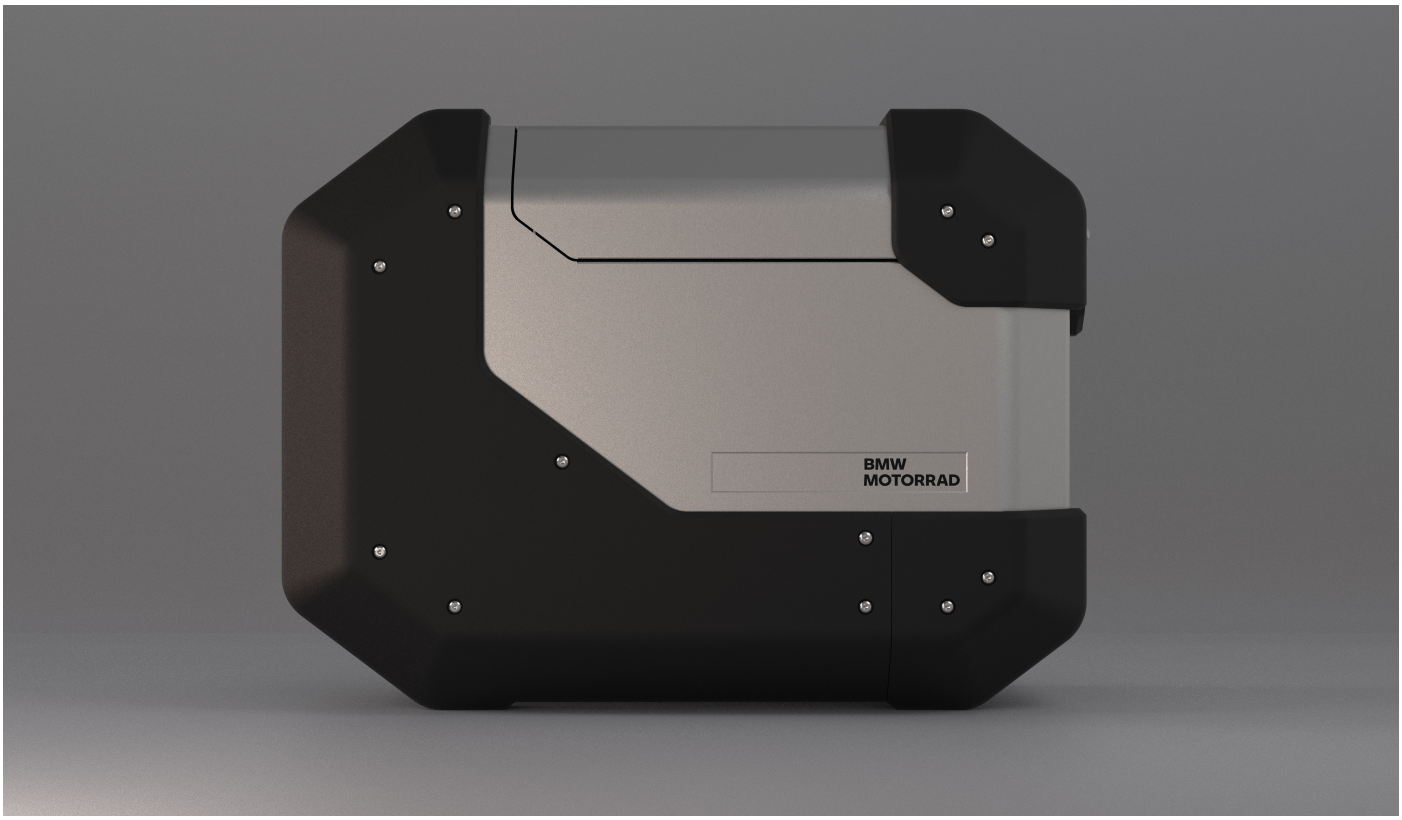
Master Thesis

BMW GS PROTERRA

A REPAIRABLE CONCEPT LUGGAGE STORAGE SYSTEM FOR BMW MOTORRAD



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Delft, May 2025

Delft University of Technology
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Master Integrated Product Design

BMW MOTORRAD TU Delft

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GRADUATION DATE
23rd of May 2025

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TU Delft

BMW MOTORRAD

Acknowledgement

Elmer Thank you for your continuous support and guidance. I have gained a great deal of knowledge from you, not only throughout this project, but also during the Minor ‘People in Transit’, various Master’s courses and the preparation phase leading up to this graduation project. I especially appreciate your ability to ask critical questions that were necessary for shaping the direction of this project. This kind of challenge has consistently pushed me to develop new skills and grow both personally and professionally.

Stefan Thank you for your guidance and support throughout this project. I always felt welcome to step into your office for feedback or a positive mindset boost whenever I encountered challenges.

Bart I would like to thank you for the opportunity to complete my graduation project in collaboration with BMW Motorrad, and for the valuable discussions we had throughout the process. Every meeting offered me a unique insight into motorcycle design and consistently left me feeling inspired. The skills and insights you shared have significantly contributed to my development as a designer and have strengthened my design capabilities.

PMB Thank you, Don, René, Wiebe, Ismaël and Kevin, for all your help in building my prototypes. Your knowledge and insights were invaluable in helping me create the prototypes for this project.

Luuc Thank you for being there for me. I could always count on your honest advice and unconditional support.

EXECUTIVE SUMMARY

This graduation project, conducted in collaboration with BMW Motorrad and TU Delft, presents the BMW GS Proterra concept: a repairable and sustainable aluminium luggage storage system (LSS) developed for the BMW R 1300 GS Adventure. The objective is to create a concept that facilitates effortless lifespan extension through circular design strategies, while addressing the diverse needs of GS riders.

Problem

The construction of the existing aluminium GS Adventure LSS presents significant challenges with regard to disassembly, repair practices and reuse. The used connections are non-reusable rivets, making it almost impossible to replace individual components. Unfortunately, this often results in the entire LSS being replaced. This premature disposal is further driven by the desire of GS riders to maintain the 'as new' appearance of their motorcycles and LSS.

Research and analysis

Research into the behaviour and experiences of BMW GS riders with regard to damage and repair practices revealed that most damage occurs at low speeds. Although 60% of users attempted to repair the damage themselves, barriers such as inaccessible parts and complex assembly processes prevented more widespread repair practices. Assessment methods such as Hotspot Mapping and Disassembly Mapping confirme that priority parts are difficult to access due to high-force, non-reusable connections, and that a large number of dependent actions are necessary before removal. This makes successful roadside repairs and efforts to extend the LSS's lifespan unlikely.

Design strategy

In response, the concept of a sacrificial design was developed, involving the incorporation of features designed to absorb external impact forces. This reduces the forces that reach the core structure and minimises its plastic deformation drastically. The sacrificial parts that absorb impact forces are designed to deform and are easily replaceable, thereby making it possible to prolonging the LSS's lifespan and retaining value for the GS rider. Additionally, this design strategy allows visible wear and tear to be accepted as part of the product's robust and durable narrative.

Concept

The BMW GS Proterra concept is an all-terrain aluminium LSS that demonstrates how sacrificial design can enhance durability, user engagement, and emotional attachment. The architecture of the system places vulnerable components safely inside, while positioning easily replaceable sacrificial parts externally. GS riders have the option of retaining signs of wear as evidence of their past adventures or restoring the appearance by replacing these parts. The final concept was validated using a high-fidelity aluminium prototype, confirming the ease of part replacement.

