliance with building and safety regulations is also important for installation on buildings.

Ethical considerations include responsibility and accountability in cases of system failure or unexpected behavior. Since automated decisions are based on sensor data, transparency regarding system behavior, limitations, risks and data usage is important. There is also a risk of system behavior favoring certain conditions or usage scenarios, making fairness considerations relevant. Additional ethical considerations arise from conducting the thesis in collaboration with a company, involving access to proprietary and potentially patentable information, which is therefore anonymized or omitted when necessary to respect confidentiality agreements while maintaining verifiable thesis content.

From an ecological perspective, the sensor may increase product lifespan by detecting damaging conditions, potentially reducing material consumption over time. However, the sensor and housing still contribute to environmental impact. The project therefore follows Design for Environment (DFE), considering material selection, standard components, resource use, energy consumption and recyclability from a life-cycle perspective.

2

Methodology

This chapter describes the development process and methods applied to identify needs, generate concepts, evaluate alternatives and refine the final design.

2.1 Product Development Process

The development process was based on the product development framework described by Ulrich et al. (2020). The project followed a structured sequence of phases, while concepts and design decisions were evaluated and refined iteratively within the individual phases. The process included the following phases:

1. Planning and Pre-study
2. Concept Development
3. System-Level Design
4. Detail Design
5. Prototyping, Testing and Refinement

2.2 Applied Product Development Methods

Literature studies, competitor benchmarking and patent analysis were used during the pre-study to identify existing solutions, technical constraints and opportunities for improvement. Interviews with installers and observations were used to identify recurring challenges related to installation, maintenance, durability and integration with different awning systems. The collected insights formed the basis for the requirement specification and concept generation.

Structured concept development methods were used to generate and evaluate solution alternatives for the housing and mounting system. Function analysis, brainstorming and morphological matrices were used to develop and combine sub-solutions into complete concepts. An elimination matrix was used to screen the concepts against the identified requirements and stakeholder priorities. The remaining concepts were then compared in more detail using Pugh and Kesselring matrices to support the final concept selection.

CAD modeling was used throughout the project to develop, visualize and refine concepts and design solutions. Selected concepts were manufactured as 3D-printed prototypes and evaluated through assembly, handling and functional testing. Prototype testing was used to assess aspects such as sealing performance, mounting compatibility, usability and robustness. Manufacturability, assembly and material-related considerations were also included throughout the development process to support continued development towards practical implementation and outdoor use.

Environmental considerations inspired by DFE principles were included throughout the development process, primarily through material selection, durability-oriented design and manufacturability considerations. The work also focused on reducing unnecessary material usage and supporting long-term maintainability.

3

Pre-study and Background Research

This chapter presents the pre-study activities used to build an initial understanding of the problem, existing solutions and relevant technical aspects.

3.1 Literature Study

The literature study primarily focused on design principles related to housing robustness, including environmental exposure such as moisture, temperature variations and UV radiation, as well as sealing concepts and durability. Since academic literature on similar products was limited, other existing products were also analyzed to identify relevant design solutions and approaches.

3.2 Competitor Benchmarking

A market and competitor analysis was conducted to evaluate existing products and identify their features, strengths, weaknesses and potential areas for improvement. The analysis aimed to identify gaps in current solutions and establish benchmarks that could support the development process. The complete benchmarking results are presented in Appendix A, Tables A.1 and A.2.

Seven commercially available sensors were evaluated to understand how common design challenges are addressed in existing products. The evaluation focused on aspects such as protection of the electronics, sealing concepts, mounting solutions and accessibility for battery replacement and configuration. Each product was assessed through disassembly, component inspection and review of available documentation, including product manuals. Performance under real wind loads and long-term durability were not experimentally evaluated and are therefore excluded from the results. The selected products represent different design approaches within the European awning market, with emphasis on widely used and established brands.

The benchmarking showed that all products use standard battery types, with five using AAA batteries and two using AA batteries. Attachment to the awning was primarily achieved using screws, either by direct fastening into the awning profile or through nuts inserted into the profile grooves. Some products also offered double-sided tape as an alternative mounting method. All products incorporated synthetic rubber gaskets for sealing, but visible gaps were observed in two cases, indicating possible quality control or seal positioning issues. Access to batteries and configuration buttons required partial disassembly for all products, while only two designs allowed tool-free access to the buttons. The collected findings from the benchmarking were used to define system requirements and identify opportunities for improvement.

3.2.1 Current Solution Overview

Current vibration sensors for awnings generally have similar designs, consisting of a protective plastic housing that shields the electronics and batteries from environmental exposure. Sensors are typically mounted on the inside of the front profile of the awning using screws or adhesive tape, either through the awning T-slot or by drilling directly into the profile. In limited spaces, front-mounted solutions are also used. Initial configuration and sensitivity adjustment are most commonly performed using potentiometers and buttons on the circuit board by opening the housing, while maintenance mainly involves battery replacement. Housing designs vary between prioritizing tool-free access, sealing performance and visual integration.

3.3 Overview of Awning Profiles

The three main types of awnings are full cassette, semi cassette and open designs. These differ mainly in how much of the awning fabric and mechanical components are protected when retracted. A full cassette awning encloses the entire system, providing maximum protection, while a semi cassette offers partial protection. Open awnings have no enclosing structure, leaving the components more exposed to environmental conditions. The geometry of awning profiles differs both between awning types and manufacturers. Since these profiles are not standardized, compatibility became an important design consideration and influenced the development of a mounting interface adapted to multiple geometries.

3.4 Patent Analysis

Patents were explored using open databases, primarily through Espacenet (European Patent Office, 2026). The review showed that vibration-based sensing is already an established solution area. Together with competitor benchmarking, the patents provided insight into which design principles and technical solutions have remained relevant and commercially viable over time. A more detailed patent review is provided in Appendix B.

4

Identifying Stakeholder and Customer Needs

This chapter presents the activities used to identify stakeholder and customer needs, including interviews, observations, benchmarking and analysis of recurring design requirements.

4.1 Stakeholder and Customer Needs Analysis

The collected insights from interviews, observations and benchmarking were analyzed to identify recurring patterns, stakeholder needs and opportunities for improvement related to existing awning sensor solutions.

4.1.1 Interviews

Semi-structured interviews were conducted with installers experienced in vibration sensors and competing products to identify stakeholder needs, practical challenges and views on existing solutions. The interviews focused on durability, technical constraints, user expectations and experiences related to installation, service and long-term use. Open-ended, thematically organized questions enabled flexibility and follow-up discussions during the interviews. In total, seven expert interviews covering installation, maintenance and after-sales support were conducted. Similar insights began to repeat after several interviews, indicating thematic saturation and supporting the reliability of the findings. Interviews lasted approximately one hour, with remote sessions being slightly shorter. Audio recordings were used to improve accuracy, and key sections were extracted instead of producing full transcriptions.

The interviews highlighted several recurring issues related to existing vibration sensors and their integration with awning systems. Although the sensing principle itself was generally perceived as effective, many installers associated vibration sensors with frequent service issues and reduced reliability. A common challenge was related to mounting and integration, where limited installation space and restrictive mounting orientations made it difficult to position the sensors correctly on certain awning systems. Several installers also considered existing sensors unnecessarily large and visually intrusive, negatively affecting the appearance of the awning. Problems related to environmental protection were also identified. Some installers reported cases where water entered the sensor housing and damaged the internal electronics, indicating insufficient sealing performance in certain products. Mounting solutions were also considered problematic, as many products relied either on adhesive tape, which risked detachment over time, or direct screw attachment into the awning profile, resulting in permanent marks on the awning.

4.1.2 Observations

In addition to expert interviews, observations were conducted to complement the qualitative data collection and gain a deeper understanding of how existing products are used and integrated in practice. The observations focused on the mechanical operation of awnings, including extension and retraction, available mounting interfaces and space constraints along the front bar and support arms. Installation, battery replacement and handling during mounting and maintenance were also studied to identify practical advantages, disadvantages and usability related challenges of current solutions.

Since realistic wind conditions were outside the scope of the study, the observations primarily focused on physical integration and accessibility. This provided practical insights into geometric limitations, mounting constraints and risks associated with existing awning sensor installations. The findings also reinforced results from interviews, particularly regarding limited installation space and restrictive mounting conditions on certain awning systems.

4.1.3 KJ-method

The interview data was systematically analyzed using the KJ-method (Scupin, 1997) to identify common patterns and repeated concerns. All relevant information from the interviews was compiled into a document and grouped into categories based on recurring themes and related topics. Redundant entries were removed and every quote was visualized as a virtual post-it note in Mural (Appendix C). Notes addressing similar topics or expressing related ideas were then grouped together, forming categories that highlighted recurring patterns and insights. This method provided a structured overview of the data, making it easier to identify key findings and interpret the interview results. At a later stage in the process, these insights were used to define concrete needs that guided the continued development of the product.

4.2 Identified Needs

Insights from stakeholder interviews, market analysis and observations were compiled into a stakeholder needs list. The identified needs describe what the product must achieve without specifying how the solution should be designed. The resulting list covers both functional performance and mechanical design aspects of the sensor, including reliability, durability, ease of installation and maintenance, and proper integration with the awning. All identified needs are presented in Table 4.1 and were later translated into a requirement specification with measurable requirements.

Table 4.1: Identified stakeholder needs used to guide concept development and requirement specification.

No.	Requirement / Desirable Feature	Need
Reliability		
1	Requirement	Protect the sunshade from damage caused by wind and sudden or unpredictable weather conditions, with or without user presence
2	Desirable	Ensure that single-point failures do not increase the risk of sunshade damage
3	Requirement	Provide reliable protection performance over long periods of time
4	Desirable	Maintain functional performance under long-term outdoor environmental exposure
5	Requirement	Withstand different weather conditions and climate
6	Desirable	Increase likelihood of the awning being used
7	Desirable	The sensor should be perceived as robust
Maintenance and Service		
8	Desirable	The risk of damage during handling or maintenance of the sensor should be minimized
9	Desirable	Require minimal service and maintenance
Installation		
10	Required	Remain securely attached once installed
11	Required	Support deployment across a wide range of sunshade geometries and configurations
12	Desirable	Minimize installation effort and complexity
13	Required	Maintain the sunshade's original mechanical operation
Control		
14	Desirable	Balance protective actions with normal usability to avoid unnecessary loss of comfort or availability
15	Desirable	Avoid unnecessarily prolonged restriction of sunshade operation after protective actions
16	Required	Retain protective functionality regardless of manual or automated operation
User interface		
17	Desirable	Easy to configure correctly by installers
Aesthetics		
18	Desirable	The overall visual appeal of the sunshade product is not negatively affected
Market & Ecosystem		
19	Desirable	Provide value relative to added cost to motivate customer adoption
20	Desirable	Provide a compelling commercial case for retailers and installers to recommend the system
21	Desirable	Fit within prevailing installation practices in the target market
22	Desirable	Avoid triggering additional or uncommon regulatory and certification requirements

4.3 SWOT Analysis

Based on the identified stakeholder and customer needs, together with insights from competitor benchmarking, patent analysis, interviews and observations, a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis (Benzaghta et al., 2021) was conducted to summarize recurring strengths, weaknesses, opportunities and threats related to existing vibration sensors. The results are summarized in Figure 4.1 and were used, together with the identified needs, to support the formulation of the requirement specification.

Strengths	Weaknesses
• Acts as a safety mechanism for awning • Cost-effective insurance relative to awning price • No external wiring required • Discrete placement • Effective against sudden gusts • Simple and fast programming • Safety-oriented fail behavior • Effective against sudden gusts	• Not durable enough for outdoor use (susceptible to moisture, corrosion, and battery wear) • Short battery life and dependency (leads to higher maintenance and service needs) • Low trust in reliability and durability • Limited functional scope • Challenging to operate reliably in real-world conditions • Limited placement options (may collide with awning arms or have tight space constraints) • No robust mounting solution • Aesthetic and design limitations (size, visibility, and color may affect overall appearance)
Opportunities	Threats
• Longer battery life • Design integration into awning profiles • More user feedback/alerts • Possibility of hiding sensor or making more aesthetically pleasing • Increased demand due to more strict environmental regulations/laws • Growing demand for automation and smart shading • Improved technology could reposition the category • Self-powered or hybrid energy solutions • Integrated sensor solutions • System-level solutions for installers • Collaboration with awning manufacturers for better mounting solutions • Standardization across awning brands • Data driven maintenance insights for manufacturer/installers • Partnerships to pre-install sensors	• Sensor integration in motors • Wind sensor used instead • Support feet/legs used instead • Wall mounted pergola gaining larger marketshare • Awnings getting out of fashion • Awnings getting strong enough to handle strong winds/ weather conditions • Strong substitution by wind sensors and sun/wind combinations • Negative installer experiences damage category reputation • Environmental exposure in harsh climates • Customer misuse and misunderstanding • Technological lock-in and incompatibility • Risk of being perceived as outdated technology • Price pressure from low-cost generic sensors • Liability risk if sensor fails and damage occurs • Limited functionality may drive customers to alternative products

Figure 4.1: SWOT Analysis of Existing Vibration Sensors.

4.4 Requirement Specification

The stakeholder needs list was translated into measurable and verifiable technical requirements through a requirement specification. The specification was used throughout the development process to ensure that the identified needs were addressed and that the final product could be evaluated against defined criteria. It covered both physical design and functional performance aspects, with each requirement assigned values to support evaluation and validation. The requirements were also classified as demands or wishes to distinguish essential requirements from desirable features. The requirements related to the physical design are summarized in Table 4.2. The complete requirement specification, which also includes broader sensor-related requirements, is presented in Appendix D, Table D.1.

Table 4.2: Technical requirements for the sensor housing and mounting system.

	Criteria	Value	Unit	Type of requirement	Demand/Wish	Importance	Verification method	Justification
	Function(s)							
1	Reliability							
1.1	The sensor housing shall protect internal components from corrosion and prevent rust formation during intended outdoor use	Yes	-	Non-functional requirement	Demand	High	Analysis + test	Reduces risk of failure due to corrosion during long-term outdoor exposure
1.2	The sensor shall maintain protective functionality within the temperature range relevant to intended outdoor use.	-30 to 60	°C	Non-functional requirement	Demand	High	Analysis + test	Outdoor installation exposes the sensor to low and high temperatures that must not prevent protective functionality.
1.3	Components exposed to sunlight shall withstand UV exposure during intended outdoor use without loss of functionality	Yes	-	Non-functional requirement	Demand	High	Analysis + material selection	Outdoor exposure to sunlight may degrade materials over time
1.4	The sensor shall be protected against water and dust ingress	IP44	-	Non-functional requirement	Demand	High	Testing according to IP standard (IEC 60529)	Outdoor installation exposes the sensor to water and particles, so ingress protection is required to preserve functionality and protect internal components
2	Maintenance and Service							
2.1	The sensor shall withstand repeated opening and closing during installation and service without functional degradation	≥ 20	Cycles	Non-functional requirement	Demand	Medium	Test	Ensures durability during installation and maintenance, including battery replacement
2.2	The sensor shall withstand repeated mounting and removal from the mounting plate without functional degradation	≥ 100	Cycles	Non-functional requirement	Demand	Medium/High	Test	Ensures durability during installation, maintenance and potential repositioning
2.3	The sensor shall allow easy battery replacement, without damaging the product	Yes	-	Functional requirement	Demand	High	Test	Battery replacement is expected during the product lifetime and should be possible without requiring installer time or added service cost
3	Installation							
3.1	The sensor shall remain securely attached once installed under normal operational and environmental loads	Yes	-	Non-functional requirement	Demand	High	Test	Loss of attachment would compromise protective functionality and could damage the product or awning
3.2	The sensor shall be installable on a wide range of sunshade configurations without modification of the sunshade	Yes	-	Non-functional requirement	Wish	High	Test	Enables installation without modifying the sunshade, reducing installation effort and complexity
3.3	The mounting plate shall allow efficient mounting on the awning by professional installers	Yes	-	Non-functional requirement	Demand	High	Test	Efficient installation reduces labor time, cost, and installation complexity for professional installers
3.4	The system shall not hinder or alter the sunshade's original mechanical operation	Yes	-	Constraint	Demand	High	Inspection + test	The sensor must not interfere with normal awning movement or compromise the original mechanical functionality of the sunshade
4	Aesthetic							
4.1	The sensor should match the most common colors of sunshade profiles	Black/Grey/White	-	Non-functional requirement	Wish	Medium	Inspection	Color compatibility helps the sensor blend with common awning designs and reduces visual intrusion
4.2	The sensor should not visibly degrade the perceived aesthetic quality of the installed sunshade	Yes	-	Non-functional requirement	Wish	Medium	Inspection (subjective evaluation)	Preserves the overall appearance and visual quality of the installed sunshade
4.3	The product shall follow the company's design guidelines and visual identity	Yes	-	Non-functional requirement	Wish	Medium	Inspection (subjective evaluation)	Ensures consistency with brand identity and existing product portfolio
5	Market & Ecosystem							
5.1	The manufacturing cost should allow competitive product pricing	≤ X	SEK	Business requirement	Wish	High	Analysis	Competitive pricing is necessary for market acceptance and commercial viability
6	Environment							
6.1	The sensor should be designed to minimize environmental impact over its life cycle, including consideration of material sustainability and end-of-life recyclability	Yes	-	Environmental requirement	Wish	Medium	Analysis	Reduces environmental impact and supports sustainable product development over the product life cycle

During the early stages of the project, precise values could not be defined for all criteria. The requirement specification was therefore continuously updated throughout the development process to support trade-offs and refinement of the design. The specification also provided a basis for concept evaluation and verification during testing.

5

Concept Development

This chapter presents the concept development phase, including generation, screening, scoring and testing of potential solutions for the sensor housing and mounting system. These activities supported the selection of concepts for continued development.

5.1 Concept Generation

The concept generation phase focused on developing a range of potential solutions for the sensor housing and mounting system. Function analysis, brainstorming and sketching were used to develop sub-solutions for different product functions. A morphological matrix was subsequently used to organize and combine the sub-solutions into complete concepts for further evaluation.

5.1.1 Function Analysis

Function analysis (Gama, 2004) was used to identify and structure the product's main function and sub-functions. By focusing on what the product needed to achieve rather than on specific technical solutions, the method provided a structured basis for later concept generation and reduced the risk of focusing too early on initial solutions. The functions were identified based on needs from interviews, observations and market analysis to understand how the product should function and improve upon existing solutions.

A hierarchical function tree was created to visualize the identified functions (see Figure 5.1), with the main function representing the overall purpose of the product and the sub-functions arranged below to describe functions supporting its implementation. The main function was divided into two sub-functions: "Detect and react to wind" describing the functional operation of the sensor, and "Provide physical product architecture", relating to the physical design, housing and integration of the sensor.

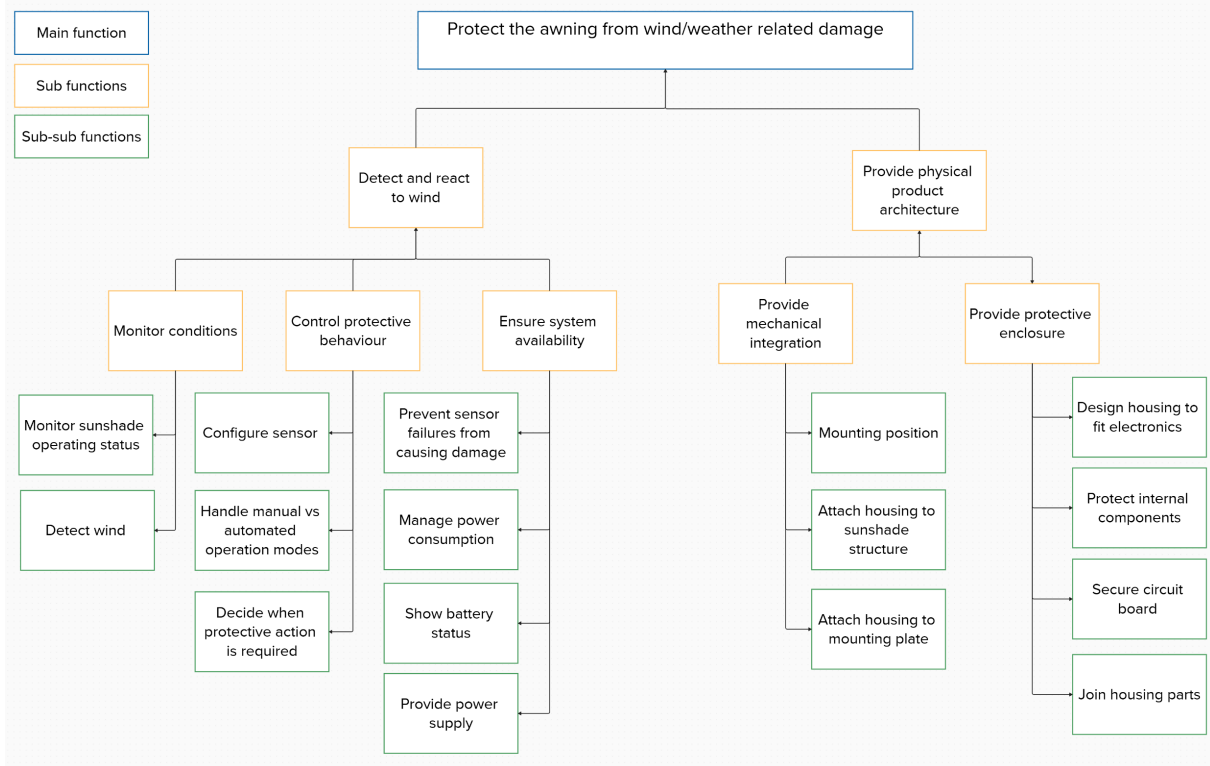


Figure 5.1: Function tree illustrating the main function and sub-functions.

5.1.2 Battery Selection and Trade-offs

Different power supply solutions were considered, including battery-powered, solar-powered and wired alternatives. Wired solutions were considered unsuitable as they would require cables to follow the awning structure, increasing installation complexity, visual impact and risk of mechanical wear. Solar-powered solutions were also considered inappropriate, since the sensor may receive limited and inconsistent sunlight, leading to an unreliable energy supply. Battery-powered solutions were therefore selected for further development due to their simplicity, independence and ease of integration.

Battery choice affects operational lifetime, size and reliability in outdoor conditions. Several standardized battery types were evaluated based on voltage, capacity, temperature range, size and cost to identify a suitable balance between energy capacity, integration and environmental performance. The comparison is summarized in Appendix E, Table E.1. Operating temperature was considered important for outdoor use, since alkaline and zinc-carbon batteries typically operate down to around 0°C , making them less suitable for colder climates. Lithium batteries provide a wider temperature range, typically down to approximately -30°C to -40°C , and were therefore considered more suitable for this application. Capacity was also important, as it directly affects operational lifetime and maintenance intervals. Larger batteries, such as AA, generally provide higher capacity than AAA and coin cells, reducing the need for frequent replacement. Although smaller batteries enable more compact integration, the increased size of an AA battery was considered acceptable due to its improved reliability and longer replacement interval.