Future application

The project offers valuable insights for both BMW Motorrad and TU Delft by demonstrating how repairability and sustainable product design can align with aesthetic and functional objectives. The GS Proterra is a valuable source of inspiration for the implementation of circular design in mobility products and has the potential to influence future product development within BMW Motorrad.

TABLE OF CONTENT

GLOSSARY

ADV	Adventure
CE	Circular Economy
Enduro	Type of motorsport run on off-road and cross-country terrain.
Frangible	When an object is designed to break in a designated location.
GS	Gelände/Straße, which translates to off-road/road. Used as a model designation by BMW Motorrad.
GSA	GS Adventure model designation
LSS	Luggage Storage System
OEM	Original Equipment Manufacturer
Pannier	A luggage storage system carried in pairs on the sides of a motorcycle
Proterra LSS	Name of the final concept: Protection All-Terrain Aluminium Luggage Storage System

CHAPTER 1

INTRODUCTION OF THE PROJECT

This chapter introduces the project, including the project assignment, research questions and the project approach.

Content

PROJECT PARTNERS

This graduation project marks the final step towards graduating from the Master's programme in Integrated Product Design at Delft University of Technology, and has been conducted in collaboration with the Design department of BMW Motorrad.

BMW Motorrad Design Department

BMW Motorrad is a manufacturer of motorcycles. The design department is responsible for the development and design of new motorcycles.

For BMW Motorrad, the primary interest lies in the design of a showcase concept for sustainable and repairable principles in the context of motorcycle luggage storage systems. The insights derived from this project have the potential to contribute to future BMW projects.

BMW Motorrad Nederland

BMW Motorrad Nederland is the local partner in this project.

TU Delft

Delft University of Technology is a technical university in the Netherlands, this graduation thesis is the final project for the Master Integrated Product Design, given at the facutly of Industrial Design Engineering.

The project introduces a novel design approach for developing products in the automotive sector. The approach is centred on enhancing durability and providing users with greater opportunities to extend the lifespan of their LSS. The insights gained from the design and development of this concept LSS are invaluable to TU Delft, as it facilitates a connection between sustainable thinking and practical consumer product design.

DOMAIN OF THIS PROJECT

This graduation thesis is situated within the domain of automotive design, innovation, and sustainability. The focus is on the implementation of R-strategies, including repairability, in the context of luggage storage systems (LSS) for BMW Motorrad GS Adventure models.

BMW's GS Adventure models are renowned for their versatility in both on- and off-road riding, making them a popular choice for a wide range of motorcycle riders, from commuters to long-distance travellers. Luggage storage systems are an essential component of the rider experience, allowing individuals to transport personal belongings during their journeys.

A standard luggage system for a BMW GS Adventure model consists of a luggage rack, two panniers, and a top case. The positioning of luggage systems on the exterior of the motorcycle renders them susceptible to damage, including scratches and dents. Unfortunately, this frequently results in the replacement of an entire case. A repair-focused luggage storage system enables the BMW GS rider to replace damaged parts, and thus the ability to extend the lifespan.

ASSIGNMENT & RESEARCH QUESTIONS

Problem Statement

Upon initial observation, the current luggage system for the BMW GS Adventure appears to be constructed with a number of non-reversible connections. These types of connections present a challenge when attempting to disassemble, repair, and reassemble the luggage system in a way that maintains all of its core functions, such as waterproofing and dust-proofing, at optimal levels.

Furthermore, the cost of purchasing these systems is considerable. The implementation of R-strategies, such as repairability, can effectively prolong the lifespan of these systems, thus reducing their impact on the environment and the costs for the GS rider. In addition, dents and scratches can be seen as aesthetically unpleasing and 'broken'. There is an opportunity to make repairability part of the design in an aesthetically pleasing way.

Project Assignment

The aim of this graduation project is to design a sustainable and repairable motorcycle luggage storage system for the BMW R 1300 GS Adventure, ensuring optimal user experience and prolonging the functional lifespan.

Research Questions

Core functions

RQ1 What are the main functions of a hard metal LSS?

RQ1.1 How does a GS rider use their motorcycle?
RQ1.2 In what situations are luggage storage systems used?
RQ1.3 What type of LSS do BMW GS riders use?

Damage

RQ2 Why are LSSs discarded?

RQ2.1 Which part of the a LSS is most susceptible to damage?
RQ2.2 In what situation do GS riders damage their LSS?
RQ2.3 Are riders of a BMW GS Adventure LSS able to prolong the lifespan after damage?

Circular Economy

RQ3 What is the current state regarding the Circular Economy for a BMW GS Adventure LSS?

RQ3.1 What is the current state regarding disassembly and reassembly of a BMW GS Adventure LSS?
RQ3.2 What parts of the analysed LSS are most important? (Priority parts)
RQ3.3 How repairable/replaceable are the priority parts?
RQ3.4 What is the current ecological impact?

Design strategy

RQ4 How can we prolong the lifetime of a LSS?

RQ4.1 What strategy can be implemented to increase the lifespan of a LSS for BMW R 1300 GS and R 1300 GS Adventure motorcycles?

PROJECT APPROACH

Project structure

The project is structured using the double diamond approach (Design Council, 2003), which consists of three diverging and converging phases during the project lifecycle. The approach and the process can be observed in Figure 1.1.

The project is initiated with an analysis phase. In this phase, the motorcycle, BMW Motorrad, the GS rider and its experiences with damage and repair, and the existing luggage storage system are investigated. This phase is followed by a research phase, in which circular assessment methods are utilised to evaluate the ease of disassembly and the current state of repair.

These findings have resulted in the formulation of a design direction. Ideation and conceptualisation using this design direction as a guideline ultimately led to the creation and selection of the final design. This final design was developed in the last diamond (see Figure 1.1).

Project approach

This project uses a research-through-design methodology, where the iterative creation and evaluation of ideas and concepts is the main way of generating knowledge. Through repeated cycles of design exploration, reflection and refinement, the project aims to establish a new approach to the development of automotive products. The approach focuses on enhancing product durability and empowering users to extend the lifespan of their LSS. The outcomes provide TU Delft with valuable insights by bridging the gap between sustainable design principles and real-world consumer product applications.

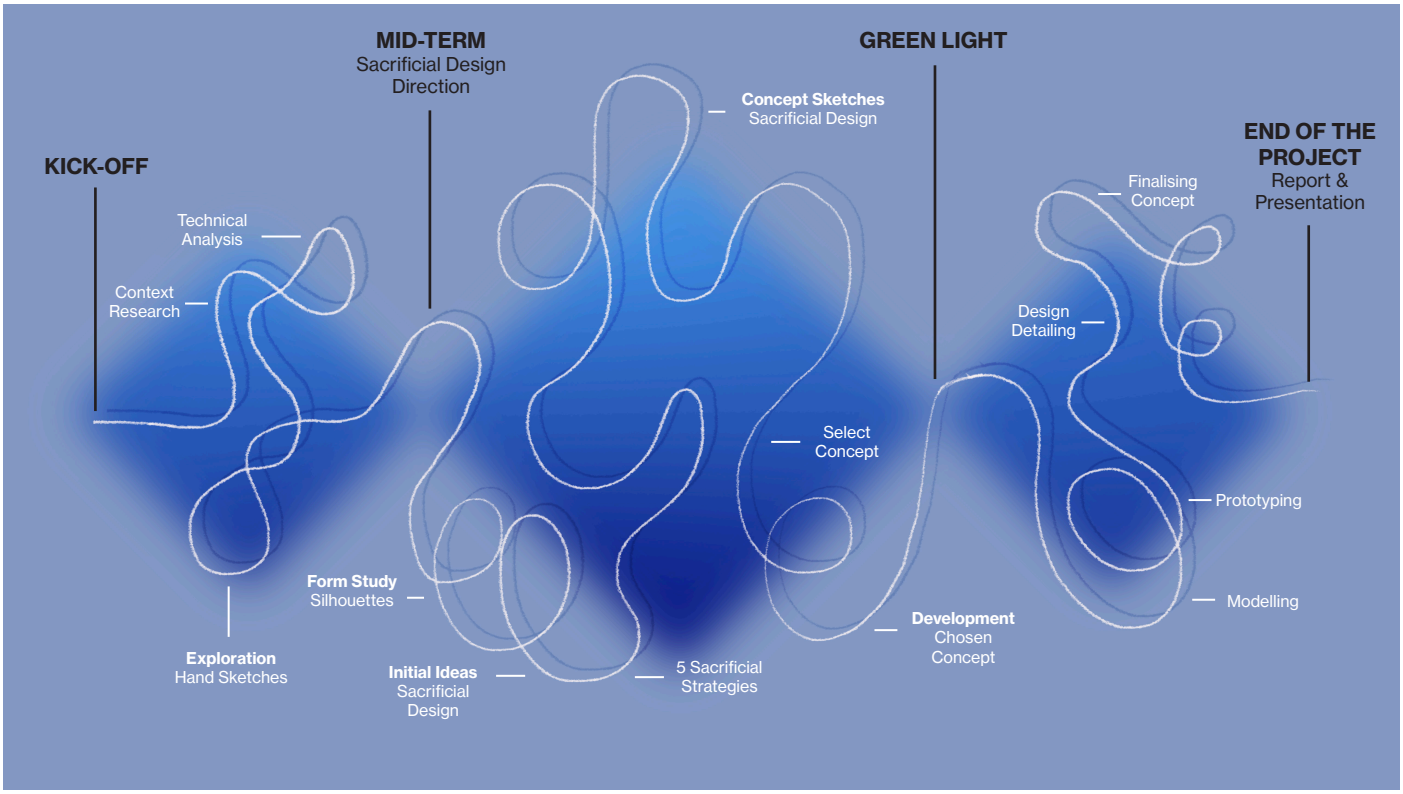


Figure 1.1 | Design Approach - Double diamond approach with process visualized.

CHAPTER 2

BMW MOTORRAD

For a better understanding of BMW and BMW GS, this chapter delves into the history of BMW GS, the R 1300 GS Adventure and its styling.

Content

History of BMW GS
Identity of BMW GS
BMW R 1300 GS Adventure
Design language analysis BMW R 1300 GS Adventure
Key finding BMW Motorrad

HISTORY OF BMW GS

BMW Motorrad's history goes back for more than a hundred years, full of stories and heritage (BMW Group, 2023).

BMW R 80 GS | The birth of the adventure motorcycle segment

BMW Motorrad is a recognised innovator in the motorcycle industry, setting the baseline for the entire sector. One of these significant innovations is the development of the adventure motorcycle (ADV) segment.

Prior to the 1980s, motorcycles were designed with a single, specific purpose in mind (Kusek, 2023). The 1980 BMW R 80 GS marked a significant shift in motorcycle design, being the first model to focus on both on-road and off-road capabilities (The Rise of the Adventure Motorcycle, 2024).

The 'GS' in the model name stands for 'Gelände/ Straße', which translates to 'off-road/road' in German. The history of the flagship boxer-engine GS models can be seen in Figure 2.1.

Paris-Dakar Rally | The growth of BMW GS

The BMW GS models gained worldwide recognition after winning the Paris-Dakar rally in 1981, 1983, 1984 (Lieback, 2024), 1999 and 2000 (GS Wolves Germany, 2021). The model's popularity was further enhanced by cultural icons such as Ewen McGregor in the series "The Long Way Round" (Lieback, 2024).

Unstoppable | BMW GS in 2024/2025

The ADV market and BMW GS products are still growing in popularity. The GS portfolio has grown from one model in 1980 to six in 2025, as can be seen in Appendix C. Furthermore, 2024 marked BMW Motorrad's highest worldwide sales of new motorcycles, with the GS models being a large contributor (BMW Motorrad Corporate Communications, 2025).

Popularity

This popularity has been growing due to the wide range of capabilities, high comfort levels, high-end technological features, implementation of innovative solutions, and aesthetic appeal. At the same time, these motorcycles can be large in size, have relative high weight and come with significant cost. Full explanation can be found in Appendix C.

BMW GS models are the swiss knife of motorcycles

It can be said that BMW GS motorcycles are the Swiss knife of motorcycles, practical for daily commute, a weekend stroll and long-distance travel (The Rise of the Adventure Motorcycle, 2024).

TIMELINE OF BMW GS MODELS

Figure 2.1 | BMW Motorrad GS - Model timeline

IDENTITY OF BMW GS

BMW Motorrad has a unique identity in the mobility sector, as demonstrated by its popularity of its GS portfolio. The GS core values and brand identity are Adventure and Robust, and are meticulously designed to deliver a product that meets the specific needs and desires of the adventure motorcycle rider.

These core values are: **Adventure** & **Robust**.

Adventure

Providing a motorcycle that enables and facilitates the rider to find and experience their own adventure is one of the core values of GS.

BMW's marketing and communication of the GS portfolio uses the tag #SpiritOfGS (Figure 2.2) and the tag-line 'The call of adventure' for its main communication (BMW Motorrad, 2024b). In addition, BMW Motorrad communicates adventure and boundless exploration, which is supported by concepts such as the 2024 BMW Concept F 450 GS (2024a) (Figure 2.3).

Robust

The adventure GS models in the portfolio focus even more on robustness with their go-anywhere capabilities and styling.

This is communicated through concept motorcycles such as the 2016 BMW Concept Lac Rose (Figure 2.4), which is inspired by and builds on the success of the original BMW R80 G/S Paris-Dakar. The ruggedness of the GS models is also demonstrated during the biennial GS Trophy Experience (Figure 2.5), where participants test their riding skills over several days in challenging riding conditions.

Figure 2.2 | Image BMW Motorrad website - Used to communicate their tag-line (BMW Motorrad, 2024b).

Figure 2.3 | 2024 BMW Concept F 450 GS.

Figure 2.4 | 2016 BMW Concept Lac Rose.

Figure 2.5 | 2024 BMW Motorrad - GS Trophy Namibia.

BMW R 1300 GS ADVENTURE

The BMW R 1300 GS Adventure (see Figure 2.6 on the next page) is the latest high-tech GS Adventure flagship from BMW Motorrad, replacing the successful and maxi-enduro class-leading R 1250 GS Adventure. The R 1300 GS Adventure shares a platform with the BMW R 1300 GS, RS, RT and S.