Based on this comparison, the AA/FR6 lithium battery was selected due to its wide temperature range, high capacity and availability. To ensure that the correct battery type is used during replacement, this recommendation should be clearly communicated to the user, through markings inside the battery compartment and in the product documentation. This helps reduce the risk of incorrect battery replacement and supports reliable operation in outdoor environments.

5.1.3 Brainstorming and Generation of Sub-solutions

Based on the function tree (see Figure 5.1), sub-solutions for each sub-function were generated using both brainstorming and brainwriting methods (Litcanu et al., 2015), which were iterated multiple times to refine and expand the ideas. The focus was on the mechanical design of the sensor and therefore only functions related to the housing and mounting were considered at this stage. Solutions for the rest of the system, including functions related to how the sensor operates, will be addressed later in the process. In total, seven specific sub-functions were targeted for idea generation:

- **Attach housing to sunshade structure** - How the sensor is attached to the sunshade structure.
- **Mounting position** - Where on the sunshade the sensor should be positioned.
- **Attach housing to mounting plate** - The sensor may consist of different parts, a housing that is attached to a mounting plate, which in turn is mounted on the sunshade.
- **Design housing to fit electronics** - How the internal electronics should be arranged within the housing.
- **Protect internal components** - How the sensor should be sealed to protect internal components from environmental exposure.
- **Secure circuit board** - How the circuit board should be fixed inside the housing.
- **Join housing parts** - How the housing parts should be assembled.

For each sub-function, multiple potential solution principles were identified and explored to ensure a broad range of options for subsequent concept development. In the next step of the process, the sub-solutions will be presented and combined to form complete solutions.

5.1.4 Morphological Matrix

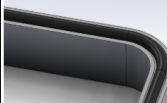
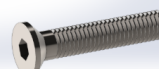
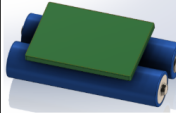
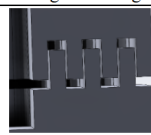
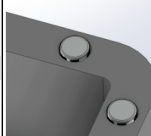
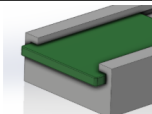
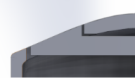
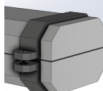
A morphological matrix was created to systematically explore potential solutions by combining sub-solution for different sub-functions, following the concept combination approach described by Ulrich et al. (2020). The matrix was developed using the Morpheus tool (Bonde, 2026) and combines sub-solutions for each of the seven sub-functions into complete concepts. The complete morphological matrix is shown in Appendix F, Table F.1.

Initially, combining all sub-solutions resulted in several million concepts, which was impractical. To reduce this number, incompatible and unsuitable sub-solutions were identified and removed. Permanent solutions were also excluded to avoid modifying the awning, such as through glue, screws or drilling into the profile. Sub-solutions compatible with only a few awning products were also removed. Despite these reductions, the number of concepts remained too high. The following sub-functions were therefore excluded from the morphological matrix, since all sub-solutions were compatible with each other:

- Attach housing to sunshade structure
- Mounting position
- Attach housing to mounting plate

Excluding these sub-functions required an alternative approach for later concept selection, as discussed in Sections 5.4.2 – 5.4.4. The matrix resulted in 72 concepts, which was manageable for the next step. CAD models were created to support visualization and assessment (see Table 5.1).

Table 5.1: Reduced Morphological matrix after excluding selected sub-functions.

Sub-Functions		Design housing to fit electronics	Protect internal components	Secure circuit board	Join housing parts
Sub-Solutions	1	 Batteries side by side	 O-ring/Silicone gasket	 Screws	 Screws
	2	 Batteries below or on top of circuit board	 Multi flange seal with several overlapping flanges on both halves.	 Snap-fit clips along edges of board	 Magnet
	3			 Slots along housing that the board slides into	 Twist locks
	4				 Latches
	5				 Slide and lock rails
	6				 External clamping ring

5.1.5 Concept Catalog

All generated concepts were compiled into a concept catalog, which is presented in Appendix G (Figures G.1 and G.2). The catalog includes all combinations of sub-functions and sub-solutions generated from the reduced morphological matrix. The purpose of the concept catalog was to provide a structured overview of all generated concepts.

5.2 Concept Screening

Of the 72 generated concepts, a structured concept screening process was carried out to systematically reduce the number of solutions based on defined criteria. An Elimination Matrix was used to remove concepts that did not satisfy the key requirements, after which the remaining concepts were evaluated using multiple Pugh Matrices. This supported a structured and objective evaluation process and helped identify the most promising concepts for further development.

5.2.1 Elimination Matrix

All 72 concepts were compiled in an elimination matrix for systematic evaluation against selected criteria from the requirement specification (Pahl & Beitz, 1996). The elimination matrix enabled a systematic screening of the concepts and ensured that only the most promising alternatives proceeded to the next stage. The elimination criteria were defined to assess the concepts derived from the reduced morphological matrix, while the excluded sub-functions were evaluated separately in Sections 5.4.2 – 5.4.4. The criteria were selected to ensure that the remaining concepts met key requirements. The criteria used in the elimination matrix were:

- **Perceived as robust** - The concept should give an impression of robustness and durability to maintain user trust and perceived quality.
- **Weather resistance** - Since the sensor is mounted outdoors, it should withstand environmental exposure such as moisture, rain and salt.
- **Tolerate normal handling during installation and service** - The design should withstand normal mechanical loads during installation, maintenance and handling without being easily damaged.
- **Easy to handle** - The concept should be easy for installers and users to handle without requiring complicated procedures or special tools.
- **Not hinder the sunshade's original mechanical operation** - The solution must not interfere with the normal mechanical movement or operation of the sunshade.
- **Not degrading visual aesthetics** - Since the sensor is visible on the awning, the concept should not negatively affect the overall appearance.

Concepts failing one or more criteria were eliminated, with reasons documented in the matrix to ensure transparency. Concepts meeting all criteria proceeded, while some uncertain cases were retained for further evaluation. The complete elimination matrix is presented in Appendix H, Table H.1. In total, 28 of the 72 concepts were selected for the next stage.

5.2.2 Pugh Matrix

The remaining 28 concepts were evaluated using the Pugh matrix method (Ulrich et al., 2020). Three iterations were conducted to reduce bias from the initial reference and allow comparison from different perspectives, using the evaluation criteria defined below:

- **Weather resistance:** Ability to withstand environmental exposure such as moisture, water and salt.
- **Cost:** Expected manufacturing cost and its impact on overall product cost.
- **Ease of use:** Ease of handling during maintenance and interaction during operation.
- **Durability:** Expected lifetime and resistance to wear or failure.
- **Perceived robustness:** How strong and stable the concept appears, and its ability to withstand loads and handling.

In the first iteration, Concept 72 was used as the reference, with Concepts 24, 36 and 60 scoring highest but showing high similarity. To enable a more varied comparison, Concept 47 and another high-performing concept were used as references in the following iterations. The complete Pugh matrices are presented in Appendix I, Figures I.1–I.3. To summarize the results, a matrix combining all concepts and scores from the three iterations was created, including totals and evaluation comments. High-scoring concepts were selected for further development, while lower-scoring ones were eliminated. Similar concepts were reduced to one representative to ensure variation. In total, seven concepts progressed to the next stage. A full overview is presented in Table I.4 in Appendix I.

5.3 Concept Scoring

After the concept screening phase, the remaining concepts were evaluated in more detail through a concept scoring process. The aim was to systematically compare and rank the concepts based on weighted criteria derived from the requirement specification, see Table 4.2.

5.3.1 Kesselring Matrix

To further evaluate the remaining concepts, Kesselring matrices were applied as a weighted scoring method, following the general concept scoring approach described by Ulrich et al. (2020). Seven concepts (31, 34, 36, 63, 68, 71 and 72) were evaluated using criteria

derived from the requirement specification, including weather resistance, aesthetics, cost, ease of use, durability and perceived robustness. Criterion importance was determined using pairwise comparison matrices (McBride, 2022), where the criteria were compared in pairs to establish rankings and weights. Separate matrices were created for different stakeholder perspectives, including the project team, company priorities and installer input. The matrices are presented in Appendix J, Figure J.1.

In the Kesselring matrices, each concept was rated from 1 (best) to 5 (worst) for each criterion, and the ratings were multiplied by the corresponding weights to obtain weighted scores. Since the weights differed between stakeholders, separate matrices resulted in different rankings. A combined Kesselring matrix based on averaged stakeholder values is presented in Appendix K, Table K.1, while the detailed rankings for each perspective are shown in Table K.2. Based on the combined Kesselring matrix results, Concepts 36 and 72 achieved the highest rankings and were selected for continued development together with Concepts 34, 63 and 68, while Concepts 71 and 31 were excluded.

5.4 Concept Testing

Based on the concept scoring results, the remaining concepts were modeled in CAD, 3D-printed and evaluated through visual and practical assessments of design, functionality and integration. The evaluation also included solutions for attaching the housing to the mounting plate and attach the mountingplate to the awning. The evaluation aimed to identify strengths, weaknesses and potential improvements in the concepts, supporting the selection of the most suitable solutions for continued development and prototyping.

5.4.1 Evaluation of Selected Concepts

The selected concepts were further developed in CAD for detailed visualization and evaluation (Figure 5.2). To minimize product height and overall build volume, the AA batteries were placed alongside the circuit board, leading to a modification of Concept 34. Concept 36 was excluded due to its similarity to Concept 72. An overview of the implemented sub-solutions are presented in Table 5.2.

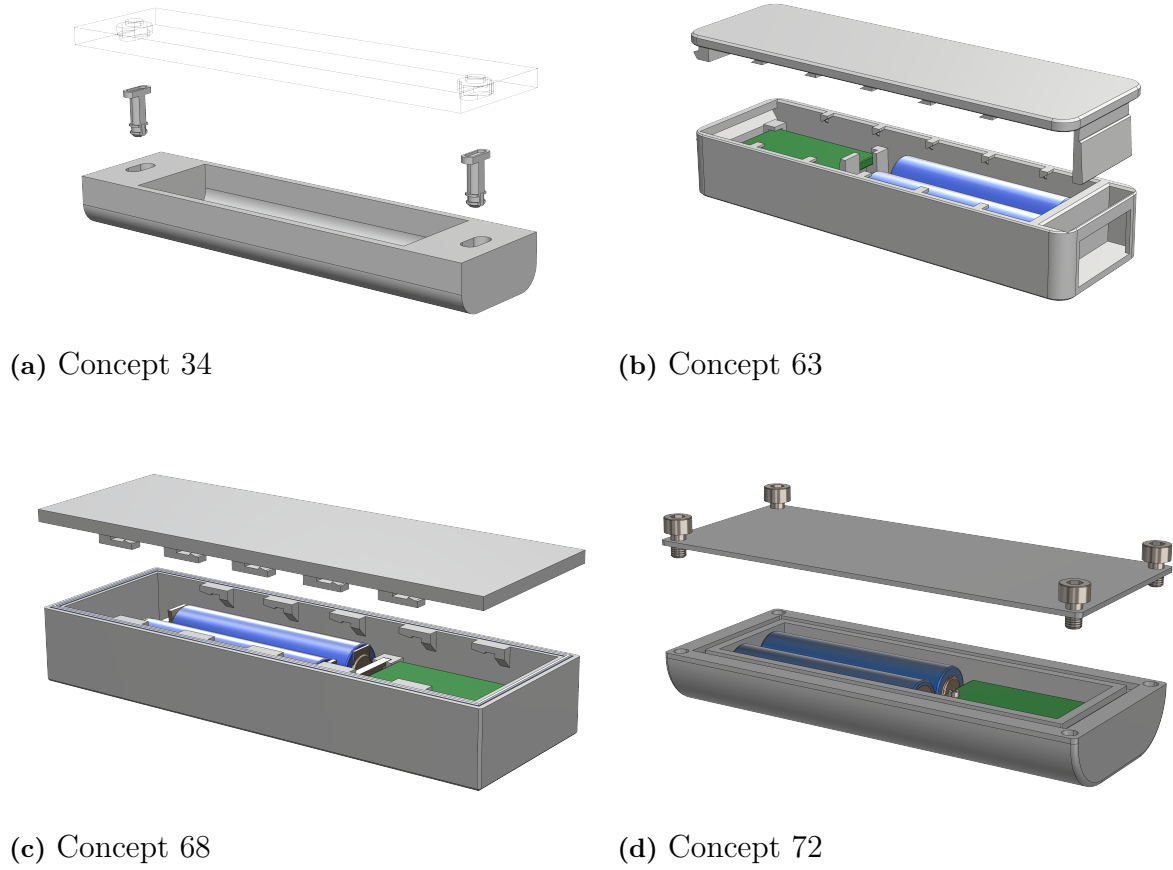


Figure 5.2: CAD models of four selected concept variants developed during the concept generation phase.

Table 5.2: Overview of implemented sub-solutions in the evaluated concepts.

Concept	Design housing to fit electronics	Protect internal components	Secure circuit board	Join housing parts
34	Batteries side by side	O-ring / gasket	Screws	Twist locks
63	Batteries side by side	O-ring / gasket	Snap-fit clips	Latches
68	Batteries side by side	O-ring / gasket	Screws	Slide and lock rails
72	Batteries side by side	O-ring / gasket	Screws	Screws

The four remaining concepts were evaluated based on usability, sealing performance, manufacturability and robustness. Concept 34 improved sealing and aesthetics through hidden fastening, but increased manufacturing complexity. Concepts 63 and 68 enabled tool-free operation, although both introduced challenges related to sealing, durability and manufacturability. Concept 72 provided the most robust and reliable sealing solution through screw fastening, at the cost of reduced accessibility and longer opening time. A more detailed evaluation of each concept is presented in Appendix L.

Final Selection

Based on concept evaluation and testing of 3D-printed prototypes, Concept 72 and a modified concept combining the screw solution from Concept 72 with the hook feature from Concept 63 were selected for further evaluation. The combined concept aimed to retain the reliable sealing performance of the screw-based design while improving usability. Several design variations of screw placement and hook geometry were developed in CAD and evaluated through physical assembly, handling and screw-tightening tests to assess pressure distribution and sealing performance. The evaluation showed that configurations using two screws provided the most even pressure distribution and best sealing performance. As a result, Concept 72 was selected as the final design. The evaluated design variations are presented in Appendix M.

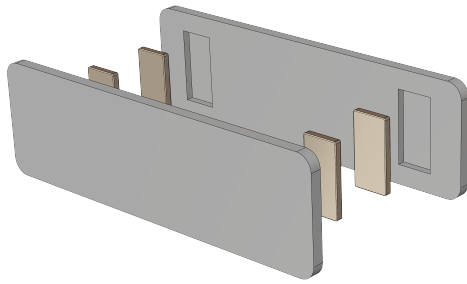
5.4.2 Attach Housing to Mounting Plate

The sub-function of attaching the housing to the mounting plate was initially removed from the morphological matrix due to the large number of resulting concept combinations and was instead evaluated separately. A mounting plate is used as an interface between the awning and the sensor, where the sensor attaches to the plate and the plate to the awning. This solution was selected as it simplifies sealing of the housing. A key requirement was that the housing should be removable from the mounting plate, otherwise the plate would serve no purpose. The evaluation and decision on whether the sub-solutions identified in the morphological matrix should be retained or discarded are presented in Table 5.3.

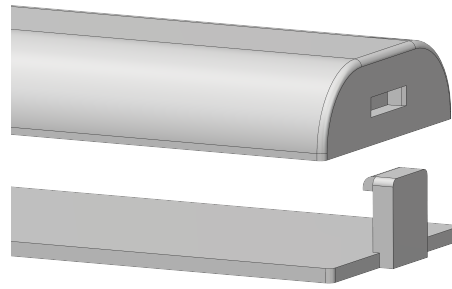
Table 5.3: Evaluation of sub-solutions for attaching the housing to the mounting plate.

Solution	Evaluation	Decision
Screws	Considered unnecessary. If screws were used, the housing could be attached directly to the awning, making the mounting plate redundant. Tool-free removal was preferred.	Discarded
Magnet	Considered a promising solution, enables quick attachment and removal while still providing sufficient holding force.	Retained
Tape	Creates a permanent joint between the housing and mounting plate, preventing easy removal of the housing.	Discarded
Snap joint	Considered suitable as it can provide a secure connection while still allowing disassembly if designed properly.	Retained
Slide joint	Retained as it can provide a stable connection and guide the housing into the correct position during assembly.	Retained
Threaded joint	Considered less suitable. A bayonet-type rotational locking solution was considered more appropriate.	Discarded
Bayonet	Selected as the preferred rotational locking solution	Retained

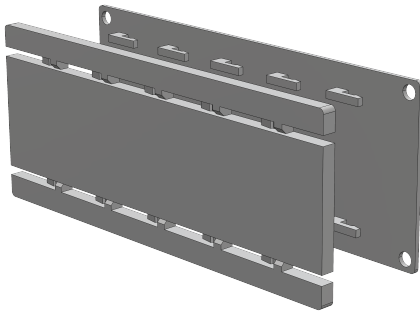
Based on the evaluation, four attachment principles were selected for further development: magnetic attachment, snap joint, slide joint, and bayonet mount. Screw, tape, and threaded solutions were excluded. CAD models were developed to visualize and assess feasibility, and 3D-printed prototypes were used for physical testing. The retained concepts are shown in Figures 5.3a–5.3d.



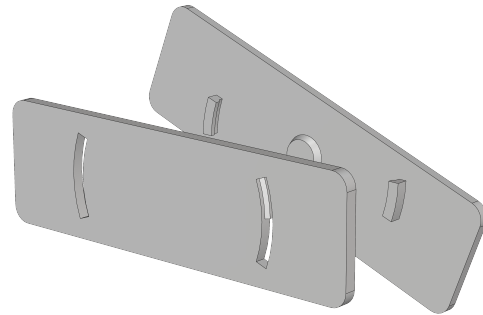
(a) Magnetic attachment



(b) Snap joint



(c) Slide joint



(d) Bayonet joint

Figure 5.3: CAD models of attachment mechanisms between the mounting plate and the housing.

The magnetic attachment was easy to use but raised concerns regarding holding strength, cost and environmental impact. The snap joint risked wear and breakage of plastic features and included visible side components. The slide joint provided a hidden connection but was considered more difficult to manufacture and protruding parts could break easily.

Final selection

Based on evaluation of the attachment methods and testing of 3D-printed prototypes, the bayonet solution was selected for attaching the sensor housing to the mounting plate. The mechanism provided a concealed and compact design while offering a good balance between secure attachment, robustness and ease of use. Overall, the bayonet solution was considered the best compromise between functionality, robustness and design integration.

5.4.3 Attachment to the Awning

Another sub-function removed from the morphological matrix due to the large number of resulting combinations was ‘Attach housing to sunshade structure’. The sub-solutions identified for this function were evaluated separately and the results are presented in Table 5.4.

Table 5.4: Evaluation of attachment solutions between the mounting plate and the awning.

Solution	Evaluation	Decision
Clamps/straps	Unsuitable due to poor aesthetics and impracticality, as it cannot be routed around the front bar	Discarded
T-nuts and screws	Considered compatible with most awnings.	Retained
Steel plate with magnets	Unnecessary since the housing is already removable.	Discarded
Tape/Glue	Creates a permanent joint between the mounting plate and the awning, tape may serve as a secondary option.	Discarded
Adapter brackets	Allowed flexible positioning but depended heavily on slot location or required adjustability.	Discarded

Based on the evaluation, T-nuts and screws were selected as the preferred solution while the other alternatives were discarded due to limitations in aesthetics, compatibility or functionality. The solution uses existing T-slots in the awning profile by fastening the mounting plate with T-slot nuts and screws. During installation, the screws are inserted through the slots in the mounting plate and into the T-nuts. The mounting plate is then held against the T-slot while tightening the screws, causing the T-nuts to rotate and clamp against the flanges of the T-slot, as illustrated in Figure 9.6. This approach was also considered compatible with most awnings, provided the slot geometry is not significantly different. If the slot cannot be used, the mounting plate can instead be attached by creating threaded holes or using self-tapping screws into the awning profile.

5.4.4 Mounting Position

Another sub-function removed from the morphological matrix due to the large number of resulting concept combinations was the mounting position, meaning where on the awning the sensor should be placed. The evaluated mounting positions and corresponding decisions are presented in Table 5.5.

Table 5.5: Evaluation of mounting positions on the awning.

Solution	Evaluation	Decision
Inside of the front bar	Considered a reliable alternative with low risk of obstruction.	Retained
Under the front bar	Allows mounting in existing slots without interfering with awning movement	Retained
On the awning arm	Risk of interfering with arm movement and may transfer vibrations less consistently	Discarded
Awning fabric	Could restrict movement and would need to be placed on the outer layer when stowed.	Discarded
Outside of the front bar	More exposed and may negatively affect aesthetics.	Discarded
End cap	End cap is often obstructed when stowed.	Discarded

The sensor is assumed to function in any orientation, allowing flexible placement. However, the selection was constrained by the decision to utilize existing T-slots in the awning profile. These slots are typically located on the inside of the front bar or underneath it and in some cases both positions are available. Since T-slot mounting is preferred, the inside of the front bar is considered the primary position. If space is limited, alternative positions can be used, prioritizing existing slots without interfering with the awning's motion. When multiple slot positions are available, the mounting location should be selected based on available space and level of protection. If no slot is available, screws can be inserted directly into the awning profile in which case the outside of the front bar also becomes an option. But the inner side of the front bar should still be prioritized if there is available space for the sensor. To maximize vibration amplitude, the sensor should be mounted as far out from the wall as possible.

6

System-Level Design

This chapter presents the system-level design of the selected concept. The chapter defines the system boundary, main subsystems and interfaces of the vibration sensor, providing a basis for the following detail design.

6.1 System Overview

After the main mechanical concept had been selected, a simplified system-level approach was used to define the overall system and its functionality. Since the project primarily focused on the mechanical design of the sensor, the purpose was not to evaluate all possible system configurations in detail, but to identify the sub-functions and interfaces needed to support the continued development of the housing and mounting system. The most relevant sub-solutions for each sub-function were therefore selected based on qualitative assessment, project requirements and compatibility with the selected concept.

This approach also allowed flexibility, as some sub-functions require combinations of solutions rather than a single solution. Interviews indicated limitations in current sensor functionality and highlighted areas for improvement, which motivated the need to consider the overall system context even though electronics and software development were outside the main scope of the project. The system-level overview therefore reduced unnecessary complexity while keeping the focus on the mechanical design. The identified sub-functions related to the overall system are listed below and are based on the function tree introduced during concept generation, see Figure 5.1.