Market position of the BMW R 1300 GS and GS Adenture

Reiner Fings (Product manager BMW GS, 2024) elaborates that BMW has decided to spread the character of the two GS models, with the standard GS positioned as a more universal and every day motorcycle. While the GS Adventure positioned as a robust, can-do-anything multi-tool inspired multi-purpose motorcycle specialized for long distance travel, touring, and off-road riding.

Luggage storage systems (LSS) are popular in this segment of motorcycle, allowing the rider to pack all the necessary gear for their adventures. The next chapter will go into more detail about luggage racks and LSSs.

Luggage storage system part of the aesthetics

A large number of the BMW R 1300 GS Adventure motorcycles will be fitted with an aluminium luggage storage system (LSS). The aluminium LSS is considered to be more durable, stronger and more resistant. It also enhances the aesthetics of the motorcycle to tell the adventurous narrative of the GS rider. The GS rider is discussed in chapter 3, and the different types of LSS are discussed in chapter 4.

Luggage rack is a popular option

The luggage rack was redesigned for the R 1300 GS Adventure to allow the electronics to be integrated into the LSS. In November 2024, 100% of the 207 R 1300 GS Adventures ordered in the Netherlands were fitted with a factory-fitted luggage rack (Kruijs, 2024). The fact that all orders were fitted with optional luggage racks shows that the buyers of these motorcycles really appreciate LSS on their motorcycles.

Sharing LSS across the R 1300 platform

The luggage racks of the GS and GSA are different, so the aluminium LSS will not fit the standard GS. However, according to Fings (2024), BMW is planning to produce an adapter plate that will allow the aluminium LSS to be fitted to the standard GS.

The project focuses on an aluminium LSS that will fit on the newly designed R 1300 GS Adventure luggage rack, but this adapter plate will allow it to be used on the entire R 1300 platform.

From a circular economy perspective, it is important to be able to share LSS and components across models as this increases flexibility for the GS owner and reduces redundancy as the GS owner can take the LSS with them when moving between GS motorcycles.

DESIGN LANGUAGE ANALYSIS
BMW R 1300 GS ADVENTURE

The BMW GS design language uses horizontal composition and can be described as controlled and mature, with a 'will get the job done' look and feel to the styling. A detailed analysis of key design features, comparing BMW with seven other ADV motorcycles, can be found in Appendix F.

Evolution versus revolution

In previous generations, the GSA represented an evolution of the GS. The differences in styling between the GS and the GSA are so significant that they are more accurately described by the use of the word 'revolution'.

Key design elements

The GSA adopts a more robust and multi-tool-like appearance, along with key design elements that set it apart from the GS. The key design features can be found in Figure 2.6.

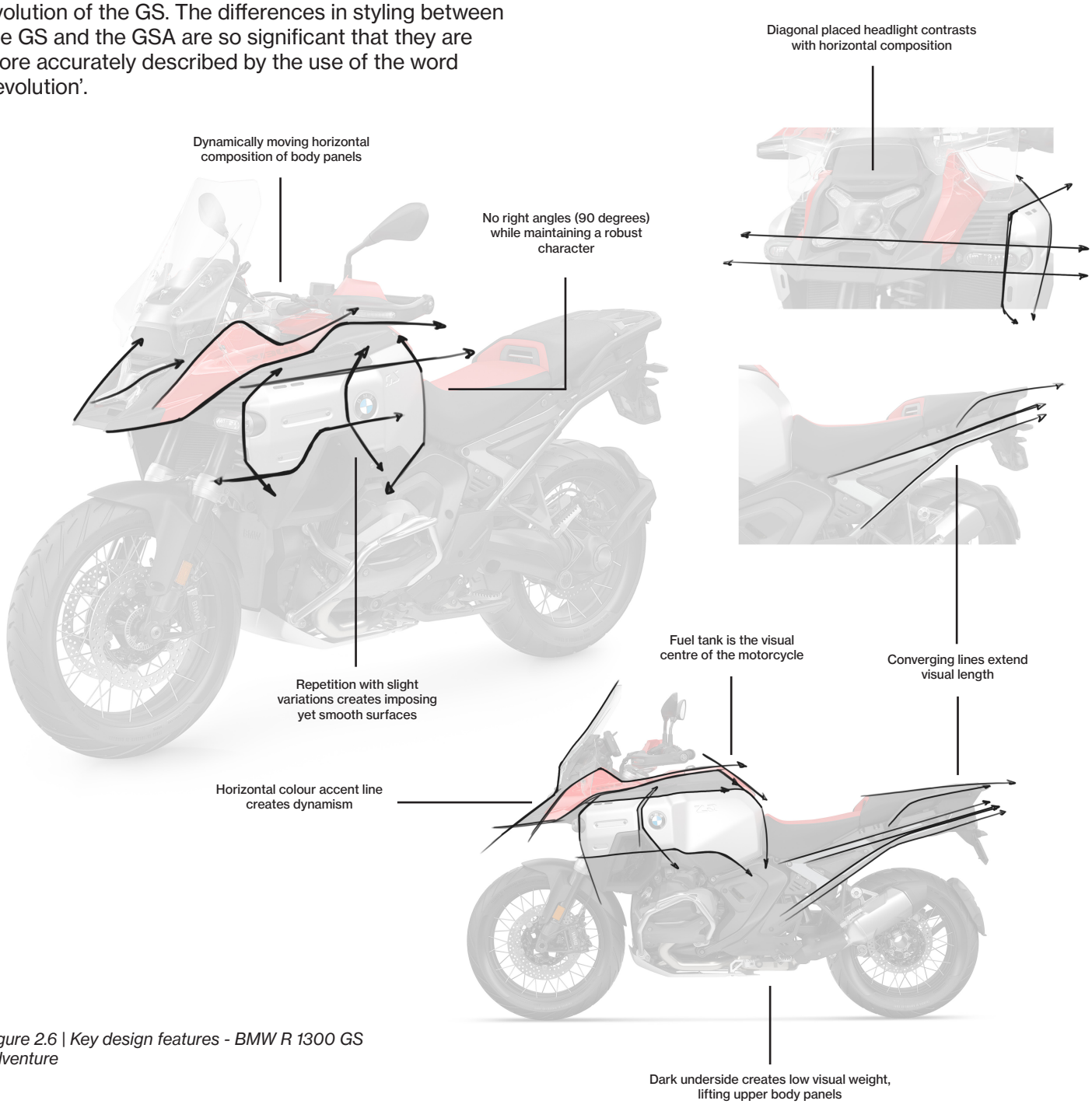


Figure 2.6 | Key design features - BMW R 1300 GS Adventure

KEY FINDING
BMW MOTORRAD

KEY FINDING 1

BMW GS motorcycles are the Swiss knife of motorcycles.

RQ 1.1 How does a GS rider use their motorcycle?

Adventure motorcycle riders, a group in which BMW GS motorcycle riders fit, are a versatile group of riders. The type of terrain, duration of rides and luggage requirements vary according to the specific use case. The R 1300 GS is designed as an all-rounder, while the R 1300 GS Adventure is designed as a more robust, multi-tool and off-road machine. According to R. Fings (2024), BMW Motorrad GS product manager, only 5 – 10% of GS Adventure riders use their motorcycle off-road, suggesting that the majority of owners utilise the vehicle for on-road purposes.