- **Detect wind:**
Detects the presence of wind acting on the awning.
- **Monitor the operating status of the sunshade:**
Determines whether the sunshade is currently deployed. This allows the system to operate only when needed, reducing unnecessary power consumption.
- **Decide when protective action is required:**
Evaluates sensor input to determine when protective action is needed, such as retracting the awning when excessive vibrations are detected.
- **Handle manual vs automated operation modes:**
Manages the operation mode of the system, allowing different behavior depending on whether the awning is operated manually or automatically.
- **Configure the sensor:**
Enables configuration of the sensor, such as adjusting settings and parameters through a suitable interface.

- **Provide power supply:**
Supplies electrical power to the system to enable operation.
- **Indicate battery status:**
The system provides information about battery level to inform the user when replacement is required.
- **Manage power consumption:**
Controls power usage to maximize battery lifetime.
- **Prevent sensor failures from causing damage:**
Ensures that sensor failures do not lead to unsafe conditions or damage to the awning.

6.1.1 Sub-Solutions

Several sub-solutions were identified for each sub-function. All considered sub-solutions can be found in Appendix N, while the selected sub-solutions are presented in Table 6.1.

Table 6.1: Selected sub-solutions for the identified system sub-functions.

Sub Function	Sub Solution					
A. Architecture choices						
Detect wind	Accelerometer					
Configure sensor	Adjustable threshold via app/software					
Provide power supply	Batteries					
B. Preferred design principles						
Monitor sunshade operating status	The control system sends a signal when the awning is extending/retracting	The sensor detects wind and infers deployment				
Decide when protective action is required	Gust-based triggering from sudden acceleration	Time above threshold	Context-based thresholds (rain, freezing, user control)			
Handle manual vs automated operation modes	Priority hierarchy (Safety > Local > Remote/App)	Automatic fallback on fault or loss of communication				
Prevent sensor failures from causing damage	Fail-safe (awning stowed if uncertain data)	Fault detection (watchdog, self-tests, power failure detection)				
Indicate battery status	Mobile app	Indication via awning movement				
C. Later embodiment decisions						
Manage power consumption	Deep sleep with periodic wake-ups	Interrupt-driven wake	Adaptive sampling during wind	Communication minimization	Temperature-adjusted strategy	Hardware power gating

Several sub-functions were found to have multiple sub-solutions that perform best when combined. In Table 6.1, the sub-functions are therefore grouped into three categories: architecture-defining choices, preferred design principles, and later embodiment decisions. The sub-function related to power consumption was considered difficult to fully define at this stage and is instead intended to be addressed during circuit board design. The architecture-defining choices are proposed as the main system-level decisions, with the possible addition of physical buttons for sensor configuration alongside the app-based interface. The preferred design principles represent selected and in some cases, merged solutions from Appendix N, serving as recommended approaches for the corresponding

sub-functions. These may be revised or removed later if deemed unnecessary or if better solutions emerge. Changes are also easier to implement when the function is primarily handled through firmware.

6.2 System Architecture

The system architecture defines the overall system boundary, the main subsystems of the vibration sensor and the most important interfaces within the product and to the surrounding products. The selected concept was organized into a structured architecture to clarify how the sensor functions as part of the awning protection system and to provide a basis for the following detail design.

A simplified system architecture is shown in Figure 6.1. The figure shows the main subsystems and interfaces relevant to the selected concept. More detailed architectural diagrams, including the surrounding products, are provided in Appendix O, Figures O.1–O.4. Since the appendix figures are more detailed, the figure in this section is intentionally simplified to focus only on the most important physical elements and interactions.

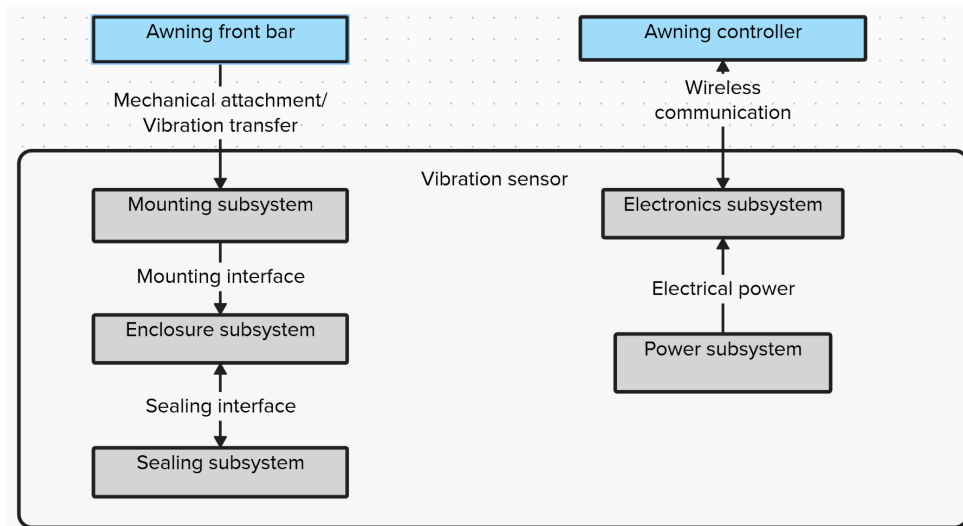


Figure 6.1: Simplified system architecture.

At a system level, the vibration sensor was treated as part of an integrated awning protection system. In the simplified system architecture, only the vibration sensor and the products directly connected to it were included: the awning and the awning controller. The awning provides the physical structure to which the sensor is attached and from which vibrations are transferred. The awning controller communicates wirelessly with the sensor. These three elements were included to describe the main physical and information interactions relevant to the function of the sensor.

User interaction through a phone app or other interface is included as part of the broader control system shown in Appendix O, Figures O.1–O.4, but is excluded from this simplified system architecture since the phone app does not normally communicate directly with the sensor. The awning forms the mechanical context of the system and provides the physical structure from which vibrations are transferred to the sensor, as well as the structure

to which the sensor is attached using existing slots, if available. The awning controller transmits and receives wireless information to and from the sensor, which is used to support decisions on when the awning should be retracted to reduce the risk of damage.

6.3 Product Architecture

The product architecture of the vibration sensor was defined by dividing the product into subsystems with distinct responsibilities. At this level, the sensor consists of a mounting, enclosure, electronics, power and sealing subsystem. This decomposition clarifies how the selected concept can be realized as a complete product while maintaining a system-level perspective rather than focusing on detailed design. The architecture also defines the key interactions between these subsystems. The product architecture is shown in Appendix O, Figure O.4.

The mounting subsystem consists of the mounting plate, T-slot nuts and screws used to attach the sensor and transfer vibrations from the awning structure. The enclosure subsystem includes the housing halves and screws, protecting internal components and defining the outer shape and interfaces with the sealing, mounting, power and electronics subsystems. The sealing subsystem consists of a gasket that reduces the risk of moisture reaching the electronics. The power subsystem includes the batteries and contacts supplying electrical power, while the electronics subsystem consists of the circuit board and components, interfacing with the housing and communicating wirelessly with the awning controller.

7

Detail Design

This chapter presents the detailed design of the developed concept, including geometry, material selection and design decisions related to manufacturability, assembly and compatibility with different awning systems.

7.1 Final Concept

The final concept, shown as an exploded view in Figure 7.1, consists of a two-part housing closed using two screws, a gasket placed between the housing halves for sealing and a mounting plate connected to the housing using a bayonet mechanism. The mounting plate is attached to the awning using two screws and T-slot nuts inserted into the existing slot of the awning profile. Inside the housing, space is provided for a circuit board and two AA batteries positioned next to the circuit board.

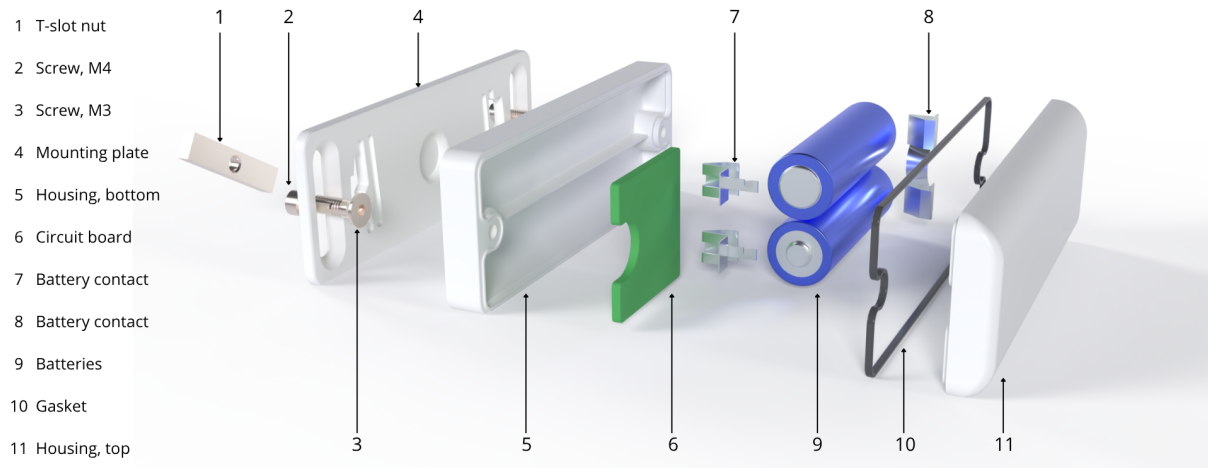


Figure 7.1: Exploded view showing the components of the final housing and mounting system.

7.2 Compatibility with Different Awning Systems

Since the attachment solution is based on fastening the sensor to the existing T-slots of the awning using T-slot nuts and screws, existing T-slot profile geometries were investigated through measurements and comparison of multiple awning profiles. The collected dimensions and observations were used as the basis for dimensioning the custom T-slot nuts to fit a wide range of existing awning profiles. In addition, the mounting plate was developed with slotted screw holes, allowing vertical adjustment when mounted against the T-slot. The overall design was also developed to be as compact as possible to simplify integration with different awning geometries and limited installation spaces.

7.2.1 Design of T-slot nuts

Following the selection of T-nuts and screws as the attachment solution, as described in Section 5.4.3, T-slot profile geometries from different awning brands and models were investigated to ensure compatibility with a wide range of awnings. Variations in profile dimensions were considered in the design of the t-nuts. Detailed geometry definitions and measured dimensions are presented in Appendix P.

Based on measurements of T-slot profiles from different awning systems, a t-slot nut was developed to ensure compatibility with varying slot geometries. Different geometries, dimensions and materials were evaluated through competitor analysis and physical testing. A rectangular geometry was selected due to its simple manufacturing and efficient use of space, while steel was chosen to provide sufficient stiffness and prevent deformation during tightening. The dimensions were selected to balance compatibility, strength and secure locking within the slot. A width of 6 mm was determined to provide the best compromise between compatibility with narrow slots and sufficient structural strength. The final design was also dimensioned with a length of approximately 30 mm and a thickness of 3 mm. Detailed evaluations of geometries, dimensions, materials and physical testing that formed the basis for the final dimensioning are presented in Appendix Q.

7.2.2 Adjustable Mounting Plate Design

The mounting plate was designed to allow vertical adjustment of the sensor position, as shown in Figure 7.2. The elongated mounting holes enable adjustment of the sensor height relative to the awning profile, allowing adaptation to different awning geometries. In some awning configurations, the available installation space is limited by the awning fabric, making vertical adjustment important to avoid interference between the sensor and the fabric.



Figure 7.2: Mounting plate enabling vertical adjustment for different awning profiles.

7.2.3 Compact Design

To simplify integration with different awning systems and reduce the visual impact of the product, the design was developed to be as compact as possible. Several housing design variations were explored to minimize the overall product size while accommodating the batteries and circuit board. A rounded geometry was selected for the final concept to

improve visual integration with the awning system while maintaining sufficient internal space for the electronics. The evaluated housing variations are presented in Appendix R, Figure R.1.

As shown in Figure 7.3, the internal housing geometry was adapted to follow the battery shape as closely as possible. Local geometric cutouts were introduced around the battery positions to reduce unnecessary internal volume and contribute to a more compact product design. In addition, reinforcing ribs were introduced between the battery positions to compensate for the reduced wall thickness and increase structural stiffness.

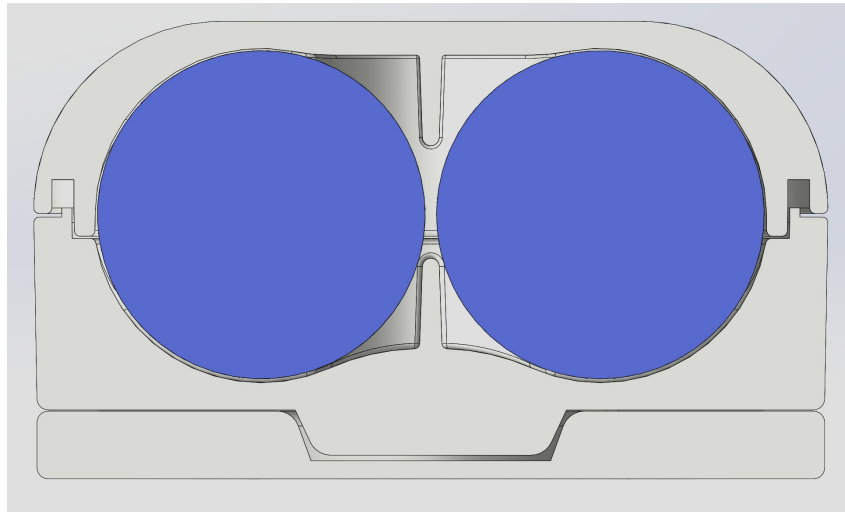


Figure 7.3: Cross-sectional view of the housing geometry following the battery shape.

As shown in Figure 7.2, chamfered regions were introduced around the screw holes of the mounting plate to allow the screw heads to be positioned further into the geometry. This reduced the required thickness of the mounting plate and thereby contributed to a thinner overall product design. In addition, the housing walls were designed to be as thin as possible while still maintaining sufficient structural strength. To compensate for the reduced wall thickness, reinforcing ribs were introduced between the battery positions, as shown in Figure 7.3, to increase stiffness and structural stability.

7.3 Protect Internal Components

To protect the internal components from moisture and environmental exposure, the product was designed using a separate mounting plate and a two-part housing sealed using a gasket and two screws. Screws were used to clamp the housing parts together and generate sufficient pressure on the gasket to create compression and improve sealing performance. As shown in Figure 7.4, the gasket geometry (shown in black) follows the inner perimeter of the housing and curves around the screw holes so that the screws remain outside the sealed region. This reduces the risk of water entering through the screw holes.

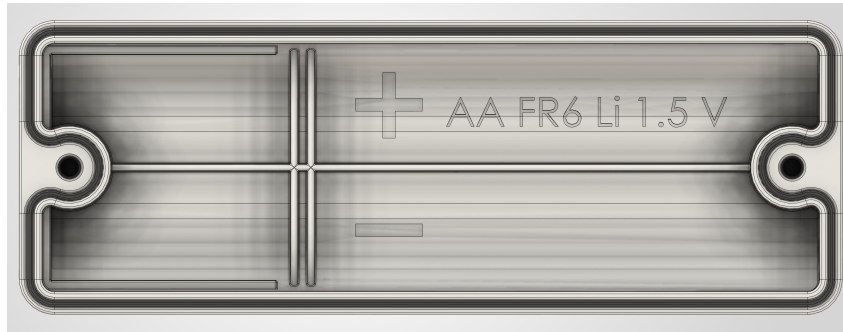


Figure 7.4: Housing geometry and gasket placement used for sealing.

The use of a separate mounting plate in combination with a two-part housing also improved sealing performance by separating the attachment interface to the awning from the sealed electronics enclosure. Since the mounting screws are positioned in the mounting plate rather than through the housing enclosure itself, there is no need to seal around the mounting screw holes. This simplified the sealing geometry and reduced potential leakage paths.

7.4 Serviceability and Maintenance

To simplify maintenance and battery replacement, the housing can be removed independently from the mounting plate fixed to the awning. A bayonet interface was integrated between the housing and mounting plate to enable quick attachment and removal while remaining hidden when mounted, improving visual integration with the awning system. During assembly, the housing is positioned in a rotated orientation where a circular guiding feature aligns the housing with the mounting plate. The bayonet features on the housing shown in Figure 7.5 engage with the corresponding openings in the mounting plate shown in Figure 7.2, after which the housing is rotated into its locked position.

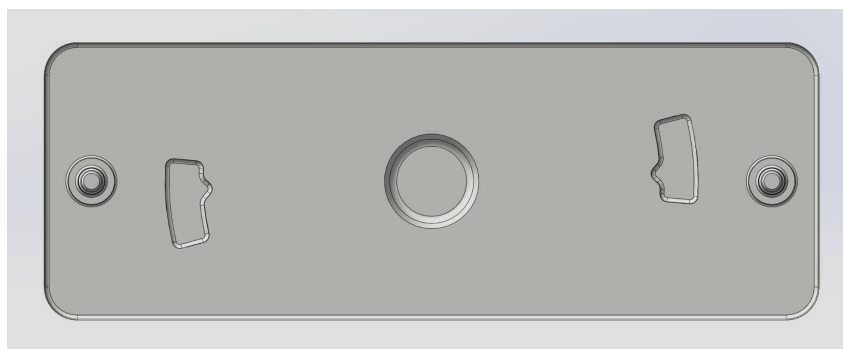


Figure 7.5: Bayonet interface enabling quick attachment and removal of the housing.

The removable housing design also reduces the risk of moisture reaching the internal components during outdoor maintenance operations such as battery replacement or access to the circuit board. The bayonet geometry was also adapted to limit the required rotation angle to maintain compatibility with different awning geometries and limited installation spaces, as discussed in Section 7.2.

7.4.1 Battery Replacement Guidance

As shown in Figure 7.6, markings indicating the recommended battery type (AA/FR6) were also integrated into the battery compartment geometry to guide the user during battery replacement and reduce the risk of incorrect battery selection, since the recommended battery type provides improved reliability and performance in outdoor environments.

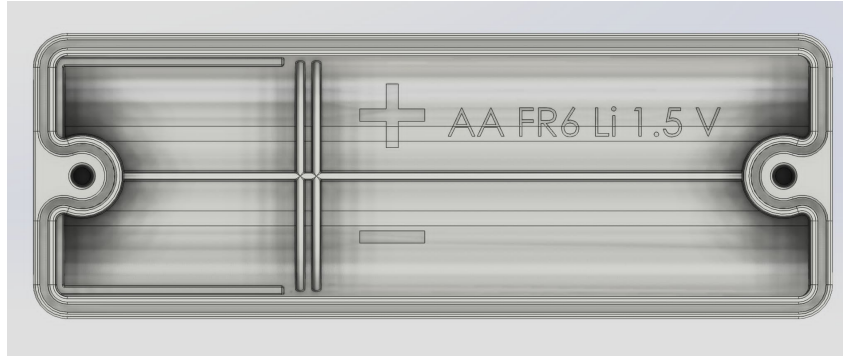


Figure 7.6: Battery compartment geometry with integrated AA/FR6 battery markings.

7.5 Secure Circuit Board

The housing includes integrated features for securing internal components. Custom-designed battery connectors, shown in Figure 7.7, are positioned in dedicated integrated slots in the housing, allowing them to be inserted and secured during assembly. The connectors were designed to better fit the housing geometry, enabling a more compact design compared to standard components. When mounted, the battery connectors apply force to the circuit board, pressing it against the internal support surfaces of the housing and securing it in position without requiring additional fastening components.

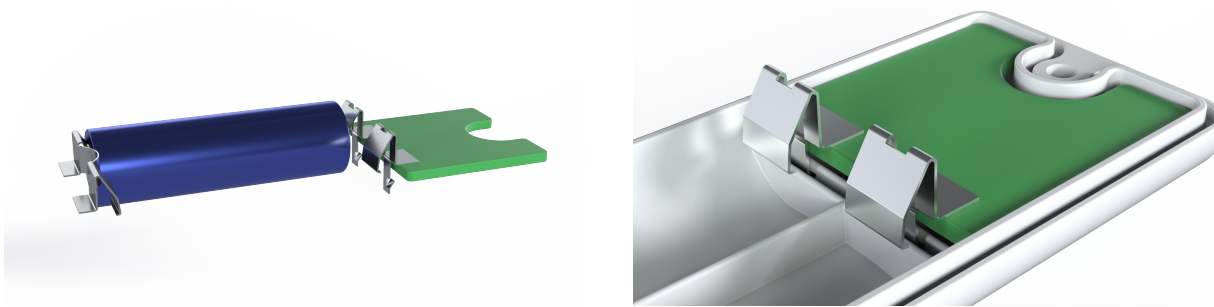


Figure 7.7: Custom-designed battery connectors used for electrical connection and circuit board retention.

7.6 Material Selection

To meet the identified requirements and needs, different materials were selected for the components of the housing and standard components. The suitable material highly depends on intended production method, which in turn also depends on the planned pro-

duction scale. Granta Edupack was used to find suitable materials from a large database (Ansys, Inc., 2026). Excluding the electronics, three material categories were identified: The housing and mounting plate, the gasket and the material for the standard components such as screws. A separate material selection process was used for each of these three.

7.6.1 Housing and Mounting Plate

At an early stage, polymers, metals, alloys and composites were considered for the housing material. Since the sensor is intended for high-volume production, manufacturing cost and manufacturability were prioritized during material selection. Polymers were considered to provide sufficient mechanical and environmental performance for the application while enabling lower manufacturing cost. Polymers are well suited for injection molding, enabling efficient mass production at low unit cost compared to metals and composites, which often require more complex and costly manufacturing processes. A trade-off was therefore made between material performance and manufacturing cost, resulting in polymers being selected as the most suitable material class for the housing.

Material Properties

Based on the initial literature study, interviews and observations, requirements for the housing material were established (see Table 7.1). Since the housing is exposed to sunlight, rain, moisture, saltwater and temperature variations, the material needed sufficient environmental durability. Durability was also considered an environmental requirement, since long material lifetime can reduce replacement frequency, material consumption and waste. The evaluation therefore focused on durability, recyclability and selecting material performance levels suitable for the product requirements. Following the selection of polymers as the material class, the material also needed to be suitable for injection molding. Recyclability was included due to end-of-life considerations, although environmental impact also depends on material marking, collection and disassembly.

Table 7.1: Required material properties for the housing material.