CHAPTER 3

GS RIDERS

The previous chapter showed that BMW GS motorcycles are as versatile as Swiss knives. This chapter looks in more detail at how GS riders use their motorcycles and concludes with four key findings regarding experiences with use, damage, and repair.

Content

CHARACTERISTICS OF BMW GS RIDERS

As outlined in the previous chapter, BMW GS motorcycles are renowned for their versatility, making them a popular choice for adventure motorcycle riders.

Versatile group of motorcycle riders

GS riders are a good match for the character of GS motorcycles. The riders are diverse, while all embrace the versatile nature and endless possibilities for adventure (Scheffer, 2019). The characteristics of BMW GS riders are summarised in Figure 3.1.

Differences between GS riders
Riding distances vary from daily commutes to long-distance trips around the world, and riders use their GS to navigate different types of terrain - from smooth tarmac to loose sand. GS riders also have different luggage storage needs. See Appendix B for supporting information.

It is clear that BMW GS riders can be defined by one central theme: **versatility**.

Figure 3.1 | Overview of the characteristics of BMW GS riders (Ipillion, 2023).

IMAGE OF BMW R 1300 GS ADVENTURE

BMW GS riders are characterised by their versatility. This section delves into the image of BMW GS, the image of the R 1300 GSA and the contrast between image and identity.

Image of BMW GS

Adventurous

The overarching image associated with BMW GS motorcycles is described as adventurous. This is supported by storytelling and myths, such as winning the Paris-Dakar Rally five times and the television series ‘Long Way Round’.

Figure 3.2 | BMW R 1300 GS Adventure in an urban environment (2025 BMW R 1300 GS Adventure - CalMoto, 2025)

Image of BMW R 1300 GS Adventure

Intimidating and comfortable status symbol

Reviews, interviews with GS riders, online comments, and two co-creation sessions with mobility specialists revealed that the image of the R 1300 GSA is shifting towards intimidating, big, and comfortable luxe adventure. As a reference, see figure 3.2.

Only 5 to 10 percent of the GSA riders takes their motorcycle on off-road adventures (R. Fings, 2024). These adventures come with a larger chance of scratches and dents. Many owners are worried about these scratches and dents since they see their motorcycle as a **status symbol** that needs to be kept in ‘new’ condition. The full reasoning can be read in Appendix J.

Contrast between image and identity

The image of a intimidating, comfortable, luxurious adventure status symbol contrasts sharply with the robust adventure identity communicated by BMW Motorrad. This perception of the R 1300 GSA as a status symbol, rather than the multi-tool use for which it was designed, creates a situation where the motorcycle is used in a way other than intended.

EXPERIENCES OF GS RIDERS WITH DAMAGE & REPAIR

Having discovered the versatile nature of GS riders and the image of the R 1300 GS Adventure, it is time to find out the experiences of GS riders with BMW GS motorcycles and their luggage storage systems (LSS).

A quantitative study (n=263) was conducted among ADV enthusiasts. The setup, demographics and detailed outtakes can be found in Appendix O. The most interesting outtakes are discussed in this paragraph.

Aluminium LSS are popular with BMW GS riders

LSS are popular with both ADV and BMW GS riders, as shown in Figure 3.3. Interestingly, the percentage of GS riders using an aluminium LSS is much higher than the percentage of all ADV riders. This shows the strong bond BMW GS riders have with aluminium LSS (See Figure 3.3).

The five most important reasons for BMW GS owners to choose an aluminium LSS are weather resistance, durability, security features, storage capacity, and ease of installation/removal.

Damage occurs mainly at low speeds or when stationary.

According to the respondents who reported experience of damage to aluminium LSS, the damage occurs mainly at low speeds or when stationary. These include slipping on a wet roundabout, falling over on loose surfaces, dropping the motorcycle on its side, tipping over while riding up a hill, and the motorcycle falling over its side stand on a hill.

Rider safety concerns

The questionnaire participants, as well as the GS riders interviewed, expressed their concern for safety when riding with aluminium LSS. Hard aluminium can cause serious damage to the legs in the event of a fall, so a little more protection might be helpful. One respondent commented that he thought rider safety was very important and that the legs should be protected in the event of a fall.

Increased visibility with reflections can improve safety by making the rider more visible to other road users.

Experiences with damage to aluminium LSS

Of all participants with aluminium LSS, more than half had experience of damage to their LSS, with external impact being the main cause of damage.

Of those who had experience of damage, more than half were able to make the necessary repair. Interestingly, 34% did not even attempt a repair and immediately replaced their LSS. The exact results are shown in Figures 3.4, 3.5 and 3.6.

How did they repair?

Participants were also asked how they repaired their hard metal LSS. Five respondents explained that they used a hammer to hammer the body of the pannier back into shape, four respondents said they did not bother to repair the visual dents and scratches, and two respondents had to replace their luggage rack but not the LSS after a fall.

Finally, several respondents provided further insight into the effect of a fall or crash. They noted that weatherproofing became an issue as the seal no longer prevented dirt and water from entering the LSS.

Additional remarks from GS Riders

Interesting comments from participants included that the LSS should allow a sporty lean angle for fast cornering and manoeuvrability. Light and power are useful additional features. In addition, the front of the aluminium LSS is easily covered with bugs and stone chips, so additional protective panels could act as a buffer against impacts.

The key findings on the next page synthesise the findings from the GS rider character, brand image, and the experiences of GS riders concerning damage and repair of aluminium LSS. The subsequent chapter will provide an in-depth analysis of the various types of LSS and their core functions.

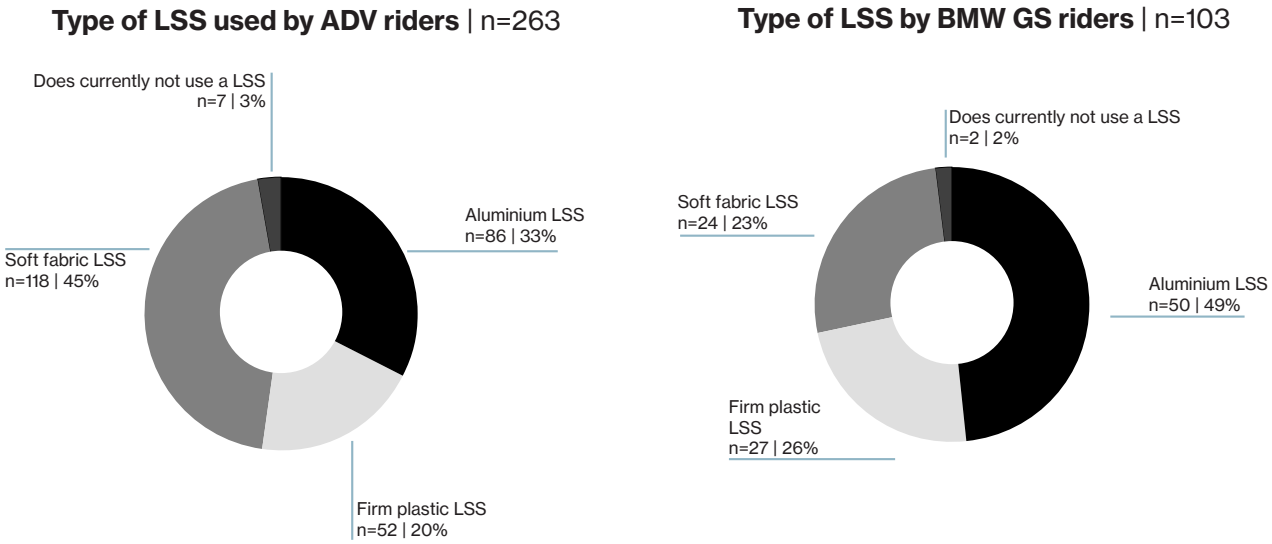


Figure 3.3 | Type of LSS used - (left) by ADV riders, (right) by BMW GS riders.

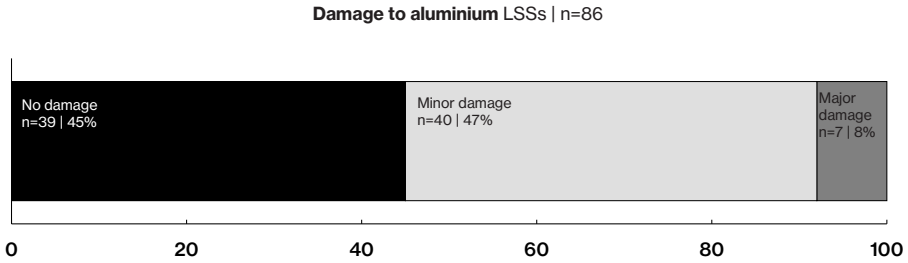


Figure 3.4 | Experience of damage of aluminium LSSs.

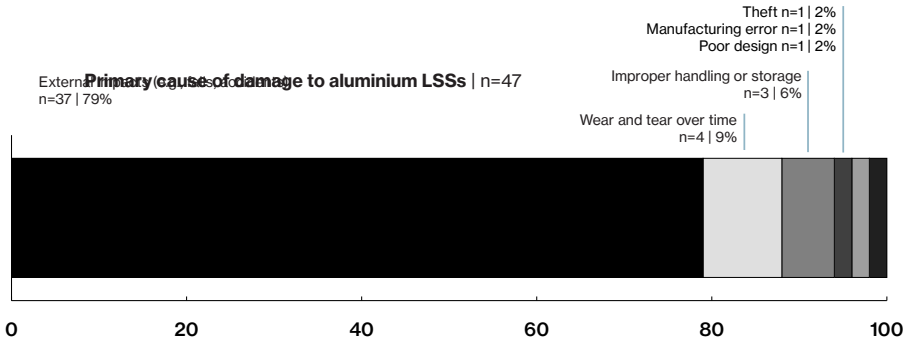


Figure 3.5 | Primary cause of damage to aluminium LSSs.

Figure 3.6 | Was the damage to the aluminium LSSs repairable by the participant?.

KEY FINDINGS
GS RIDERS

KEY FINDING 2

The majority of BMW GS riders adopt a full aluminium LSS configuration.

RQ 1.2 In what situations are luggage storage systems used?

A significant proportion of GS riders are drawn to the robust and adventurous identity of the BMW GS Adventure. The GS and GS Adventure models have become increasingly associated with status and image enhancement, with many users preferring their motorcycle to be used for non-off-road activities due to concerns over scratches and other forms of damage.

The LSS is designed to meet the diverse needs of a wide range of users, including daily commuters, day riders, and those planning longer trips. However, it is vital that the luggage storage system functions effectively in an off-road environment. This is because a substantial part of its identity and appeal stems from its off-road and adventure capabilities.

KEY FINDING 3

The majority of BMW GS riders adopt a full aluminium LSS configuration.

RQ1.3 What type of LSS do BMW GS riders use?

BMW GS riders have a strong preference for aluminium LSSs. Of the participants riding BMW GS motorcycles (n=102), 49% used aluminium LSS, 26% firm plastic LSS and 23% soft fabric bags.

The aluminium LSS offers riders a range of configuration options. Of the 86 participants (across all brands) who used aluminium LSS on their motorcycles, 66% opted for a full system, 23% chose a pannier system, and 9% selected a top case only.

KEY FINDING 4

Damage to an aluminium LSS is most likely to occur in low-speed or stationary situations on both tarmac and loose surfaces.

RQ2.2 In what situation do GS riders damage their LSS?

Participants reported damage to their LSS in primarily low-speed or stationary situations, on all types of surfaces. Forty-seven percent of participants with aluminium LSSs have experienced minor damage to their LSS, while eight percent have experienced major damage. The main cause of the damage (n=47) is external impacts, with 79% of cases being attributed to this cause.

KEY FINDING 5

Following an incident, 60% of users successfully engage in LSS repair practices.

RQ2.3 Are riders of a BMW GS Adventure LSS able to prolong the lifespan after damage?

Of the total number of participants (n=263), 47 reported damage to aluminium LSS. It is important to note that 60 percent of those participants with damage successfully engaged in repair practices, while 34 percent did not attempt to repair.

It is vital to invite this group of riders to encourage the lifespan of their LSS. The creation of a system that is easier to disassemble and assemble, as well as the availability of spare parts, customer support, maintenance and repair manuals, and repair services, will contribute to more successful extensions of the lifespan and more riders being involved in the maintenance and repair of their LSS.

CHAPTER 4

LUGGAGE STORAGE SYSTEMS

As outlined in the previous chapter, GS Adventure motorcycles and GS riders have a highly versatile character. This chapter explores three different types of luggage storage systems (LSS) and their core functions. In addition, an exploration of the history and competitors of aluminium LSS is conducted. The chapter concludes with a comprehensive overview of the damage profile and key findings.

Content

Types of luggage storage systems
Core functions of a luggage storage system
History of BMW GS Adventure LSSs
Direct competitor analysis

Damage analysis | case study
Damage profile
Key findings luggage storage systems

TYPES OF LUGGAGE STORAGE SYSTEMS

The luggage storage systems (LSSs) for motorcycles can be divided into three categories: soft fabric, firm plastic, and aluminium LSSs. An in-depth analysis of all three categories (see Figure 4.1) is carried out on this page, further elaboration can be found in Appendix G.

Soft fabric LSS

Soft fabric LSS are made from weather-resistant fabrics and deformable during an impact, dampening the forces and reducing rider injury.

In interviews, GS riders have expressed interest in this type of system because of its ability to absorb impact forces, reducing damage to the motorcycle and increasing rider and passenger safety.

Firm plastic LSS

Firm plastic LSSs are often side loading and the storage can in some LSSs be extended easily.

Aluminium LSS

Aluminium LSSs are less complex, welded and riveted boxes with a utilitarian nature and appearance. BMW Motorrad produces its own aluminium LSS trough Touratech.

This project focuses on the aluminium LSS fitted to the BMW R 1200 GS Adventure and R 1250 GS Adventure. The following paragraphs focus on the core functions, history, competitors and damage profiles of this aluminium LSS.

Impact of a LSS on motorcycle dynamics

The placement of the luggage system has a significant impact on weight distribution and motorcycle handling. In order to optimise the motorcycle's performance, it is recommended that loads be distributed as low and centrally as possible (Scott, 2020).