Property	Requirement / Value
Maximum service temperature	At least 60 °C
Minimum service temperature	Less than −30 °C
UV radiation (sunlight) resistance	Good, Excellent
Water (fresh) resistance	Excellent
Water (salt) resistance	Excellent
Recyclability	Yes
Polymer injection molding	Acceptable, Excellent

Material Screening with Granta Edupack

Using the requirements listed in Table 7.1, Granta EduPack was used to perform an initial screening. Materials that did not meet the minimum and maximum service temperature, UV resistance, water resistance, and recyclability requirements were excluded. Materials unsuitable for injection molding were also removed.

After applying the screening constraints, only three material candidates remained. These were, Acrylonitrile Styrene Acrylate (ASA), Acrylonitrile Ethylene Styrene (AES) and several variants of Liquid Crystal Polymer (LCP) filled with glass fibers. These materials were then compared again using several different charts for material properties as shown in figures 7.8 and 7.9.

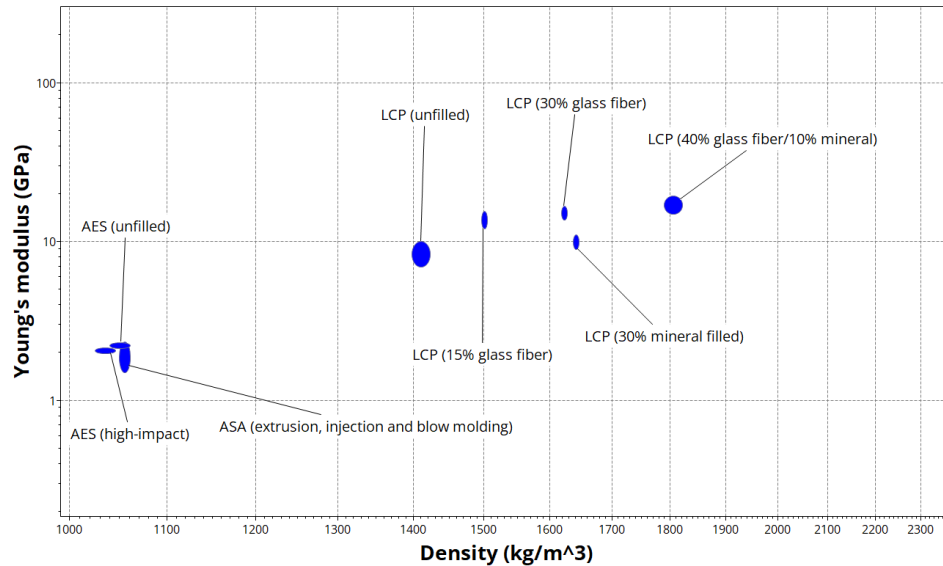


Figure 7.8: Young's modulus versus density for the remaining housing materials.

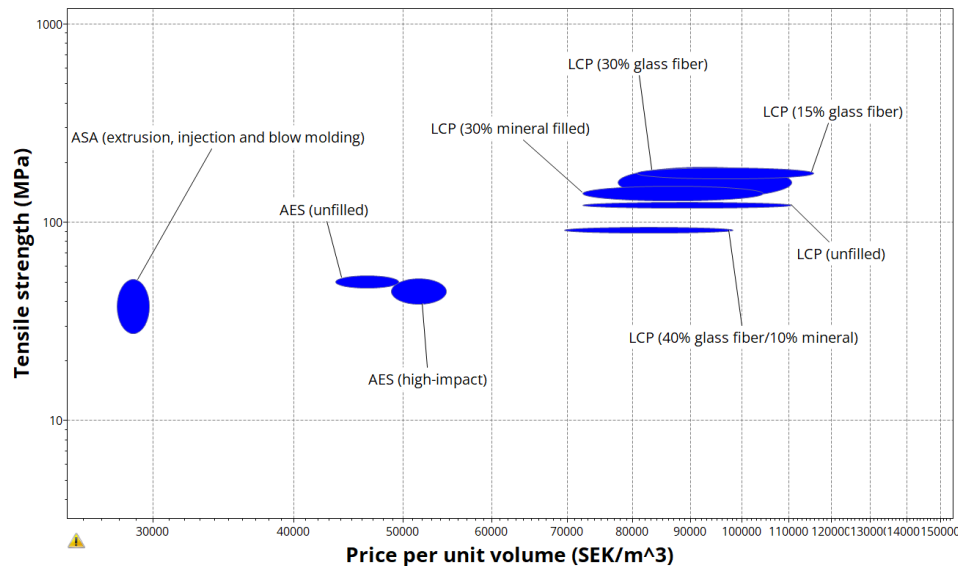


Figure 7.9: Tensile strength versus price per unit volume for the remaining housing materials.

As shown in Figures 7.8 and 7.9, LCP variants had significantly higher density, tensile strength and Young's modulus and almost three times higher cost per unit volume compared to ASA. LCP was therefore excluded, leaving ASA and AES as the remaining candidates. Although ASA and AES had similar densities, AES had almost twice the raw

material cost. ASA also provided better UV resistance and color stability, while AES offered better low-temperature impact resistance. Since low-temperature impact resistance was not the primary design criterion and fragile details could be avoided through design, ASA was selected for the housing and mounting plate.

To further support the material selection, a literature study of ASA was conducted in addition to the Granta EduPack analysis. ASA exhibits good UV resistance, weatherability, color stability, thermal stability and resistance to aging, making it suitable for long-term outdoor applications (Rimdusit et al., 2014). Studies also show that ASA performs well under repeated thermomechanical processing and recycling while maintaining good mechanical properties (Vidakis et al., 2025). Detailed literature findings are presented in Appendix S.

7.6.2 Sealing

Similar to the housing, the sealing material was selected based on requirements related to outdoor use, including resistance to moisture, UV radiation, temperature variations and long-term durability. To protect the internal sensor components from moisture and environmental exposure, the sealing material needed to provide an effective seal between the housing components. Common elastomer materials including Ethylene Propylene Diene Monomer (EPDM), silicone and nitrile rubber were evaluated. EPDM provided the most suitable combination of weather resistance, UV resistance, flexibility and cost. Silicone was associated with higher cost, while nitrile rubber showed lower resistance to environmental degradation. EPDM was therefore selected as the sealing material. EPDM is widely used in sealing applications due to its resistance to weathering, moisture, aging, ozone and UV radiation while maintaining good flexibility over time (Costa et al., 2024; Kömmeling et al., 2016, 2019). Studies have also shown that EPDM maintains sealing performance during long-term static compression, making it suitable for outdoor applications requiring long-term reliability and low maintenance (Stefek et al., 2014).

7.6.3 Screws and T-slot nuts

Since the fasteners are exposed to outdoor conditions and mechanical loads, the material required good corrosion resistance, mechanical strength and long-term durability. The mounting and housing assembly screws also needed to maintain sufficient clamping force to ensure reliable fastening and sealing without damaging surrounding material. Stainless steel was selected for all fasteners due to its high corrosion resistance, particularly in environments exposed to moisture and salt, while still providing sufficient mechanical strength for the application.

7.7 Manufacturing Methods

Selected manufacturing methods for the main components were evaluated based on manufacturability, production volume, cost and material suitability.

Housing and Mounting Plate

Different alternative manufacturing methods were considered, including vacuum forming, additive manufacturing, CNC machining and compression molding. However, injection molding was selected as the most suitable method due to its ability to produce complex geometries with high precision and repeatability at a low unit cost in large production volumes. Although the process involves a high initial tooling cost, it becomes cost-effective when producing a large number of units.

Gasket

The gasket is intended to be manufactured by stamping EPDM sheets, which is a suitable method for producing flexible sealing components in large production volumes with good repeatability and manufacturing efficiency. The method enables fast production and relatively low unit cost at higher production volumes. However, the process requires dedicated tooling and results in material waste from the stamped sheet geometry.

T-slot Nuts

The T-slot nuts are intended to be manufactured using basic machining processes, including cutting segments from flat bar stock followed by drilling and threading. This approach minimizes manufacturing steps and reduces cost.

7.8 Design for Manufacturing (DFM)

Selected Design for Manufacturing (DFM) principles were applied during development of the final prototype to reduce manufacturing complexity and adapt the design for injection molding while maintaining the required functionality and performance (Ulrich et al., 2020). The housing and mounting plate were designed using relatively simple geometries and adapted for injection molding by minimizing unnecessary geometric complexity, undercuts, sudden wall thickness variations and moving mold components such as slides. Based on injection molding guidelines from Protolabs (Proto Labs, Inc., 2026), several geometric parameters were adjusted to improve manufacturability. The main applied design guidelines are summarized in Table 7.2.

Table 7.2: Applied design guidelines for injection molding of the housing.

Parameter	Guideline	Motivation
Wall thickness	1.1–3.5 mm	Proper material flow, reduced sink marks and cooling time
Draft angle	1–3°	Facilitates ejection in the mold direction
Rib thickness	~50–60% of wall thickness	Increases stiffness without adding material avoids interference
Fillets	$\geq 0.5 \times$ wall thickness	Reduces stress concentrations, improves material flow
Hole spacing	$\geq 1 \times$ diameter to edge	Better structural integrity
Parting line	Away from critical surfaces	simplify mold design

These design principles were applied specifically to the design. Draft angles of approximately 1° were added to surfaces aligned with the mold opening direction, which was considered sufficient given the relatively small component depth while still enabling part ejection without changing the geometry more than necessary. Ribs were added between

the batteries in the center of both housing halves as well as between the circuit board and the batteries. This improved stiffness while avoiding interference with any of the internal components. Hole placement and spacing were adapted to maintain a minimum edge distance corresponding to at least one hole diameter in order to improve structural integrity around fastening features. Fillets were applied to internal corners to reduce stress concentrations and improve material flow, while also ensuring compatibility with standard mold tooling. The parting line was positioned to simplify mold design and avoid critical surfaces.

The mounting plate was specifically designed without the need for injection mold slides, resulting in lower tooling complexity and manufacturing cost while still retaining the bayonet function for secure, tool-free attachment of the sensor to the mounting plate. The corresponding bayonet interface features on the housing that interlock with the mounting plate to secure the sensor require injection mold slides due to the undercuts created by these features. Although this increases tooling complexity and cost, ensuring a secure and reliable attachment between the housing and mounting plate was prioritized. The housing geometry was also adapted to integrate the battery contacts while remaining compatible with injection molding without increasing mold complexity. The housing was designed with integrated slots for the battery contacts, which were also used to retain the circuit board in position. This simplified the mold geometry, reduced manufacturing complexity and avoided the need for injection mold slides.

7.9 Design For Assembly (DFA)

This section describes the assembly related design considerations applied to the final design. Selected Design for Assembly (DFA) principles were applied to simplify assembly and maintenance (Ulrich et al., 2020). Standardized components such as screws were used to simplify assembly and facilitate maintenance. A complete Bill of Materials (BOM), including component descriptions, materials and quantities, is presented in Appendix T.

The complete assembly consists of 10 components. Several features were integrated to facilitate positioning and alignment during assembly while simplifying the assembly process. The gasket is positioned in an integrated groove in one of the housing halves and compressed between the housing parts during assembly. Overlapping edges between the housing parts assist alignment during assembly. Circular guiding features between the housing and mounting plate were integrated to guide the housing into the correct position during attachment. This simplifies alignment during assembly before the housing is rotated into its locked position. The battery contacts were designed to both provide electrical connection and retain the circuit board in position. This reduced the need for additional fastening features and simplified assembly by reducing the number of separate components and assembly steps. During assembly, the battery contacts are positioned in integrated slots in the housing, securing the circuit board. The gasket and housing parts are then assembled and secured using two standard M3 screws. The housing is attached to the mounting plate through the bayonet interface, while the mounting plate is attached separately using standard fasteners and T-slot nuts adapted to the awning slot interface. To reduce manufacturing and assembly cost, several assembly steps are intended to be performed by the installer rather than during production. These steps include inserting the batteries and tightening the housing screws.

7.10 Manufacturing Cost

This section presents the estimated manufacturing cost of the final concept and its main components at different production volumes.

Housing and Mounting Plate

While the prototype was manufactured using 3D printing, the final design is intended to be manufactured using injection molding for large-scale production. Therefore, the manufacturing cost was estimated based on injection molding. The manufacturing cost was estimated using the method proposed by Chen and Liu (1999):

$$C_{\text{product}} = \frac{C_{\text{t,tot}}}{N} + C_{\text{m}} + C_{\text{p}} + C_{\text{a}} \quad (7.1)$$

Detailed equations, assumptions and calculations are presented in Appendix U. The cost was calculated for the housing assembly, consisting of two housing parts and a mounting plate. The values were therefore determined for the complete assembly rather than for individual components. The variables used in Equation 7.1 are defined in Table 7.3.

Table 7.3: Definition of variables used in the manufacturing cost model.

Parameter	Description	Unit
C_{product}	Cost per product	SEK
$C_{\text{t,tot}}$	Total tooling cost ($C_{t,1}$, $C_{t,2}$, $C_{t,3}$)	SEK
N	Total number of produced products	[-]
C_{m}	Material cost	SEK
C_{p}	Processing cost	SEK
C_{a}	Assembly cost (labor time)	SEK

The estimated manufacturing cost of the housing assembly was 36.16 SEK per housing at a production volume of 10 000 units. The manufacturing cost of the housing is influenced by the production volume, as shown in Table 7.4, where the estimated manufacturing cost at different production volumes is presented. Higher production volumes reduce the unit cost by distributing the fixed tooling cost over a larger number of products. The tooling cost represents the largest contribution to the total manufacturing cost.

Gasket

The manufacturing cost of the gasket was estimated based on a quotation from an external supplier (Österbergs Industrihandel, 2026). A technical drawing and the selected EPDM material specification were provided to the supplier for the cost estimation. Since the gasket is manufactured by stamping EPDM sheets, a tooling cost is required for the manufacturing process. The quoted tooling cost for the gasket was 7,500 SEK. The quoted manufacturing cost varied between approximately 1.75 and 2.4 SEK per part depending on the production volume, as presented in Table 7.4.

T-nuts

For the T-nuts, similar ones were found at prices of approximately 2-5 SEK, but after receiving quotation for the correct dimensions the cost landed at 1.15-2.09 SEK per T-nut depending on production volume, as shown in Table 7.4. This should still be considered as a rough estimate since the final cost may differ depending on selected supplier and potential changes to tolerances, material and surface treatment.

Total Manufacturing Cost

Table 7.4 presents the estimated manufacturing cost of the complete vibration sensor at different production volumes. The manufacturing cost does not include the cost of the Printed Circuit Board (PCB), the four standard screws intended to be purchased externally, or the battery contacts. Although the estimates are presented as specific values for each production volume, they should still be interpreted as rough indications rather than as final production costs, since they were not based on the company's actual suppliers.

Table 7.4: Total manufacturing cost of the complete vibration sensor at different production volumes.

Production volume	Housing [SEK]	Gasket [SEK]	T-nut (x2) [SEK]	Total cost per sensor [SEK]
10 000	36.16	3.15	4.18	43.49
50 000	20.45	2.23	2.46	25.14
100 000	18.48	1.83	2.30	22.61

7.11 Design Risks and Failure Considerations

A design risk review was conducted to identify potential failures that may occur for different individual components and for the entire sensor and the system that it's part of. It focused on risks connected to the attachment, sealing, installation, serviceability, durability and correct sensor functionality. Since the project mainly focused on the physical product design, the analysis mainly considered mechanical and material related risks rather than detailed electronic or software failures.

Several risks were identified for the housing, how it's mounted and how the internal components are integrated. The most important ones were related to maintaining reliable attachment to the awning as well as ensuring sufficient sealing performance. The most severe ones were failures where the sensor or control system still detects the sensor as operational, even though it is no longer able to provide reliable protection. These risks must be addressed to prevent the system failing to react to damaging conditions. A detailed overview of identified risks and potential mitigations is provided in Appendix V, Table V.1.

Testing and Refinement

This chapter presents the testing and refinement of the prototype. The tests evaluated aspects considered important for outdoor use, including sealing capability, mounting compatibility, handling and durability. The detail design and testing of the prototype were carried out iteratively, with test results informing subsequent design adjustments. Since the tests were performed using 3D-printed prototypes, the results should be interpreted as indicative rather than as complete validation of the final product.

8.1 Sealing Performance Test

Since the requirement related to the physical design (Table 4.2) specifies that the sensor should achieve an ingress protection rating of at least IP44, tests were conducted in order to evaluate the sealing performance of the housing concept. According to International Electrotechnical Commission (n.d.), IP44 indicates protection against solid foreign objects of 1.0 mm diameter and greater, as well as protection against splashing water from any direction without harmful effects.

A full Ingress Protection (IP) classification test according to the standard was not performed, as only the 3D-printed prototype was available. To get an indication of the sealing performance of the housing, the assembled prototype was tested by spraying and splashing water onto the housing to simulate the conditions specified for IP44. No water ingress was observed during or after the test. However, since the test was difficult to perform in a controlled way, the result should be interpreted as an indication of promising sealing performance rather than proof of meeting requirements for IP44. An additional test was performed by fully submerging the assembled sensor housing in a vertical orientation for ten hours. This test was easier to control, since both exposure time and orientation were clearly defined. In the first attempt, water quickly entered through the 3D-printed layers of the housing. After printer process adjustments to improve material fusion, a second attempt resulted in approximately one third of the housing filling with water during the duration of the test. Since the leakage path could not be determined, it is unclear whether the water entered through the housing walls or through small gaps along the gasket. However, since no water ingress was observed during the simplified splash test and the submersion test represented a more severe exposure than IP44, the results indicate that the sealing concept is promising. The gasket used in these tests was 3D-printed in Thermoplastic Polyurethane (TPU) with a shore hardness of 95A which is significantly harder than the intended EPDM gasket. Further tests with a softer gasket may potentially result in better sealing performance. The final injection-molded housing is expected to perform better than the prototype, since it will not have the same risk of leakage through porous print layers as the 3D-printed parts. However, this should still be verified through testing on housing components and a gasket manufactured using the intended production processes.

8.2 Mounting and Compatibility Test

The mounting solution was evaluated by installing the prototype on different awnings using the intended attachment method. The purpose was to assess whether the sensor could be mounted securely and whether the design was compatible with different awning profiles. The prototype was also mounted on a few 3D-printed T-slot geometries with the intention to cover a larger range of geometries than awning models accessible during the project. The prototype could be mounted to all tested awnings and T-slot geometries. This indicates that the mounting principle by utilizing the existing T-slot is compatible with the profiles included in the test. However, the test does not guarantee compatibility with all available awning profiles. The stability of the mounted prototype was evaluated by applying forces to the sensor in different directions. The prototype remained attached during the test with no visible loosening observed. This indicates that the mounting solution provided sufficient stability for the tested prototype conditions. However, the applied loads do not fully represent long-term outdoor exposure when attached to an awning.

8.3 Durability Testing

Durability testing was performed to evaluate whether repeated use of the main physical interfaces caused visible wear or loss of function. The tests focused on the bayonet mechanism between the mounting plate and sensor housing, as well as the screw connection fastening both housing halves.

The bayonet mechanism was tested by repeatedly attaching and removing the sensor from the mounting plate. A total of 100 cycles were performed. After the test, no visible degradation was observed and the sensor could still be attached, but with slightly less force required.

The housing was also tested through repeated assembly and disassembly. The screws were tightened and loosened for a total of 30 cycles to evaluate whether repeated battery replacements or maintenance could affect the screw connection. After the test, the screws could still be tightened as intended and the prototype could still be assembled.

These test results indicate that the mechanical interfaces of the prototype can withstand repeated handling. However, since the prototype was 3D-printed, the wear may not accurately represent the final product. The final injection-molded components may perform better than the 3D-printed prototype due to improved material properties, higher surface quality and dimensional consistency. This should still be verified with repeated cycle testing using production-ready components.

8.4 Test Results and Evaluation

The prototype tests provided preliminary indications of the performance of the selected design principles for sealing, mounting and repeated handling. No visible water ingress was observed during the simplified splash test, the prototype could be mounted to all tested awning profiles and no visible degradation or loss of function was observed after repeated mounting and housing assembly cycles.

Since the tests were performed using 3D-printed prototypes, simplified test procedures and a limited number of awning profiles, the results should be interpreted as indicative rather than as complete validation of the final product. Further testing should be performed on production-ready components in controlled environments that better represent the full requirement range and long-term outdoor exposure. Continued development and integration of the PCB may also require additional tests to validate the complete working product.

9

Results

This chapter presents the final housing and mounting design together with the proposed system concept. The results focus on the main components, their functions and how the solution supports integration with awning systems.

9.1 Final Design

The final design of the vibration sensor is shown in Figure 9.1. The design consists of a compact assembly adapted for installation on existing awning systems, combining the developed housing, mounting solution and sealing features into an integrated concept. A bayonet interface enables attachment and removal of the housing during installation and maintenance, while T-slot nuts allow mounting without permanent modification of the awning structure.



Figure 9.1: Final vibration sensor design shown from front and rear views.

9.1.1 Housing

The housing is designed to enclose and protect the internal electronics and battery from environmental exposure such as moisture and dust. It consists of two separate parts that are assembled using two screws, allowing access for maintenance and battery replacement. The design of the housing is shown in Figure 9.2. The housing is made of ASA, suitable for outdoor applications.

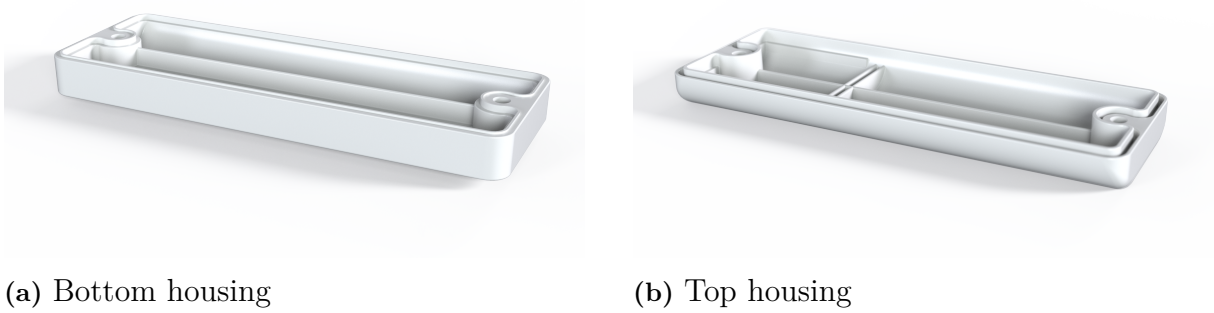


Figure 9.2: Two-part housing design of the final concept.

9.1.2 Gasket

The gasket is used to seal the housing and prevent moisture ingress. It is placed in a groove running along the edge of the housing and compressed when the screws are tightened, creating a tight seal. The groove is located inside the perimeter of the screw holes to prevent moisture from entering through the screw holes and reaching the internal electronics. The gasket is made of EPDM, a material suitable for outdoor applications due to its flexibility and resistance to environmental conditions.



Figure 9.3: Final gasket design used for sealing the housing.

9.1.3 Mounting System

The mounting plate attaches to the awning and serves as an interface between the awning and the housing. The design of the mounting plate is shown in Figure 9.4.



Figure 9.4: Mounting plate used for attachment to the awning.

The mounting plate is secured to the awning using screws and custom-designed rectangular T-slot nuts inserted into the T-slot of the awning. The screws are first inserted through the slotted holes in the mounting plate, after which the T-slot nuts are attached to the screws and inserted into the awning profile slot. As the screws are tightened, the T-slot nuts rotate and press against the inner walls of the slot, securing the mounting plate to the awning structure. This enables installation without leaving permanent marks on the awning structure and allows compatibility with a wide range of awning profiles. Figure 9.5 shows the developed T-slot nut used for the mounting solution.

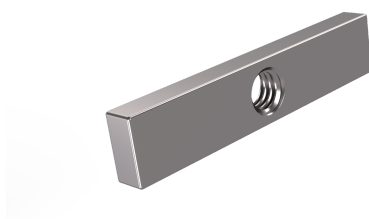
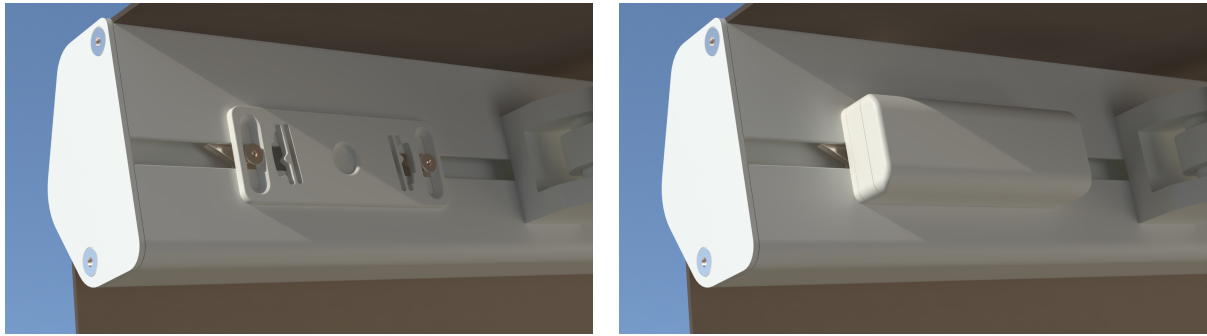


Figure 9.5: Custom-designed T-slot nut for attachment to the awning.

The complete mounting solution and final integration of the sensor on the awning are shown in Figure 9.6. The mounting plate includes slotted holes, allowing slight positional adjustment during installation.



(a) Mounting plate attached to the awning

(b) Sensor mounted on the awning

Figure 9.6: Final integration of the vibration sensor on the awning.

9.1.4 Housing Attachment Mechanism

The housing is connected to the mounting plate through a bayonet mechanism. The attachment is achieved by inserting the housing and rotating it into position, allowing quick installation and removal without the need for tools, as shown in Figure 9.7.

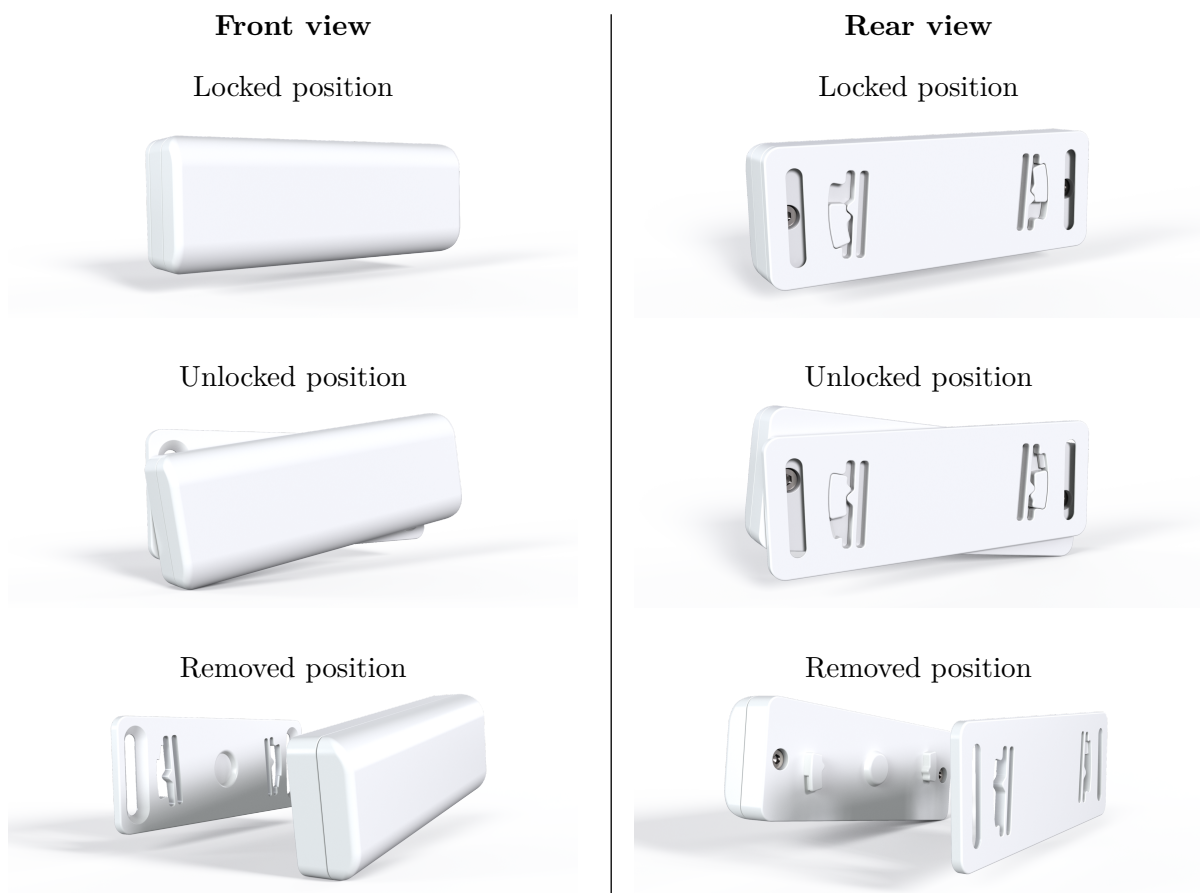


Figure 9.7: Bayonet mechanism between the housing and mounting plate shown in locked, unlocked and removed positions.

9.2 Proposed System Concept

A simplified system architecture was developed as part of the final sensor concept. The proposed system is based on vibration detection using an accelerometer, a battery-powered architecture and sensor settings configurable through an app or software interface. The selected sub-solutions include:

- **Detect wind:** Accelerometer.
- **Configure sensor:** Adjustable threshold via app/software.
- **Provide power supply:** Batteries.
- **Monitor sunshade operating status:** The control system sends a signal when the awning is extending/retracting together with deployment inference based on detected vibrations.
- **Decide when protective action is required:** Gust-based triggering from sudden acceleration, time-above-threshold evaluation and context-based thresholds depending on rain, freezing conditions and user control.
- **Handle manual vs automated operation modes:** Priority hierarchy between safety, local and remote/app control together with automatic fallback during faults or communication loss.
- **Prevent sensor failures from causing damage:** Fail-safe behavior where the awning is retracted if sensor data is uncertain together with fault detection through watchdogs, self-tests and power failure detection.
- **Show battery status:** Mobile app together with indication through awning movement.
- **Manage power consumption:** Deep sleep with periodic wake-ups, interrupt-driven wake-up, adaptive sampling during wind, communication minimization, temperature-adjusted strategy and hardware power gating.

Together, these sub-solutions define the proposed system behavior and architecture of the sensor concept.

10

Discussion

This chapter discusses the project outcome in relation to the objectives, research questions, development process and requirement fulfillment. It also reflects on limitations and societal, ethical and ecological aspects relevant to the proposed solution.

10.1 Project Complexity and Design Challenges

The project involved several technical and product development aspects that influenced each other throughout the development process. A major focus was placed on identifying stakeholder and user needs, which guided concept development and later design decisions. Through an iterative development process, multiple concepts were continuously refined and reassessed to develop a solution that aimed to balance the defined requirements, practical constraints and user expectations.

Developing a solution compatible with different awning systems introduced challenges related to varying geometries, mounting interfaces and limited installation space. One of the main challenges was developing a compact and visually integrated solution capable of withstanding outdoor environmental exposure. At the same time, the design needed to avoid negatively affecting the awning's functionality, installation and maintenance accessibility. Several concepts therefore remained under development relatively late in the process, as different solutions addressed different requirements and constraints.

The project also required continuous consideration of how the mechanical design could support integration of the electronics and other system components. In later development stages, manufacturability, material selection, production cost and potential design risks became increasingly important to support cost-efficient production and adaptation for injection molding.

10.2 Evaluation of Project Objectives

The project objectives presented in Section 1.2.1 were addressed to varying degrees. Benchmarking, patent analysis and stakeholder interviews contributed to the identification of relevant design principles, opportunities for improvement and limitations in existing solutions. Based on the identified project requirements and evaluation of alternative detection technologies, vibration sensing was selected as the basis for the continued development.

The developed mounting concept and housing design indicated potential for compatibility with awning systems using comparable profile geometries and mounting interfaces. This was based on the analysis of existing geometries, mounting solutions and prototype evaluations. However, a more extensive evaluation of different awning products would be required to assess compatibility across a broader range of systems.

The housing design and material selection addressed requirements related to outdoor use, visual integration and serviceability. Iterative prototyping and testing informed design refinements and supported evaluation of selected aspects of the concept. Since the project primarily focused on prototype development, some objectives could only be evaluated at a preliminary level. Long-term durability, large-scale compatibility and production quality remain to be verified using production-ready components and manufacturing methods.

10.3 Development Process and Methods

The applied development process provided a structured way to develop and evaluate solutions for the vibration sensor. Benchmarking and interviews with experienced installers provided relevant input regarding the product context, practical use, installation constraints and recurring challenges. Methods such as morphological, Pugh and Kesselring matrices supported systematic concept generation and evaluation, and helped guide the selection of the final concept. However, these methods rely partly on subjective judgments and weighting decisions, meaning that different evaluators could potentially reach different conclusions. CAD modelling and 3D printing were introduced early and used continuously throughout the project. This iterative approach supported early identification of design issues, evaluation of alternatives and gradual refinement of the design. Physical prototyping also contributed to new insights regarding assembly, usability and integration, which influenced several design decisions during later stages of the project.

10.4 Final Design and Project Contribution

Vibration sensing for awning protection is an established concept, and several existing competitor products already use solutions such as T-slot mounting, screw fastening, gasket sealing and separate mounting plates. The contribution of this project therefore lies primarily in the refinement and combination of existing design principles through a structured product development process adapted to the specific project context.

The developed concept addressed challenges related to compatibility with varying awning geometries, outdoor exposure, serviceability and practical installation requirements. Benchmarking and stakeholder interviews indicated recurring trade-offs in existing products related to accessibility, visual integration, mounting flexibility and sealing performance. The proposed design was developed to address these aspects through a compact housing, concealed mounting interface and removable bayonet attachment system.

The project resulted in a prototype-based concept that provides a basis for continued development of a vibration-based awning sensor. Further validation is required before the concept can be evaluated as a production-ready product, particularly regarding sealing performance, long-term durability, battery lifetime and compatibility across a broader range of awning systems.

10.5 Evaluation of Requirement Fulfillment

Since the project focused on developing and evaluating a prototype, several requirements presented in Table 4.2 could not be fully verified without a finalized product and additional testing. Requirements related to long-term durability, environmental exposure and IP classification require testing on production-ready components with final materials and production tolerances. The selected design solutions and material choices therefore indicate potential for meeting the identified requirements, but should not be interpreted as final verification.

The requirements evaluated during the project mainly concerned installation, assembly and integration. Installation tests and prototype evaluations showed that the mounting solution could be attached to the tested awning profiles. Since the attachment method is based on existing T-slots, the solution may be compatible with awnings using comparable profile geometries. However, compatibility with a broader range of awning systems remains to be verified.

The aesthetic requirements were addressed through a compact and visually discreet design, with concealed mounting features and housing screws positioned towards the mounting plate. Since visual integration depends on mounting position, profile geometry and user preferences, the aesthetic evaluation should be interpreted as preliminary.

10.6 Addressing the Research Questions

This section discusses how the results of the project address the research questions in Section 1.4. The questions are discussed in relation to the developed concept, the design decisions made during the project and the limitations that remain for future development.

RQ1: How can the housing and mounting system be designed for compatibility with different awning profiles without interfering with awning operation?

Compatibility was mainly addressed using a flexible mounting concept based on customized T-slot nuts and screws attached through existing slots on the awning. The concept allows mounting the sensor in different orientations and when necessary, in alternative locations, which increases mounting flexibility. The housing was also designed to be compact in order to minimize the risk of interfering with the mechanical movement of the awning. The main challenge was avoiding collisions with surrounding awning components during extension and retraction, particularly when the sensor is mounted inside the front bar where installation space can be limited.

However, limited dimensional data for different awning systems makes it difficult to determine how many awnings the solution would fit without interference. If the T-slot cannot be used, the sensor may still need to be attached directly to the awning profile using screws. This would increase the number of possible mounting locations, but would also create holes in the front bar and may have a greater visual impact than concealed mounting through existing slots. To better evaluate compatibility, more data needs to be gathered on different awning profiles and their dimensions, especially for the intended mounting position attached to the T-slot on the inside of the front bar.

RQ2: How can the sensor housing protect internal components from outdoor environmental exposure while remaining serviceable?

Outdoor durability was addressed through material selection, sealing and housing design. The exposed components were selected and designed with requirements related to UV radiation, water, salt and temperature variation. The gasket sealing solution and screw-fastened housing were developed to support sealing performance and reduce the risk of moisture entering the housing. The separate mounting plate also simplified sealing by separating the awning attachment interface from the sealed housing.

Serviceability was mainly addressed through the mounting plate and bayonet attachment, which allow the sensor housing to be removed from the awning before battery replacement. This makes it possible to open the sensor in a more stable environment, such as indoors. The two screws used for opening the housing increase the number of steps required compared with fully tool-free concepts, but were selected to support gasket compression, sealing performance and structural robustness. Although prototype testing and design evaluations provided useful initial indications of sealing performance, long-term environmental testing and IP verification were not possible within the project. Final sealing performance therefore remains to be verified using production-ready materials, manufacturing methods and standardized test procedures.

RQ3: How can the design balance manufacturability, cost, usability and visual integration?

Balancing manufacturability, cost, usability and visual integration was an important aspect throughout the development process. Manufacturing cost was mainly addressed through simplified geometry, material selection and designing the housing for injection molding. The housing geometry was also developed to reduce unnecessary material usage while maintaining structural stiffness through reinforcing features. Two of the injection molded components are expected to be possible to produce using relatively simple mold halves, while the housing part containing the bayonet joint geometry is expected to require a more complex mold design. Standard fasteners and simplified assembly solutions were further used to support manufacturability and cost efficiency.

The main aesthetic factors considered were size, mounting location and visual integration with the awning. A compact and visually discreet design was prioritized to reduce visual impact while still considering robustness, sealing performance and accessibility for installation and maintenance. Smooth outer surfaces and positioning the housing screws facing towards the mounting plate instead of outward were prioritized to avoid visible screws and exposed components. Several trade-offs were necessary during development. For example, screw fastening increased maintenance time compared to some tool-free concepts but was selected to support gasket compression, sealing performance and structural robustness. The final aesthetic appearance will still depend on the mounting location and geometry of a specific awning system, and aesthetics are also subjective since different users may have different opinions regarding both the importance of the sensor appearance and how the product affects the visual impression of the awning and building.

10.7 Limitations

One of the main insights from the project was that the mechanical housing and mounting solution could not be evaluated entirely independently from the complete sensor system. Although the project focused on the physical design, aspects such as vibration transfer, PCB integration, battery placement, sealing quality and manufacturing tolerances may influence the final performance more than initially expected.

The prototype testing provided indications of sealing performance, mounting compatibility and repeated handling, but the tests were performed using 3D-printed prototypes and simplified procedures. The results should therefore be interpreted as prototype-level indications rather than complete validation of the final product.

Another important limitation was the variation between awning profiles. Since available profile geometries were limited and not standardized, compatibility could only be evaluated for a limited selection of profiles. Broader compatibility, long-term outdoor durability and complete system performance therefore remain to be verified using production-ready components and standardized test procedures.

10.8 Societal, Ethical and Ecological Aspects

Societal aspects

The societal aspects of the project are mainly connected to the reliability of automated awning systems. If the sensor and control system function as intended, they may reduce the risk of weather related damage by automatically retracting the awning during unsuitable conditions. This can increase user trust in the control system and make users more willing to use the awning in everyday situations. However, this still depends on how the electronics and the complete system works. If the system fails or behaves unpredictably, user trust could instead decrease. The final product should therefore be designed and tested as a complete system to ensure reliable and predictable behavior during real-world usage.

Ethical aspects

The ethical aspects of the project are mainly related to user expectations, system reliability and responsibility. Since the sensor is intended for use in an automated system, it is important that users understand the system's limitations and do not assume complete protection against all weather-related risks. The final system behavior also depends on electronics, firmware, communication and control logic, meaning that the developed housing and mounting solution only represents part of the complete system. Ethical considerations were also relevant during the development process, as the project was conducted in collaboration with a company and involved potentially sensitive information. Confidential details were therefore anonymized or omitted when necessary. In addition, the results were presented while considering the limitations of the project and distinguishing verified results from assumptions and recommendations for future validation.

Ecological aspects

The vibration sensor introduces additional material usage, transportation and energy consumption. However, reducing awning damage and extending product lifetime may potentially reduce overall material consumption and waste generation over time. Durability was therefore prioritized throughout the project through considerations related to material selection, sealing performance and corrosion resistance.

Replaceable lithium AA batteries were selected due to improved cold-environment performance and higher capacity compared to alkaline alternatives, potentially reducing maintenance frequency and battery replacements. However, lithium batteries still contribute to environmental impact through material extraction, production and waste management. Since no full life-cycle assessment was conducted, the environmental evaluation remained primarily qualitative. The use of screws instead of permanent joining methods also improved serviceability and enabled non-destructive disassembly.

11

Future Work

This chapter presents recommendations for further development, testing and production adaptation of the proposed sensor housing and mounting system.

11.1 Environmental and Durability Testing

The product should be tested with realistic outdoor conditions before production. The prototype tests indicated promising sealing performance, but the results were limited by the 3D-printed housing halves and TPU gasket. Further tests should be performed using production-representative components made from ASA and EPDM.

This testing should include standardized ingress protection testing, long-term moisture exposure and vibration testing, as these directly depend on the assembled product design and cannot be fully evaluated from material data alone. For environmental factors such as UV exposure, temperature resistance and salt-water resistance, material data and supplier documentation can provide an initial basis for evaluation. However, final validation should still consider whether the assembled product, including the housing material, gasket and interfaces, remains reliable under the intended outdoor conditions. This is important since failures related to water ingress, degraded sealing or poor attachment may lead to product failure and customer complaints.

11.2 Ensure Long Battery Life and Utilize Accelerometer

Battery life should be treated as a key development priority. The interviews indicated that short battery life is a common weakness in existing products, especially during colder periods. Since awnings may be installed in locations that are used seasonally, the sensor should remain functional after long periods without user interaction. The final product should therefore be tested for battery performance at low temperatures and during extended standby periods.

The accelerometer should also be used to support flexible mounting orientation. By measuring the direction of gravity, the sensor can determine its orientation and adapt the signal processing accordingly. This would support the current mechanical design, which is intended to allow mounting in different orientations. The same functionality may also enable detection of abnormal awning angles, for example due to water accumulation in the fabric. These functions should be implemented without significantly increasing power consumption.

11.3 Prepare the Design for Injection Molding

The housing design should be further prepared for injection molding before production. The simulations performed in this project indicated shrinkage and possible warpage, which may affect the fit between the housing halves and the sealing interface. The mold design, cooling strategy, wall thicknesses and tolerances should therefore be refined to ensure repeatable part quality. Particular attention should be given to the gasket interface, screw bosses, mounting mechanism, battery compartment and PCB support features. These areas are critical for sealing, assembly, serviceability and reliable vibration transfer. Production trials should be used to verify that the molded components meet the required dimensions and functional requirements.

11.4 Finalize Integration and Production Details

The final integration of the PCB, battery contacts and internal support features should be completed before production. These components affect both electrical reliability and the mechanical transfer of vibration from the awning to the sensor. The design should ensure that the PCB is held securely, that the battery contacts do not introduce excessive loads into solder joints, and that battery replacement can be performed without damaging the housing or compromising the seal. Product details such as assembly procedure and service instructions should also be finalized. These details are important for manufacturability, installation and long-term usability.

12

Conclusion

This thesis resulted in a developed sensor concept intended to support automatic protection of awnings from wind-related damage. The work focused on the physical product architecture of a vibration-based sensor. This included the housing, sealing solution, mounting plate, bayonet attachment mechanism, material selection, manufacturability considerations and prototype testing. The project therefore provides a mechanical basis for the continued development of a complete awning protection sensor.

The results indicate that the developed housing and mounting solution are a promising basis for further development. The design addresses the need for a sensor that can withstand environmental exposure, be mounted to different awning profiles and remain serviceable without becoming unnecessary complex to manufacture. In addition, the concept resulted in a compact and visually clean design intended to integrate discreetly with existing awning systems. The use of a separate mounting plate allows the sensor to be removed without tools while concealing the screws for the housing. Prototype testing also indicated promising performance regarding sealing, mounting and repeated handling.

However, the thesis does not validate a complete sensor product. The protective function still depends on the final PCB, firmware, software, communication and integration with the control system. In addition, the prototype tests were performed on 3D-printed components and should therefore be interpreted as concept level validation rather than verifying the final product. Further work should include standardized environmental testing using injection-molded components with broader compatibility testing and integration of the electronics and firmware.

The thesis shows that the mechanical design of a vibration-based awning sensor can contribute to the overall reliability of the complete system by enabling secure mounting and protecting the internal components from environmental exposure. While the housing and mounting solution do not provide the protective function on their own, they create the physical basis needed for the electronics and firmware to operate reliably in outdoor use. If combined with reliable sensing, long battery life and support for different mounting orientations, the developed concept could improve the system it integrates with and offer a more usable and better-integrated alternative to existing awning vibration sensors.

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Appendices

A Competitor Benchmarking

Table A.1: Comparison of key technical characteristics of the evaluated sensors.