Luggage rack

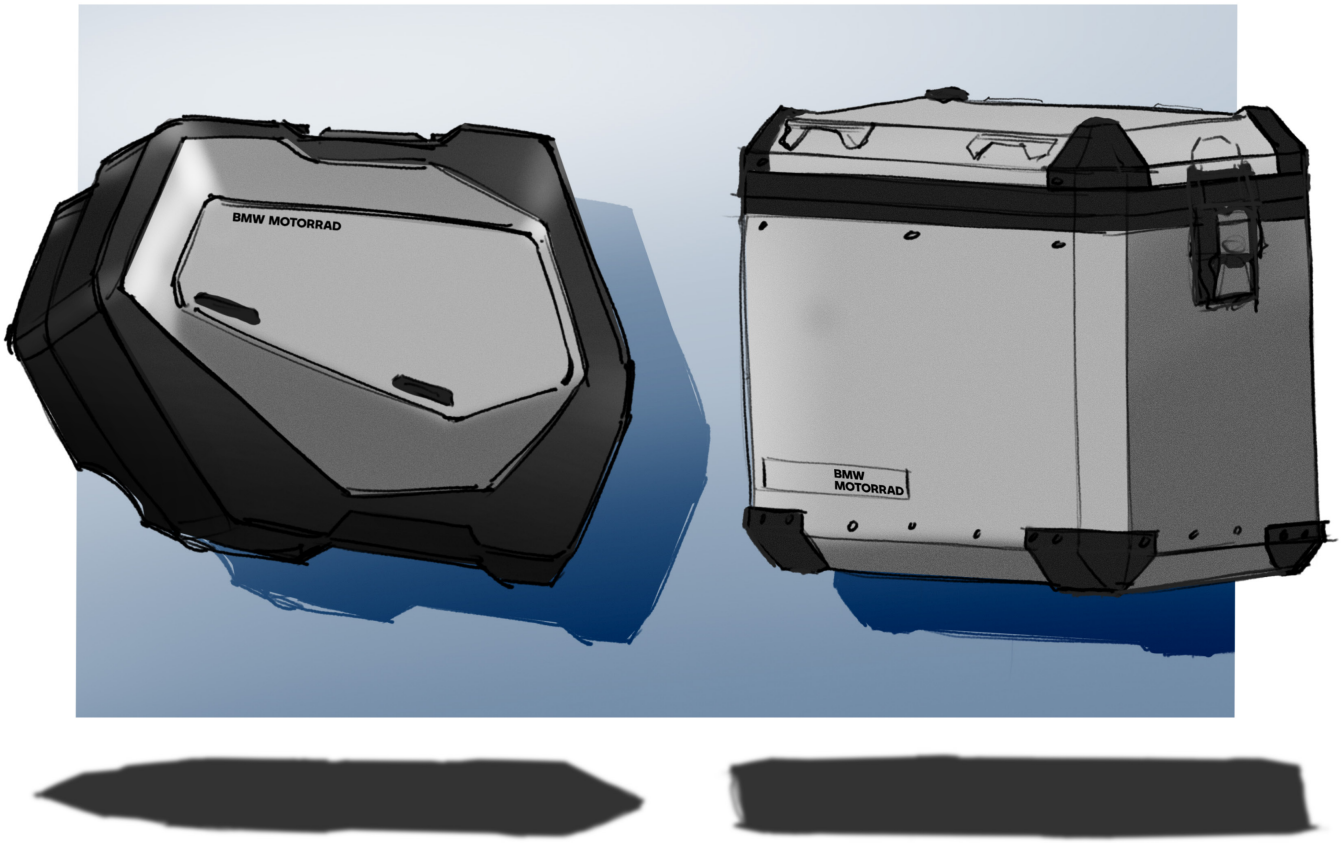
A motorcycle LSS is attached to the motorcycle in one of two ways: either via a luggage rack or directly to tie-down points on the motorcycle. A luggage rack is a metal structure attached to the subframe of the motorcycle. All aluminium and firm plastic LSSs use a luggage rack. Soft LSSs are available with and without a luggage rack (Scott, 2020).

Soft fabric LSS

+ Lightweight
+ Easy to repair
+ Absorb impact

- Less secure from theft
- Fragile luggage can be damaged

Figure 4.1 | Types of LSS - FLTR: Soft fabric LSS from Mosko Moto, firm plastic R 1300 GS Vario LSS, and BMW R 1250 GS Adventure aluminium LSS.



Hard plastic LSS

+ Robust
+ Lockable
+ Weatherproof
+ Do not dent or deform like alloy boxes.

- Heavy
- Hinges are the weak point on side loading cases
- Require luggage rack
- Locks can fail on impact
- Intricate systems that extend the storage space are susceptible to damage.

Aluminium LSS

+ Robust
+ Aesthetics
+ Strong
+ Easy to paint and wrap
+ Weatherproof until the lid deforms
+ Versatile

- Heavy
- Very expensive
- Wide
- Requires luggage rack
- Hard to straighten when deformed
- Boxes transfer stress to the subframe
- Damage to legs when trapped under LSS.

ALUMINIUM LUGGAGE STORAGE SYSTEMS

Aluminium Luggage Storage Systems (LSS) are a popular addition to the motorcycle setup of adventure and BMW GS motorcycle riders, allowing the rider to pack all necessary gear for their adventures.

Core functions of an aluminium LSS

A LSS performs seven core functions (Botan, 2022; Botan, 2024; Hughes, 2023). The core functionality includes **storage, weather resistance, quick access, protection, versatility, organisation** and **security**. See Appendix E for further information.

Other considerations before purchase include durability, ease of removal, size, weight, and robustness (Scott, 2020).

BMW R 1200/1250 Aluminium LSS

The aluminium LSS for the BMW R 1200 and R 1250 GS Adventure consists of a pannier rack, two panniers, a top case rack and a top case. This project focuses on the panniers of these specific models.

Construction

The pannier is made from 2mm-thick aluminium, divided into three parts: base, middle and lid. These are securely joined with rivets. Locks are placed at the front and back of the box.

Protective parts

PA6-MX GF30 protective parts are riveted to the aluminium sections to protect corners. These parts are designed to conceal the welds in the aluminium base and lid, and facilitate the stacking of the aluminium LSS without causing it slipping.

Additional luggage

The LSS is fitted with brackets on the lid that allow additional luggage to be attached to increase the storage capacity.

Analysis

At the end of this chapter, a damage case study of this specific LSS is carried out, and in the next chapter, an in-depth analysis of its circularity is performed.