Sr. No.	Name	IP-rating	Operating temperature	Battery type/count	Sensitivity levels	Control lockout (min)	Length (mm)	Width (mm)	Height (mm)	Weight (incl batteries)
1	Cherubini Mistral	IP44	-10°C to +50°C	2 x LR03 (AAA)	9	8	140	38	26	100 g
2	Rademacher DuoFern	IP44	-20°C to +55°C	2 x LR03 (AAA)	9	20	120	38	22	-
3	Somfy trådlös vindsensor Eolis 3D WireFree RTS	IP44	-20°C to +60°C	2 x LR03 (AAA)	9	15	153	38	25	
4	Elero Protero-868 Trådlös vibrationssensor	IP54	-20°C to +50°C	2 x LR6 (AA)	8-9	15	129	35	22	50 g
5	Nice Nemo Vibe Wind Waxing/Shaking Sensor for Awnings	IP44	-20°C to +60°C	2 x LR06 (AA)	8	15	130	36	22	18,14 g
6	Becker Centronic SensorControl	IP44	-25°C to +55°C	2 x LR03 (AAA)	9	15	140	23	39	182 g

The comparison presented in Table A.1 is based on product analysis, measurements and observations performed during the project, together with information collected from manufacturer websites, product manuals and technical datasheets (Cherubini, 2025; elero, 2025; Nice, 2025; Rademacher, 2025; Somfy, 2025).

Table A.2: Comparison of mechanical design and mounting solutions used in the evaluated sensors.

Sr. No.	Name	Assembly of housing parts	Tools Required for Opening	Unique Features	Sealing	Mounting on Awning	Placement on Awning	Battery Placement	Circuit Board Mounting
1	Cherubini Mistral	Snap fasteners on both short sides	No	Hold vertically to turn off	Foam-based seal around the circuit board and battery holder	Two screws	Inside of the front bar	Battery holder is glued and mounted on the circuit board	The circuit board is secured with two small screws
2	Rademacher DuoFern	Two-part housing: wedge + screw; snaps to mount	Yes	–	Rubber seal along the entire edge between both halves of the housing	Back plate mounted with two screws and snap attachment to the housing.	Inside of the front bar	Next to the circuit board	The circuit board is held in place with integrated plastic clips in the housing
3	Somfy trådlös vindsensor Eolis 3D WireFree RTS	Inner housing snaps to outer. Outer slides and clips to mount	Yes	Turns off when the lid is removed (magnet)	Foam material at the bottom for partial sealing. No seal between the housing and the mounting plate	Two screws	Inside of the front bar	Batteries in the inner housing with metal springs, placed next to the circuit board	One screw
4	Elero Protero-868 Trådlös vibrationssensor	One centered screw. Silicone piece clamped in between	Yes	Both vibration and tilt sensors	Silicone gasket between the housing halves, not very tight with one screw	Four slots for screws: two longitudinal, two vertical	Outside of the front bar	In the housing, contacts soldered to the circuit board, next to the circuit board	One screw
5	Nice Nemo Vibe Wind Waxing/Shaking Sensor for Awnings	One centered screw. Silicone piece clamped in between	Yes	–	Silicone gasket between the housing halves, not very tight with one screw	Four slots for screws: two longitudinal, two vertical	Outside of the front bar	In the housing, contacts soldered to the circuit board, next to the circuit board	One screw
6	Becker Centronic SensorControl	Lid wedged on one end and screwed down on the other	Yes	Turns off when the circuit board is removed	Thin silicone gasket between the housing and the lid	One screw on each side of the housing. The circuit board can be removed with the housing still on the awning	Inside of the front bar	No traditional battery holder; batteries are held in place by separate contact fixtures (four parts, two per battery) mounted on the circuit	Slotted into tracks in the housing walls, clamped in place by the lid

B Patent analysis

Table B.1: Patents identified during the pre-study patent analysis.

No.	Patent number	Publication date	Status	Patent name	Company	Country
1	US2008150717A1	2008-06-26	Active	Security Sensor-Transmitter for Detecting Wind in a Home Automation Installation	Somfy	France
2	US2008150743A1	2008-06-26	Active	Method for Setting a Safety Threshold Above Which an Awning Should be Wound Up	Somfy	France
3	DE4407342A1	1994-11-03	Expired	Shading device with an awning, an exterior blind or the like	Rademacher	Germany
4	US2010280666A1	2010-11-04	Active	Operating system for roller blinds with protection against excessive wind	Nice	Italy

A patent review was conducted during the pre-study phase using open patent databases, primarily Espacenet, to identify existing technical solutions related to vibration- and wind-based protection of sun-shading systems. Examples of the identified patents are listed in Table B.1.

The review included patents describing externally mounted vibration sensors, force-based sensing within the roller tube and additional functionality related to system monitoring. The patent study showed that monitoring wind through awning vibrations is covered by patents that have already expired. This may correlate with the similarity observed among the benchmarked products (Tables A.1 and A.2). The earliest patent family identified had a priority date of 1993-04-27, associated with priority number DE9306368U and later published as DE4407342A1 (W. Rademacher, 1994), as listed in Table B.1. The expired patents indicate that there is more design freedom and a lower risk of infringing on existing patents. But it also means there may be more competition between competitors. Some patents also describes additional uses, such as detecting break-in attempts through windows or tampering with the awning. The absence of these features in current products may suggest that they are either difficult to implement or not needed in most applications.

B.1 US2008150717A1 – Wind detection sensor for home automation

Patent US2008150717A1 describes a sensor-transmitter for detecting wind-induced motion in home automation systems (Guillemot & Grehant, 2008). Although it could restrict some concepts, it expires on 2026-12-26. The patent, held by Somfy, describes a function where the sensor is automatically disabled when removed from the awning, using a magnet and a reed switch to cut power. This solution is used in one of the benchmarked products (Table A.2). A similar function is observed in another product, but it avoids infringement either by triggering when the circuit board is removed from the casing or by using a different sensing principle. As the patent is about to expire, it is not expected to significantly limit concept development.

B.2 US2010280666A1 – Automated wind protection for roller blinds

Patent US2010280666A1 describes a system for roller blinds that provides automated protection against high wind loads (Marchetto, 2010). It measures forces in the roller tube rather than using an external sensor. This approach is not directly applicable without a different product design, but it may become a competing solution, especially after the patent expires. If effective, it could allow the sensor to be integrated into the motor, reducing the need for external devices. However, externally mounted sensors may still be relevant for retrofitting existing systems without replacing the motor.

C KJ-method

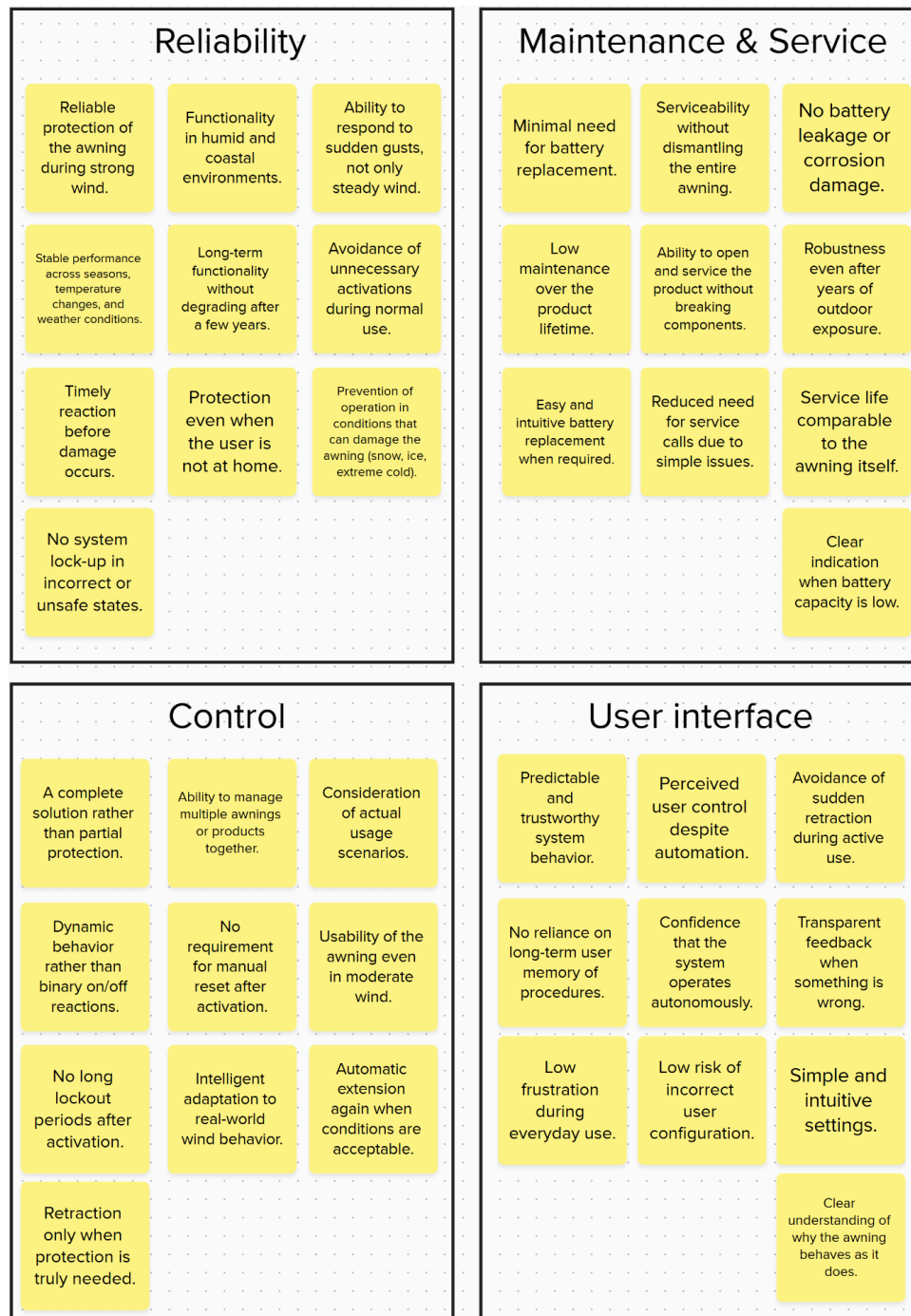


Figure C.1: KJ analysis (Part 1).

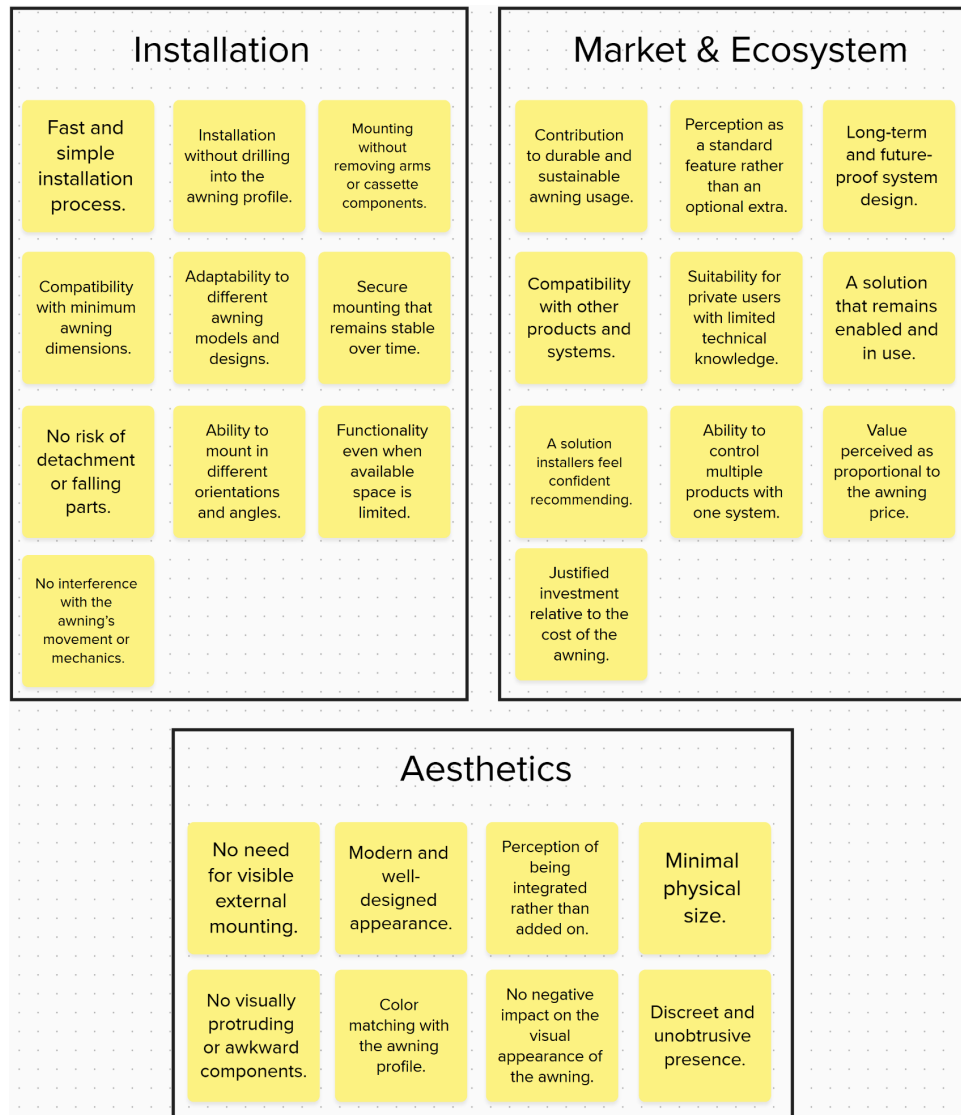


Figure C.2: KJ analysis (Part 2).

D Requirements Specification

Table D.1: Complete Requirement specification.

	Criteria	Value	Unit	Type of requirement	Demand-Wish	Importance	Verification method	Justification
	Function(s)							
1	Reliability							
1.1	The sensor housing shall protect internal components from corrosion and prevent rust formation during intended outdoor use	Yes	-	Non-functional requirement	Demand	High	Analysis + test	Reduces risk of failure due to corrosion during long-term outdoor exposure
1.2	The sensor shall maintain protective functionality within the temperature range relevant to intended outdoor use.	-30 to 60	°C	Non-functional requirement	Demand	High	Analysis + test	Outdoor installation exposes the sensor to low and high temperatures that must not prevent protective functionality.
1.3	Components exposed to sunlight shall withstand UV exposure during intended outdoor use without loss of functionality	Yes	-	Non-functional requirement	Demand	High	Analysis + material selection	Outdoor exposure to sunlight may degrade materials over time
1.4	The sensor shall be protected against water and dust ingress	≥ IP44	-	Non-functional requirement	Demand	High	Testing according to IP standard (IEC 60529)	Outdoor installation exposes the sensor to water and particles, so ingress protection is required to preserve functionality and protect internal components
1.5	Provide protective functionality against wind-induced damage without requiring user intervention	Yes	-	Functional requirement	Demand	High	Analysis + field demonstration	Wind conditions can change rapidly and the user may not be available to react in time, making autonomous protective action necessary to reduce the risk of awning damage.
1.6	A fault in the sensor system shall not increase the risk of awning damage	Yes	-	Non-Functional requirement	Demand	High	Analysis + test	Sensor faults must not create a higher risk of awning damage than operation without the sensor.
2	Maintenance and Service							
2.1	The sensor shall withstand repeated opening and closing during installation and service without functional degradation	≥ 20	Cycles	Non-functional requirement	Demand	Medium	Test	Ensures durability during installation and maintenance, including battery replacement
2.2	The sensor shall withstand repeated mounting and removal from the mounting plate without functional degradation	≥ 100	Cycles	Non-functional requirement	Demand	Medium/High	Test	Ensures durability during installation, maintenance and potential repositioning
2.3	The sensor shall allow easy battery replacement, without damaging the product	Yes	-	Functional requirement	Demand	High	Test	Battery replacement is expected during the product lifetime and should be possible without requiring installer time or added service cost
2.4	The system should not require routine service actions during normal operation	Yes	-	Non-functional requirement	Demand	High	Analysis	Routine service would increase installation and maintenance work, which would raise costs for both installers and owners.
2.5	The sensor shall provide a battery life of at least 2 years during intended outdoor use	≥ 2	Years	Non-functional requirement	Demand	High	Analysis + test	A battery life below 2 years would increase maintenance frequency and service burden
2.6	The sensor should provide a battery life of 10 years or more during intended outdoor use	≥ 10	Years	Non-functional requirement	Wish	High	Analysis + test	A very long battery life would further reduce maintenance needs and ownership cost over the product lifetime
3	Installation							
3.1	The sensor shall remain securely attached once installed under normal operational and environmental loads	Yes	-	Non-functional requirement	Demand	High	Test	Loss of attachment would compromise protective functionality and could damage the product or awning
3.2	The sensor shall be installable on a wide range of sunshade configurations without modification of the sunshade	Yes	-	Non-functional requirement	Wish	High	Test	Enables installation without modifying the sunshade, reducing installation effort and complexity
3.3	The mounting plate shall allow efficient mounting on the awning by professional installers	Yes	-	Non-functional requirement	Demand	High	Test	Efficient installation reduces labor time, cost, and installation complexity for professional installers
3.4	The system shall not hinder or alter the sunshade's original mechanical operation	Yes	-	Constraint	Demand	High	Inspection + test	The sensor must not interfere with normal awning movement or compromise the original mechanical functionality of the sunshade
3.5	The system should minimize installation effort and complexity for professional installers	Yes	-	Non-functional requirement	Demand	High	Test	Improves efficiency and reduces complexity during installation
4	Aesthetic							
4.1	The sensor should match the most common colors of sunshade profiles	Black/Grey/White	-	Non-functional requirement	Wish	Medium	Inspection	Color compatibility helps the sensor blend with common awning designs and reduces visual intrusion
4.2	The sensor should not visibly degrade the perceived aesthetic quality of the installed sunshade	Yes	-	Non-functional requirement	Wish	Medium	Inspection (subjective evaluation)	Preserves the overall appearance and visual quality of the installed sunshade
4.3	The product shall follow the company's design guidelines and visual identity	Yes	-	Non-functional requirement	Wish	Medium	Inspection (subjective evaluation)	Ensures consistency with brand identity and existing product portfolio
5	Market & Ecosystem							
5.1	The manufacturing cost should allow competitive product pricing	≤ X	SEK	Business requirement	Wish	High	Analysis	Competitive pricing is necessary for market acceptance and commercial viability
5.2	The system should provide demonstrable value relative to its added cost to support customer adoption	Yes	-	Business requirement	Wish	High	Analysis	The added functionality must justify its added cost to support adoption
6	Environment							
6.1	The sensor should be designed to minimize environmental impact over its life cycle, including consideration of material sustainability and end-of-life recyclability	Yes	-	Environmental requirement	Wish	Medium	Analysis	Reduces environmental impact and supports sustainable product development over the product life cycle
7	Control							
7.1	The system shall avoid unnecessary protective interventions	Yes	-	Non-functional requirement	Wish	High	Analysis + test	Unnecessary protective actions reduce usability and may decrease user acceptance of the system
7.2	The system should allow resumption of normal sunshade operation after hazardous conditions have ceased	Yes	-	Functional requirement	Wish	High	Test	Protective intervention should not unnecessarily prevent the return to normal use once hazardous conditions are no longer present
7.3	The system shall retain protective functionality regardless of whether the sunshade is operated manually or automatically	Yes	-	Functional requirement	Demand	High	Analysis + test	Protective functionality must remain available under all intended operating modes
8	User interface							
8.1	The system shall notify the user when the battery level falls below a defined threshold	≤ 10	%	Functional requirement	Wish	Medium	Test	Allows long battery change intervals while still notifying user before protective functionality is affected
8.2	The system should be configurable by installers with low risk of incorrect configuration affecting protective performance	Yes	-	Non-functional requirement	Wish	Medium	Inspection + test	Incorrect configuration could reduce protective performance, mechanical life and increase installer burden

E Battery Comparison

Table E.1: Comparison of battery types based on operating voltage, capacity, temperature range, size and cost.

Battery	Operating Voltage (V)	Capacity (mAh)	Temperature Range (°C)	Dimensions (mm)	Approximate Cost (SEK)
AA/LR6	1.5	2600–2970	0 to 60	∅ 14.5 × 50.5	3–10
AA/R6	1.5	600–1600	0 to 50	∅ 14.5 × 50.5	2–6
AA/FR6	1.5	2700–3400	-40 to 60	∅ 14.5 × 50.5	15–35
AA/HR6	1.2	700–2800	-20 to 50	∅ 14.5 × 50.5	25–50
AA/ER14500	3.6	2000–2600	-55 to 85	∅ 14.5 × 50.5	50–150
AAA/LR03	1.5	900–1200	0 to 60	∅ 10.5 × 44.5	2–8
AAA/R03	1.5	500–1000	0 to 50	∅ 10.5 × 44.5	1–5
AAA/FR03	1.5	1100–1300	-40 to 60	∅ 10.5 × 44.5	12–30
AAA/HR03	1.2	600–1100	-20 to 50	∅ 10.5 × 44.5	20–45
CR2450	3	500–620	-30 to 85	∅ 24.5 × 5.0	10–30
CR2032	3	210–240	-30 to 85	∅ 20 × 3.2	5–25
CR2477	3	850–1050	-30 to 85	∅ 24 × 7.7	25–60
CR3032	3	500–600	-30 to 85	∅ 30 × 3.2	20–50

F Morphological Matrix

Table F.1: Complete morphological matrix including all sub-functions and sub-solutions.

Unnamed Morphological Matrix

Sub-Functions	Sub-Solutions						
Attach housing to sunshade structure	Clamps or straps	T-nuts and screws	Magnetic mount with steel plate attached to awning either inside or outside aluminium profile	Tape/glue	Adapter bracket attached to existing t-slot/groove		
Mounting position	Inside front bar	Under front bar	On the arm of the awning				
Attach housing to mounting plate	Screws	Magnet	Tape	Snap joint	Slide joint	Threaded joint	Mounting plate not required
Design housing to fit electronics	Single compartment	Segmented internal compartments	Batteries below or on top of circuit board				
Protect internal components	O-ring	Multi flange seal with several overlapping flanges on both halves.	Full potting or coating with epoxy or similar	Desiccant, to absorb some moisture			
Secure circuit board	Screws	Snap-fit clips along edges of board	Slots along housing that the board slides into				
Join housing parts	Screws	Magnet	Twist locks	Latches	Slide and lock rails	External clamping ring	
Facilitate maintenance access	Opened by separating both housing parts	Hatch	No need for access				

G Concept Catalog

Table G.1: Concept catalog showing all generated concepts based on the Morphological matrix (Part 1).

Solution	Design housing to fit electronics	Protect internal components	Secure circuit board	Join housing parts
1	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	External clamping ring
2	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	Slide and lock rails
3	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	Latches
4	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	Twist locks
5	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	Magnet
6	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Slots along housing that the board slides into	Screws
7	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	External clamping ring
8	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	Slide and lock rails
9	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	Latches
10	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	Twist locks
11	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	Magnet
12	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Snap-fit clips along edges of board	Screws
13	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	External clamping ring
14	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	Slide and lock rails
15	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	Latches
16	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	Twist locks
17	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	Magnet
18	Batteries below or on top of circuit board	Multi flange seal with several overlapping flanges on both halves.	Screws	Screws
19	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	External clamping ring
20	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	Slide and lock rails
21	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	Latches
22	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	Twist locks
23	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	Magnet
24	Batteries below or on top of circuit board	O-ring/Silicone gasket	Slots along housing that the board slides into	Screws
25	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	External clamping ring
26	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	Slide and lock rails
27	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	Latches
28	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	Twist locks
29	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	Magnet
30	Batteries below or on top of circuit board	O-ring/Silicone gasket	Snap-fit clips along edges of board	Screws
31	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	External clamping ring
32	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	Slide and lock rails
33	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	Latches
34	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	Twist locks
35	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	Magnet
36	Batteries below or on top of circuit board	O-ring/Silicone gasket	Screws	Screws

Table G.2: Concept catalog showing all generated concepts based on the Morphological matrix (Part 2).

Solution	Design housing to fit electronics	Protect internal components	Secure circuit board	Join housing parts
37	Batteries side by side	Multi flange seal with several	Slots along housing that the	External clamping ring
38	Batteries side by side	Multi flange seal with several	Slots along housing that the	Slide and lock rails
39	Batteries side by side	Multi flange seal with several	Slots along housing that the	Latches
40	Batteries side by side	Multi flange seal with several	Slots along housing that the	Twist locks
41	Batteries side by side	Multi flange seal with several	Slots along housing that the	Magnet
42	Batteries side by side	Multi flange seal with several	Slots along housing that the	Screws
43	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	External clamping ring
44	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	Slide and lock rails
45	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	Latches
46	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	Twist locks
47	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	Magnet
48	Batteries side by side	Multi flange seal with several	Snap-fit clips along edges	Screws
49	Batteries side by side	Multi flange seal with several	Screws	External clamping ring
50	Batteries side by side	Multi flange seal with several	Screws	Slide and lock rails
51	Batteries side by side	Multi flange seal with several	Screws	Latches
52	Batteries side by side	Multi flange seal with several	Screws	Twist locks
53	Batteries side by side	Multi flange seal with several	Screws	Magnet
54	Batteries side by side	Multi flange seal with several	Screws	Screws
55	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	External clamping ring
56	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	Slide and lock rails
57	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	Latches
58	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	Twist locks
59	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	Magnet
60	Batteries side by side	O-ring/ Silicone gasket	Slots along housing that the	Screws
61	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	External clamping ring
62	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	Slide and lock rails
63	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	Latches
64	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	Twist locks
65	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	Magnet
66	Batteries side by side	O-ring/ Silicone gasket	Snap-fit clips along edges	Screws
67	Batteries side by side	O-ring/ Silicone gasket	Screws	External clamping ring
68	Batteries side by side	O-ring/ Silicone gasket	Screws	Slide and lock rails
69	Batteries side by side	O-ring/ Silicone gasket	Screws	Latches
70	Batteries side by side	O-ring/ Silicone gasket	Screws	Twist locks
71	Batteries side by side	O-ring/ Silicone gasket	Screws	Magnet
72	Batteries side by side	O-ring/ Silicone gasket	Screws	Screws

H Elimination Matrix

Table H.1: Elimination matrix for generated concepts.

	Perceived as robust	Weather resistance	Tolerate normal handling during installation and service	Easy to handle	Not hinder the sunshade's original mechanical operation	Not degrading visual aesthetics	(+) Fulfills criteria (-) Does not fulfill criteria	
Solution							Comment	Decision
1	+	-					Not sealing well	Remove
2	+	-					Not sealing well	Remove
3	+	+	+	+	+	+		Continue
4	+	-					Not sealing well	Remove
5	+	-					Not sealing well	Remove
6	+	+	+	+	+	+		Continue
7	+	-					Not sealing well	Remove
8	+	-					Not sealing well	Remove
9	-							Remove
10	+	-					Not sealing well	Remove
11	+	-					Not sealing well	Remove
12	-							Remove
13	+	-					Not sealing well	Remove
14	+	-					Not sealing well	Remove
15	+	+	+	+	+	+		Continue
16	+	-					Not sealing well	Remove
17	+	-					Not sealing well	Remove
18	+	+	+	+	+	+		Continue
19	+	+	+	+	+	-	Clamping ring not aesthetic	Remove
20	+	+	+	-			Slide and lock not possible with o-ring	Remove
21	+	+	+	+	+	+		Continue
22	+	+	+	+	+	+		Continue
23	-						Not sealing well	Remove
24	+	+	+	+	+	+		Continue
25	-							Remove
26	-							Remove
27	-							Remove
28	-							Remove
29	-						Not sealing well	Remove
30	-							Remove
31	+	+	+	+	+	+		Continue
32	+	+	+	-			Slide and lock not possible with o-ring	Remove
33	+	+	+	+	+	+		Continue
34	+	+	+	+	+	+		Continue
35	-						Not sealing well	Remove

Table H.1: Elimination matrix for generated concepts (continued).

Solution							Comment	Decision
36	+	+	+	+	+	+		Continue
37	+	-					Not sealing well	Remove
38	+	-					Not sealing well	Remove
39	+	+	+	+	+	+		Continue
40	+	-					Not sealing well	Remove
41	+	-					Not sealing well	Remove
42	+	+	+	+	+	+		Continue
43	+	-					Not sealing well	Remove
44	-						Not sealing well	Remove
45	-							Remove
46	-						Not sealing well	Remove
47	+	+	+	+	+	+	Added to see how well magnet works	Continue
48	+	+	+	+	+	+		Continue
49	+	+	+	+	+	+	Ring not aesthetic but added to see how bad	Continue
50	+	-					Not sealing well	Remove
51	+	+	+	+	+	+		Continue
52	+	+	+	+	+	+	Added to see how well multi flange works	Continue
53	+	-					Not sealing well	Remove
54	+	+	+	+	+	+		Continue
55	+	+	+	-			Clamping ring not aesthetic	Remove
56	-	+	+	-			Slide and lock not possible with o-ring	Remove
57	+	+	+	+	+	+		Continue
58	+	+	+	+	+	+		Continue
59	-						Not sealing well	Remove
60	+	+	+	+	+	+		Continue
61	+	+	+	+	+	-	Clamping ring not aesthetic	Remove
62	+	+	+	-			Slide and lock not possible with o-ring	Remove
63	+	+	+	+	+	+		Continue
64	+	+	+	+	+	+		Continue
65	-						Not sealing well	Remove
66	+	+						Remove
67	+	+	+	+	+	-		Remove
68	+	+	+	+	+	+	Added to see if possible with o-ring	Continue
69	+	+	+	+	+	+		Continue
70	+	+	+	+	+	+		Remove
71	+	+	+	+	+	+	Added to see how well magnet works	Continue
72	+	+	+	+	+	+		Continue
Concepts proceeding to the next stage:								28

I Pugh Matrices

Table I.1: Pugh matrix – First iteration.

Pugh Matrix - First iteration																												
Criteria	Ref: 72	3	6	15	18	21	22	24	31	33	34	36	39	42	47	48	49	51	52	54	57	58	60	63	64	68	69	71
Perceived as robust	0	-	-	-	-	-	-	0	0	-	-	0	-	0	-	0	-	-	-	0	-	-	0	-	-	-	-	-
Weather resistance	0	-	-	-	-	-	-	0	0	-	-	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-
Ease of use	0	+	0	+	0	+	+	0	-	+	+	0	+	0	+	0	-	+	+	+	0	+	0	+	+	+	+	+
Durability	0	-	0	-	0	-	-	0	0	-	-	0	-	0	0	0	0	-	-	0	-	-	0	-	0	-	0	0
Σ+	0	1	0	1	0	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	1	1	0	1	1	1	1	1
Σ-	0	3	2	3	2	3	3	0	1	3	3	0	3	1	2	1	3	3	3	1	3	3	0	3	3	2	3	2
Σ0	6	0	2	0	2	0	0	4	3	0	0	4	0	3	1	3	1	0	0	3	0	0	4	0	0	1	0	1
Total	0	-2	-2	-2	-2	-2	-2	0	-1	-2	-2	0	-2	-1	-1	-1	-3	-2	-2	-1	-2	-2	0	-2	-2	-1	-2	-1

Table I.2: Pugh matrix – Second iteration.

Pugh Matrix - Second iteration		Ref. 47	3	6	15	18	21	22	24	31	33	34	36	39	42	48	49	51	52	54	57	58	60	63	64	68	69	71	72
Criteria																													
Perceived as robust		0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Weather resistance		0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	+	+	+
Ease of use		0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	-
Durability		0	-	0	-	0	-	-	0	0	-	-	+	-	0	0	-	-	-	-	-	-	0	-	-	-	-	-	+
Σ^+		0	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	1	2	3	3
Σ^-		0	2	1	2	1	2	2	1	1	2	2	1	2	1	1	2	2	2	1	2	2	1	2	2	1	2	0	1
$\Sigma 0$		6	0	1	0	1	0	0	1	1	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	2	0	1	0
Total		0	0	1	0	1	0	0	1	1	0	0	2	0	1	1	0	0	0	1	1	0	1	0	0	0	0	3	2

Table I.3: Pugh matrix – Third iteration.

Pugh Matrix - Third iteration		Ref. 31	3	6	15	18	21	22	24	33	34	36	39	42	47	48	49	51	52	54	57	58	60	63	64	68	69	71	72
Criteria																													
Perceived as robust		0	-	+	-	+	-	-	+	-	-	-	-	-	-	+	0	-	-	+	-	-	+	-	-	-	-	-	+
Weather resistance		0	-	-	-	-	0	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+
Ease of use		0	+	+	+	+	-	+	0	+	+	0	+	-	+	0	0	+	+	0	+	+	-	+	+	+	+	+	0
Durability		0	0	0	-	+	-	-	0	-	0	+	-	0	-	-	0	-	-	-	+	-	+	-	0	-	-	+	+
Σ^+		0	1	2	1	3	0	1	2	1	1	2	1	0	1	1	0	1	1	2	1	1	3	2	1	1	1	2	3
Σ^-		0	2	1	3	1	3	3	0	3	2	1	3	3	3	2	1	3	3	1	3	3	1	2	3	2	3	2	0
$\Sigma 0$		6	1	1	0	0	1	0	2	0	1	1	0	1	0	1	3	0	0	1	0	0	0	0	0	1	0	0	1
Total		0	-1	1	-2	2	-3	-2	2	-2	-1	1	-2	-3	-2	-1	-1	-2	-2	1	-2	-2	2	0	-2	-1	-2	0	3

Table I.4: Summary of Pugh matrix evaluation.

Concept	Pugh 1	Pugh 2	Pugh 3	Total score	Comment	Decision
3	-2	0	-1	-3	Similar to Concept 63; Concept 63 performed better and was selected instead.	Remove
6	-2	1	1	0	Similar concepts, only Concepts 36 and 72 were selected to proceed.	Remove
15	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
18	-2	1	2	1	Similar concepts, only Concepts 36 and 72 were selected to proceed.	Remove
21	-2	0	-3	-5	Performed poorly in the Pugh matrices.	Remove
22	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
24	0	1	2	3	Similar concepts, only Concepts 36 and 72 were selected to proceed.	Remove
31	-1	1	0	0	Performed well, selected to proceed.	Continue
33	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
34	-2	0	-1	-3	Selected to proceed.	Continue
36	0	2	1	3	Performed well; selected to proceed.	Continue
39	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
42	-1	1	-3	-3	Similar to other screw-based solutions; better options were selected.	Remove
47	-1	0	-2	-3	A magnet-based concept performed better.	Remove
48	-1	1	-1	-1	Similar to Concepts 36 and 72 already selected.	Remove
49	-3	0	-1	-4	Performed poorly in the Pugh matrices.	Remove
51	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
52	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
54	-1	1	1	1	Similar concepts; only Concepts 36 and 72 were selected to proceed.	Remove
57	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
58	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
60	0	1	2	3	Similar concepts; only Concepts 36 and 72 were selected to proceed.	Remove
63	-2	0	0	-2	Selected to proceed.	Continue
64	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
68	-1	0	-1	-2	Selected to proceed.	Continue
69	-2	0	-2	-4	Performed poorly in the Pugh matrices.	Remove
71	-1	3	0	2	Performed well; selected to proceed.	Continue
72	0	2	3	5	Performed well; selected to proceed.	Continue

J Pairwise Comparison Matrices

	Weather resistance	Aesthetics	Cost	Ease of use	Durability	Robustness	Sum	Weight
Weather resistance		1	1	1	0,5	0	3,5	0,233
Aesthetics	0		0	1	0	1	2	0,133
Cost	0	1		1	0	1	3	0,200
Ease of use	0	0	0		0	1	1	0,067
Durability	0,5	1	1	1		1	4,5	0,300
Robustness	1	0	0	0	0		1	0,067

(a) Project team (Member 1)

	Weather resistance	Aesthetics	Cost	Ease of use	Durability	Robustness	Sum	Weight
Weather resistance		1	1	1	0,5	1	4,5	0,321
Aesthetics	0		1	1	0	1	3	0,214
Cost	0	0		0	0	1	1	0,071
Ease of use	0	0	1		0	1	2	0,143
Durability	0,5	1	1	1		1	4,5	0,321
Robustness	0	0	0	0	0		0	0,000

(b) Project team (Member 2)

	Weather resistance	Aesthetics	Cost	Ease of use	Durability	Robustness	Sum	Weight
Weather resistance		1	1	1	0,5	1	4,5	0,300
Aesthetics	0		0	1	0	1	2	0,133
Cost	0	1		0	0	1	2	0,133
Ease of use	0	0	1		0	1	2	0,133
Durability	0,5	1	1	1		1	4,5	0,300
Robustness	0	0	0	0	0		0	0,000

(c) Installer perspective

	Weather resistance	Aesthetics	Cost	Ease of use	Durability	Robustness	Sum	Weight
Weather resistance		1	1	1	0,5	1	4,5	0,321
Aesthetics	0		0	0,5	0	1	1,5	0,107
Cost	0	0		0,5	0	1	1,5	0,107
Ease of use	0	0,5	0,5		0	1	2	0,143
Durability	0,5	1	1	1		1	4,5	0,321
Robustness	0	0	0	0	0		0	0,000

(d) Company perspective

Figure J.1: Pairwise comparison matrices used to determine the relative weighting of evaluation criteria for different stakeholder perspectives.

K Kesselring Matrix

Table K.1: Combined Kesselring matrix using weighting factors based on the pairwise comparison matrices across all stakeholder perspectives, resulting in an overall concept ranking.

Concepts		Ideal		31		34		36		63		68		71		72	
Criteria	w	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t
Weather resistance	0,29	5	1,44	3	0,87	3	0,87	5	1,44	3	0,87	1	0,29	1	0,29	5	1,44
Aesthetics	0,14	5	0,72	1	0,14	3	0,43	4	0,57	2	0,29	5	0,72	5	0,72	4	0,57
Cost	0,13	5	0,63	3	0,38	4	0,51	5	0,63	4	0,51	5	0,63	4	0,51	5	0,63
Ease of use	0,12	5	0,60	2	0,24	4	0,48	3	0,36	4	0,48	3	0,36	4	0,48	3	0,36
Durability	0,31	5	1,53	3	0,92	2	0,61	4	1,22	2	0,61	2	0,61	2	0,61	4	1,22
Robustness	0,02	5	0,08	4	0,07	3	0,05	4	0,07	3	0,05	3	0,05	3	0,05	4	0,07
$T = \sum t_i$		5		2,61		2,94		4,30		2,80		2,66		2,65		4,30	
T/Tmax		1		0,52		0,59		0,86		0,56		0,53		0,53		0,86	
Ranking				7		3		1		4		5		6		1	

Table K.2: Concept rankings based on the Kesselring matrices, evaluated across different stakeholder perspectives, where 1 represents the highest-ranked concept and 7 the lowest.

	Concepts						
Perspective	31	34	36	63	68	71	72
Team + Company	7	3	1	4	5	6	1
Company	5	3	1	4	7	6	1
Installer	5	3	1	4	7	6	1
Team + Company + Installer	7	3	1	4	5	6	1

L Concept Evaluation

This appendix presents a more detailed evaluation of the four remaining concepts following the concept scoring phase. The concepts were assessed based on identified advantages and disadvantages related to usability, sealing performance, manufacturability and robustness. The evaluation supported the selection of the final concept for continued development.

Concept 34 offers a solution where the housing applies direct pressure onto the O-ring, which is beneficial for sealing performance. The design also allows the fastening mechanism to be hidden, resulting in a more visually appealing product. In addition, it is easier to open compared to screw-based solutions and does not include loose components. However, the concept is currently complex to manufacture and relies on non-standard components, which may complicate replacement if parts are lost. It also requires tools and a relatively stiff lid to ensure even pressure distribution. Compared to screw-based solutions, the achievable sealing pressure may be lower.

Concept 63 enables tool-free opening and closing, which improves usability. It also applies direct pressure onto the O-ring and is relatively simple to operate. On the other hand, achieving sufficient sealing may make the mechanism difficult to open. The design includes plastic parts that stick out and may break easily.

Concept 68 is also tool-free and easy to open, while offering a clean and minimalistic design. However, there are uncertainties regarding the sealing performance, as it may be difficult to achieve sufficient pressure on the O-ring. Integrating a sliding mechanism with sealing elements can be challenging and small plastic features may be easy to break. Additionally, the opening mechanism may not be intuitive for first-time users, and the design could be difficult to manufacture without through-holes.

Concept 72 is based on a screw-fastened design, which is straightforward to manufacture and provides reliable sealing due to the ability to apply high and even pressure on the O-ring. The screws can also be positioned to remain hidden, improving aesthetics. The concept is perceived as robust and reliable. However, it requires tools for opening and closing, and the screws may be lost if not properly integrated into the design. Opening the housing takes more time compared to tool-free solutions.

M Final Concept Iterations

Figure M.1 presents the evaluated design variations of screw placement and hook geometry developed during the final concept selection phase. The black circles indicate different screw positions evaluated to study how the placement affected pressure distribution across the gasket. The red lines represent variations in hook geometry, including differences in hook length and placement, developed to investigate whether usability could be improved while maintaining sufficient sealing performance.

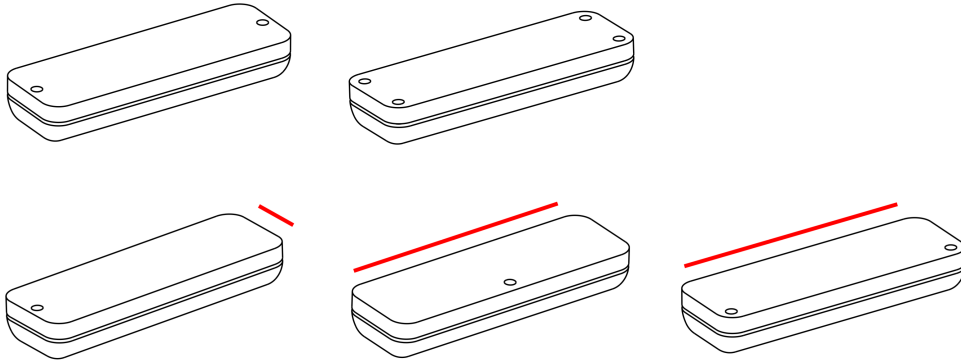


Figure M.1: Design variations of screw placement and hook geometry.

The design variations were developed in CAD and evaluated through assembly and screw-tightening tests using 3D-printed prototypes. The evaluation showed that screw placement significantly affected pressure distribution across the gasket. Configurations using two screws provided the most even pressure distribution and best sealing performance. Hook-based and combined concepts failed to achieve sufficient gasket compression and were therefore discarded. As a result, Concept 72 was selected as the final design direction due to its superior sealing performance.

N Morphological matrix for the system and electronics

Table N.1: Morphological matrix with all sub-solutions for the system and electronics.

Sub Function	Sub Solution									
Detect wind	Accelerometer	Anemometer	Ultrasonic wind sensor							
Monitor sunshade operating status	Send signals when needed and query the control system / motor / JAL for status	The control system only sends a signal when the awning is extending and when it is retracting	The control system continuously sends status signals to the sensor	The sensor detects wind and thereby infers that the awning is deployed	Tilt sensor slightly different value than when awning stowed	The sensor determines its position relative to the wall/motor, or how far the awning is extended	Limit switches at end positions	Magnetic switch	Optical sensor	proximity sensor
Configure sensor	Adjustable threshold via potentiometer	Button based adjustment	Adjustable threshold via app/software	Adjusted at the awning controller						
Decide when protective action is required	Fixed threshold	Multi-level thresholds, where the awning is retracted a bit for each level	Cost-based triggering, from sudden powerful acceleration	State-dependent thresholds varying with the current extension length of the awning	Trigger when wind/vibration increases rapidly compared to how it was recently	Time above threshold	Thresholds adjusted for different contexts, like rain, freezing, user control	Combine multiple indicators	User-selectable sensitivity	Adaptive/self-calibrating sensitivity
Handle manual vs automated operation modes	Automation always overrides user control	Manual override with hard safety limit	Time-limited manual override	Hold to override. Can only manual control when holding down (button)	Priority hierarchy (Safety > Local manual > Remote/App)	Context dependent override rules	Confirmation-based override	Local override dominates remote commands	Automatic fallback to automation on fault/loss of communication	Installer configurable authority policy
Manage power consumption	Deep sleep with periodic wake-ups	Interrupt-driven wake	Adaptive (increases sampling during windy conditions)	Communication minimization	Temperature adjusted power strategy (reduce when cold)	Hardware power gating				
Prevent sensor failures from causing damage	Fail-safe, if sensor unavailable or uncertain data, awning is stowed	More than one sensor	Two accelerometers	Watchdog, if sensor stops reporting, stow awning	Periodic self tests, to see if everything is working	Fall back to conservative/safer rules	Power-failure detection	Communication and tests to verify the sensor is attached to awning		
Provide power supply	Batteries	Solar cells	Wireless charging	Rechargeable	Mains powered 230V	Power from motor/controller				
Show battery status	On the sensor (LED indicator)	On a remote control	On the awning (slightly retracts or extends to indicate)	Sound from the sensor	Mobile app					

O Product architecture

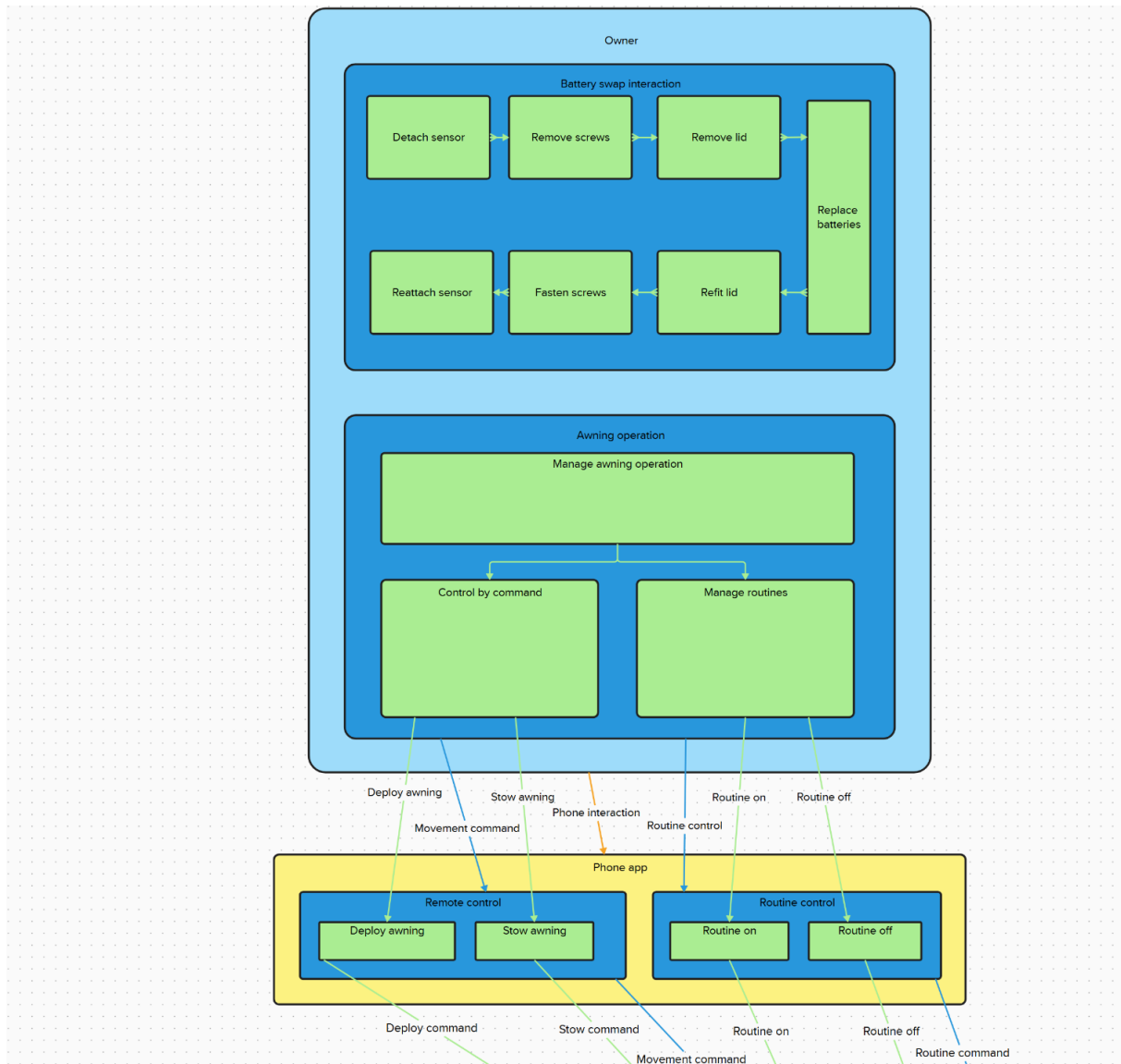


Figure O.1: Product architecture over entire system. This figure shows the owner and phone app.

The diagram illustrates the functional architecture of an awning system, organized into several interconnected blocks within a larger system boundary:

- Power Supply Block:** Receives *Electric power* (120/240 V terminals) and provides *Power* to the *Pipe motor*.
- Pipe motor Block:** *Convert power to rotation* and *Provide torque*. It receives a *State signal* and sends a *State* signal back.
- Drive train Block:** *Torque transmission* and *Transmit torque*. It receives *Torque* from the pipe motor and provides *Transmitted torque* to the fabric roller.
- Fabric roller Block:** *Rotation* and *Rotate roller*. It receives *Roller coupling* from the drive train and provides *Fabric attachment Tension transfer* to the awning fabric.
- Awning arms Block:** Contains two sub-blocks:
 - Articulated support* (Support front bar through jointed motion) and *Load transfer to mounting side* (Transfer loads to the mounting side).
 - It receives *Articulated joint* from the articulated connection and provides *Structural load* to the load distribution block.
- Awning fabric Block:** *Fabric attachment* and *Tension transfer*. It receives *Roll/unroll motion* from the fabric roller and provides *Tensile load* to the fabric attachment block.
- Articulated connection Block:** *Articulated connection* and *Recieve articulated support*. It receives *Mechanical coupling* from the pipe motor and provides *Articulated joint* to the articulated support.
- Load distribution Block:** *Load distribution* and *Distribute loads along the front bar*. It receives *Load transfer* from the articulated support and provides *Front bar* to the fabric attachment.
- Fabric attachment Block:** *Fabric attachment* and *Attach fabric and recieve tensile load*. It receives *Fabric attachment* from the awning fabric and provides *Tensile load* back to the fabric attachment.

External inputs and outputs include *Wire* (input to pipe motor), *Mechanical attachment* (input to articulated connection), and *Vibration input* (input to load distribution).

XXIII

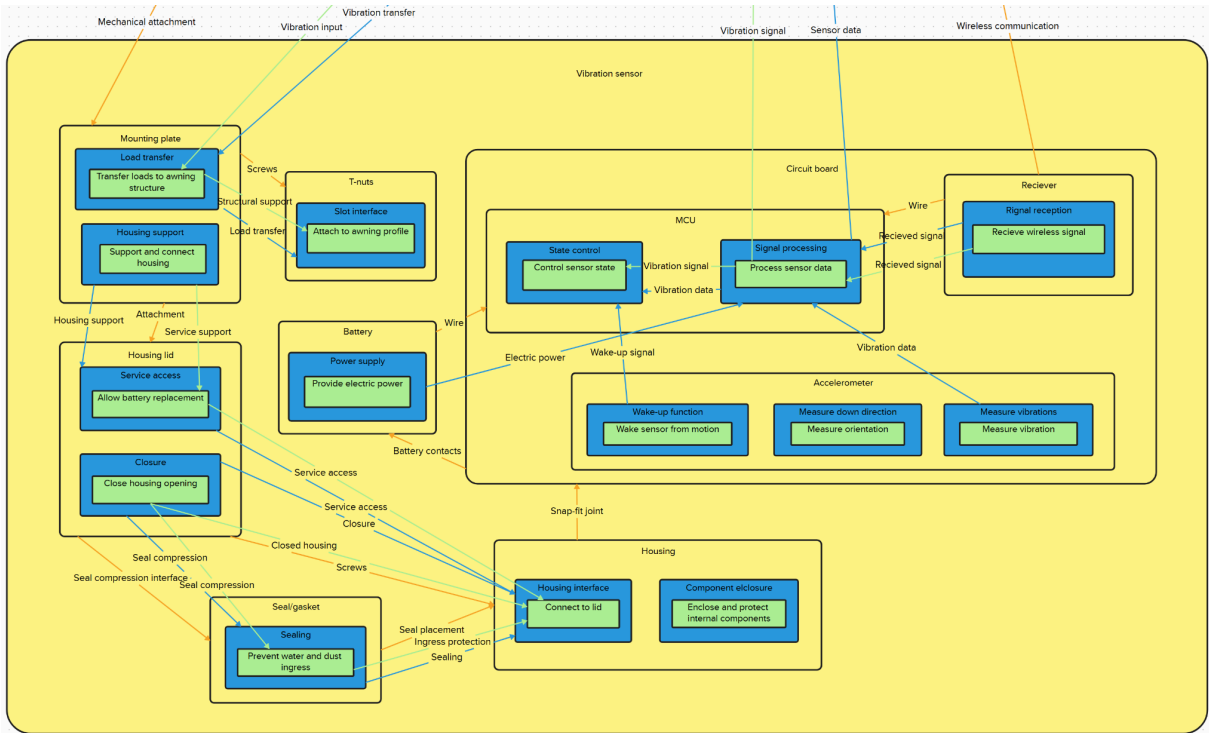


Figure O.4: Product architecture over entire system. This figure shows the vibration sensor.

P T-slot Profile Geometry

Profile geometries from different awning brands and models were examined to support the design of compatible t-nuts. The investigated profiles included variations in slot width, depth and overall geometry. The measured dimensions shown in Figure P.1 and Table P.1 were used as reference values during the design process.

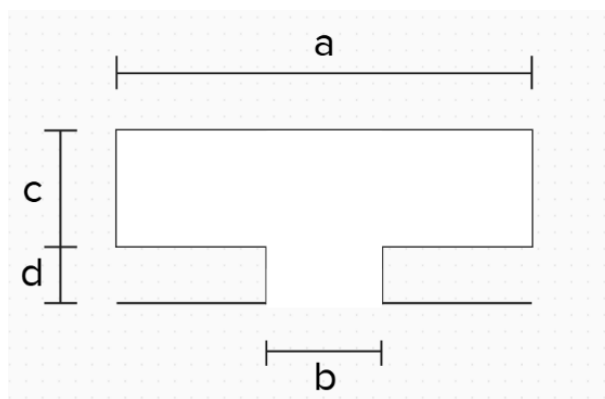


Figure P.1: Definition of t-slot profile dimensions.

Table P.1: Measured dimensions (a–d) of t-slot profiles from different awning brands and models. N/A indicates that the dimension could not be measured.

Model	a (mm)	b (mm)	c (mm)	d (mm)
1	22	8	6	3–4
2	16	9	5	3
3	23	9	8	2
4	38	17	7	2
5	N/A	8,5	N/A	N/A
6	N/A	8	N/A	N/A

Q Development of T-slot Nuts

This appendix presents the evaluations and physical testing that formed the basis for the selected t-slot nut geometry, dimensions and material.

Q.1 Geometry Considerations

Based on the measured t-slot dimensions, different t-nut geometries were considered (Figure Q.1) to ensure compatibility with varying slot sizes across awning brands and models. The slot width (X) must be small enough for insertion into different openings (dimension b in Figure P.1), while the length (Y) must be sufficient to contact the inner walls and enable locking (dimension a in Figure P.1). At the same time, Y must be limited to prevent interference between the two t-nuts used in the design. Therefore, the dimensions were selected to fit both smaller and larger slot sizes.

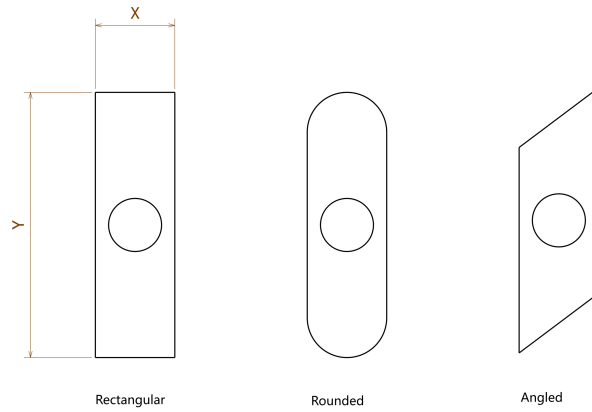


Figure Q.1: Different t-slot nut geometries considered.

Q.2 Width Evaluation

Five competitors were analyzed, where two used identical t-slot nut dimensions. To evaluate compatibility, two t-slots with opening widths of 7 mm and 10 mm were 3D printed and tested together with real awnings. The tests showed that some existing t-slot nuts were too wide to fit narrower slot geometries.

Additional t-slot nuts with widths of 7, 6 and 5 mm were therefore manufactured and evaluated. A width of 5 mm was found to be the minimum possible due to the approximately 4 mm screw hole diameter. However, the 5 mm version showed insufficient strength and risk of failure. A width of 6 mm provided a better balance between compatibility and structural strength and was therefore selected.

Although the smallest measured slot width was 8 mm, a width of 6 mm was selected instead of 7 mm to ensure compatibility with potentially smaller slots.

Table Q.1: Dimensions of competitor t-slot nuts.

Item	Length [mm]	Width [mm]	Thickness [mm]	Material
Competitor 1	29.9	9.25	3.95	Steel
Competitor 2	29.9	9.25	3.95	Steel
Competitor 3	29.95	9.45	3.6	Aluminum
Competitor 4	35.8	5.75	6.0	Plastic
Competitor 5	35.8	5.75	3.95	Plastic

Q.3 Material Evaluation

Competitors 1 and 2 used steel t-slot nuts, Competitor 3 used aluminum and Competitors 4 and 5 used plastic (ASA). During testing, the thinner plastic t-slot nuts deformed during screw tightening, indicating insufficient stiffness. Although increased thickness reduced deformation, plastic was not selected since greater thickness would reduce compatibility with shallow slot geometries. The testing showed that a stiffer material was required to ensure reliable fastening while maintaining a low profile. Steel was therefore selected.

Q.4 Length Evaluation

The length was also found to significantly influence locking performance. Excessively long t-slot nuts reduced the contact area during rotation and locking, resulting in less secure attachment. Shorter nuts improved contact area and grip but could rotate freely if too short to engage with the slot walls. Testing and competitor analysis showed that existing solutions commonly used lengths of approximately 30 mm, which was therefore selected.

Q.5 Final Dimensions

Based on measurements, competitor analysis and physical testing, the final t-slot nut was dimensioned with a width of 6 mm, a length of approximately 30 mm and a thickness of 3 mm.

R Housing Design Iterations

Several housing geometries were explored during the development process to minimize the overall product size while accommodating the batteries and circuit board. The concepts differed mainly in edge geometry and overall shape, with the housing adapted to follow the battery geometry as closely as possible. The variations were evaluated based on compactness, manufacturability, usability and visual integration. The rounded housing geometry shown in the upper-left concept was selected for the final design due to its compact shape and improved visual integration.

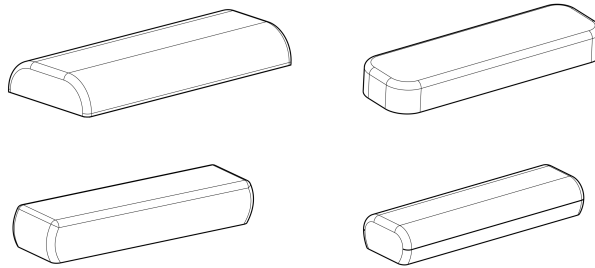


Figure R.1: Different housing design concepts considered for the final prototype.

S Detailed Material Evaluation

This appendix presents additional material evaluation results and literature findings supporting the material selection process described in Section 7.6. The appendix includes detailed material property discussions, Granta EduPack screening results and supplementary literature related to the selected housing and sealing materials.

To further support the selection, a literature study of ASA was conducted in addition to the Granta EduPack analysis. According to (Rimdusit et al., 2014), ASA provides good UV resistance, color stability, weatherability, impact strength, thermal stability and resistance to aging, making it suitable for long-term outdoor applications exposed to sunlight, environmental stresses and temperature variations. The material retains both mechanical and visual properties during prolonged outdoor exposure and supports the intended product lifespan (Rimdusit et al., 2014).

Studies also show that ASA performs well under repeated thermomechanical processing and can be recycled multiple times while maintaining, and in some cases improving, its mechanical properties (Vidakis et al., 2025). This supports its suitability for thermal reprocessing and applications requiring long-term material stability. From an environmental perspective, the durability, long service life and recyclability of ASA can reduce material consumption, resource use and waste generation. In addition, polymers such as ASA provide a good balance between cost and performance, supporting cost-effective product development (Vidakis et al., 2025).

T Bill of Materials (BOM)

Table T.1: Bill of Materials for the final prototype.

Item	Component	Description	Quantity	Material
1	Housing (top)	Upper housing part	1	ASA
2	Housing (bottom)	Lower housing part	1	ASA
3	Mounting plate	Interface to awning	1	ASA
4	Gasket	Sealing between the two housing parts	1	EPDM
5	T-slot nuts	Attachment to awning slot	2	Stainless steel A4-70
6	MC6S M3×8 screw	Housing assembly	2	Stainless steel A4-70
7	MF6S M4×10 screw	Mounting plate attachment to awning	2	Stainless steel A4-70

U Detailed Manufacturing Cost Estimation

This appendix presents the detailed equations, assumptions and supporting calculations used for the manufacturing cost estimation presented in Section 7.10. The manufacturing cost was estimated using the following equations and input parameters presented in Table U.1, representing a simplified manufacturing cost analysis.

$$C_{t,tot} = C_{t,1} + C_{t,2} + C_{t,3} \quad (.1)$$

$$C_m = m \cdot P_{material} \quad (.2)$$

$$C_p = C_{machine} + C_{manual,labor} + C_{overhead} \quad (.3)$$

$$C_{machine} = \frac{P_{machine}}{3600} \cdot t_{cycle} \quad (.4)$$

$$C_{overhead} = \alpha \cdot C_{machine} \quad (.5)$$

$$C_{manual,labor} = \frac{P_{labor}}{3600} \cdot t_{manual,labor} \quad (.6)$$

Table U.1: Input parameters used in the manufacturing cost estimation.

Parameter	Description	Value	Unit
$C_{t,tot}$	Total tooling cost	196 446	SEK
N	Production volume	10 000	[-]
$P_{material}$	Material price (Granta EduPack)	27.3	SEK/kg
m	Part mass from CAD model	0.03149	kg
$C_{machine}$	Processing cost per sensor	Calculated using Eq. .4	SEK
C_{labor}	Labor cost per part	Calculated using Eq. .6	SEK
$C_{overhead}$	Energy, maintenance, facility costs	Calculated using Eq. .5	SEK
$P_{machine}$	Machine cost	600	SEK/h
$t_{cycle,tot}$	Total cycle time	74.4	s
P_{labor}	Labor cost	280	SEK/h
α	Overhead factor	0.2	[-]
$t_{manual,labor}$	Assembly time per sensor	10	s

A production volume of 10 000 units was assumed for the cost estimation.

The total tooling cost, $C_{t,tot}$, represents the cost of manufacturing the injection mold, treated as a fixed investment distributed over the production volume. It was estimated using the online quotation tool (Xometry, 2026), where separate quotations were obtained for each mold and summed to determine the total tooling cost. The quotation resulted in a tooling cost of 96 685 SEK for international production and 196 446 SEK for production in the USA. Since the product is intended to be manufactured in Sweden, where production costs are generally higher than in low-cost countries, the USA quotation was selected as a conservative estimate. Since the value is based on an online quotation and prototype-oriented manufacturing rather than optimized large-scale production, it should be considered as an approximation.

An overhead factor of $\alpha = 0.2$ was assumed based on reported indirect manufacturing costs of approximately 25% of labor costs (Eurostat, 2026). The labor cost, P_{labor} , was estimated from an average manufacturing wage of approximately 225 SEK/h in Sweden (Trading Economics, 2026). Including additional non-wage costs (Eurostat, 2026), the total labor cost was estimated to approximately 280 SEK/h.

The machine cost, $P_{machine}$, was assumed to be 600 SEK/h, representing a reasonable estimate for injection molding including operation and maintenance costs (Kamalrudin et al., 2008). The cycle time, $t_{cycle,tot}$, was calculated in SolidWorks by summing the filling, cooling and ejection times for all three parts, resulting in a total cycle time of 74.4 s. The assembly time, $t_{manual,labor}$, was estimated to 10 s based on manual assembly operations for the housing assembly.

$$C_m = 0.03149 \cdot 27.3 = 0.859677 \text{ SEK} \quad (.7)$$

$$C_{machine} = \frac{600}{3600} \cdot 74.4 = 12.4 \text{ SEK} \quad (.8)$$

$$C_{manual,labor} = \frac{280}{3600} \cdot 10 = 0.7778 \quad (.9)$$

$$C_{overhead} = 0.2 \cdot 12.4 = 2.48 \quad (.10)$$

$$\Rightarrow C_p = 12.4 + 0.7778 + 2.48 = 15.6578 \quad (.11)$$

$$C_{part} = \frac{196\,446}{10\,000} + 0.859677 + 15.6578 = 36.16 \text{ SEK} \quad (.12)$$

V Design risks and possible mitigations

Table V.1: Identified design risks and possible mitigations.

Area	Main risk	Possible mitigation
T-nuts	Incompatible T-slot dimensions, insufficient strength or slipping may prevent secure attachment to some awning profiles.	Investigate larger range of awning profiles, adjust T-nut geometry and define tightening torque.
Mounting screws	Included screws may be too long or too short for some T-slots, preventing proper clamping.	Include alternative screw lengths or provide guidance on selecting screw lengths based on T-slot geometry.
Mounting plate	The plate may bend against curved profiles or become damaged around screw slots.	Increase local stiffness, reinforce screw slots.
Bayonet mechanism	Uneven mechanism engagement, wear or broken features.	Add markings for attachment, asymmetric keying, make attachment more intuitive and make geometry stronger with more cycle testing.
Sensor attachment	If the sensor detaches or is poorly coupled to the awning, the system may receive data that doesn't represent the actual awning movement.	Use attachment detection, monitor sensor orientation or periodic user confirmation.
Sealing gasket	Misplacement, contamination, damage or uneven compression of the gasket may reduce ingress protection.	Improve gasket positioning control, more testing of ingress protection and recommend service to be performed in a clean environment.
Housing halves	Deformation, creep, thin walls or stress concentrations may affect sealing, alignment or durability.	Adjust wall thickness, add ribs and fillets, and validate through further prototype testing and simulations.
Corrosion and condensation	Moisture, salt exposure or internal condensation may affect screws, T-nuts, battery contacts or electronic components.	Verify corrosion resistance of selected materials and surface treatments and evaluate moisture control.
Batteries and contacts and PCB support	Wrong battery type, incorrect polarity, leakage, vibration, weak spring force or insufficient PCB support may cause power loss, internal damage or solder joint failure.	Add polarity and battery type markings, use robust corrosion-resistant contacts, support contact springs and provide defined PCB support surfaces.

Area	Main risk	Possible mitigation
Service access	Incorrect reassembly after battery replacement or service may reduce sealing or attachment performance.	Add alignment features, visible gasket positioning, clear service instructions, feedback for correct closure and recommend service in a clean environment.
Tolerances and manufacturing	Injection molding shrinkage, warpage, dimensional variation or manufacturing defects may affect sealing performance and mounting mechanism.	Perform tolerance analysis, dimensional inspection during pilot production, mold-flow/warpage validation and quality control of critical interfaces.