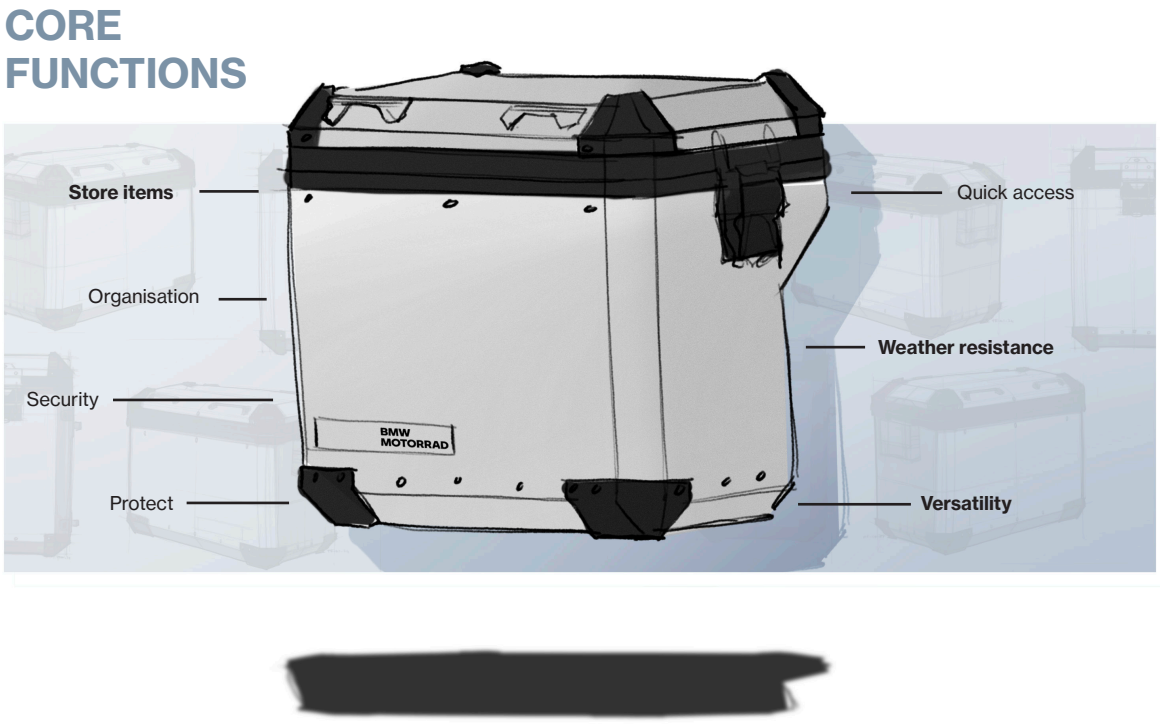


Figure 4.2 | Aluminium LSS - Core functions.

History of BMW GS Adventure LSSs

Aluminium motorcycle LSSs have been around since the first adventure motorcycles. A timeline of the main developments is shown in Figure 4.3. Three main trends can be seen in the development of GS LSSs.

The introduction of a new generation of GSA LSS often matches the introduction of a new platform and generation of GS and/or GSA. The complexity of the LSS has increased with each new generation, with systems becoming more advanced and incorporating innovative solutions (e.g. electrical connections). This has the effect that each new generation of LSS uses a different luggage rack, making cross-platform use of the LSS impossible.

Finally, the status of an LSS in the design process has evolved from being a separately designed accessory to being incorporated into the main design of the motorcycle from the start of development.

Before 2001 | Universal

Aluminium LSS were hand-made by users or produced by external companies.

2001 | R 1150 GS Adventure

First aluminium LSS designed by BMW Motorrad for the first GS Adventure.

2014 | R 1200 GS Adventure

Second iterations of the LSS designed by BMW Motorrad. Fits the R1200 GS Adventure and the later R 1250 GS Adventure.

2024 | R 1300 GS Adventure

Latest iteration of the aluminium LSS by BMW Motorrad, includes integrated lighting and charging possibilities in the top case and right pannier.

Figure 4.3 | Four generations of GS Adventure LLSs.

Direct competitor analysis

BMW GS riders have the option not to choose a BMW LSS, but instead use an universal LSS. The BMW GS aluminium LSS is compared with three well-known motorcycle LSS manufacturers. The main outtakes are discussed in this paragraph.

The compared systems are shown in Figure 4.4 and detailed information can be found in Appendix H.

Asymetrical BMW LSS

BMW GS motorcycles have a high-mounted exhaust system to minimise the risk of damage to exhaust components. The BMW aluminium LSS has a cut-out to accommodate the exhaust, allowing the LSS to sit closer to the motorcycle. The three other LSS models do not have this cut-out, resulting in a wider motorcycle set-up.

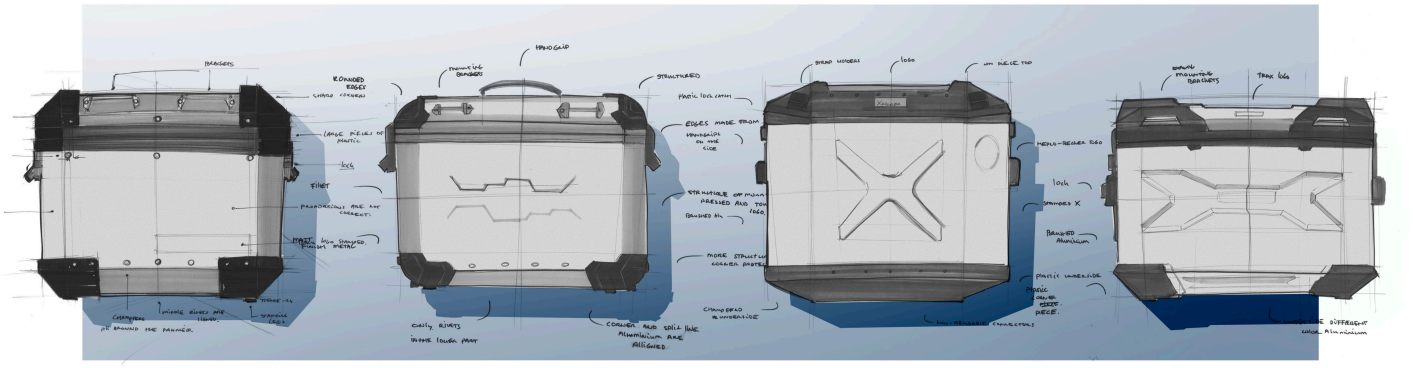
Similar construction and aesthetics

All the LSSs compared use a similar design, with welds and rivets joining the three-box aluminium structure. The utilitarian aesthetic is present in all LSS, with minor differences in the shape and position of the plastic corner protectors.

Similarities in structural and aesthetic damage

The location of damage accumulation is shared between all of these systems, with deformation of the central aluminium structure causing misalignment of the lid and therefore weatherproofing problems.

Aesthetic damage in the form of scratches is exceptionally visible on matt black LSSs compared to brushed systems. This is confirmed by user interviews and quantitative research from chapter 3: GS Riders. The next section examines these findings in more detail.



BMW Motorrad | R 1200/1250 GS Adventure

Touratech | Zega Evo

Hepco & Becker | Xplorer

SW-Motech | TRAX ADV

Figure 4.4 | Analysed LSSs - (left to right) BMW Motorrad GS Adventure, Touratech Zega Evo , Hepco & Becker Xplorer, and SW-Motech TRAX ADV.

DAMAGE ANALYSIS CASE STUDY

Two case studies of accident damage were presented. Both GS motorcycles had been fitted with aluminium GS Adventure LSSs that had been damaged by impact with another vehicle and/OR the ground. The damage of to these two LSS can be seen in Figure 4.5.

Major deformations cause wheaterproofing issues

The two LSSs have similar damage to the centre aluminium panel, although to a different degree. The lack of reinforcement and strength compared to the lid leads to greater deformation in the centre than in the lid, resulting in misalignment and weatherproofing problems.

Stress transfer through luggage rack

The stresses from an impact travel through the luggage rack, causing the same misalignment problems on the LSS on the opposite side of the impact.

Figure 4.5 | Damage - Analysis

DAMAGE PROFILE

Combining the findings from the interviews, questionnaire, GSA LSS analysis and case study produces a damage profile.

The damage profile shows the locations that are most vulnerable and/or susceptible to external impacts and forces. The damage profile is shown in Figure 4.6.

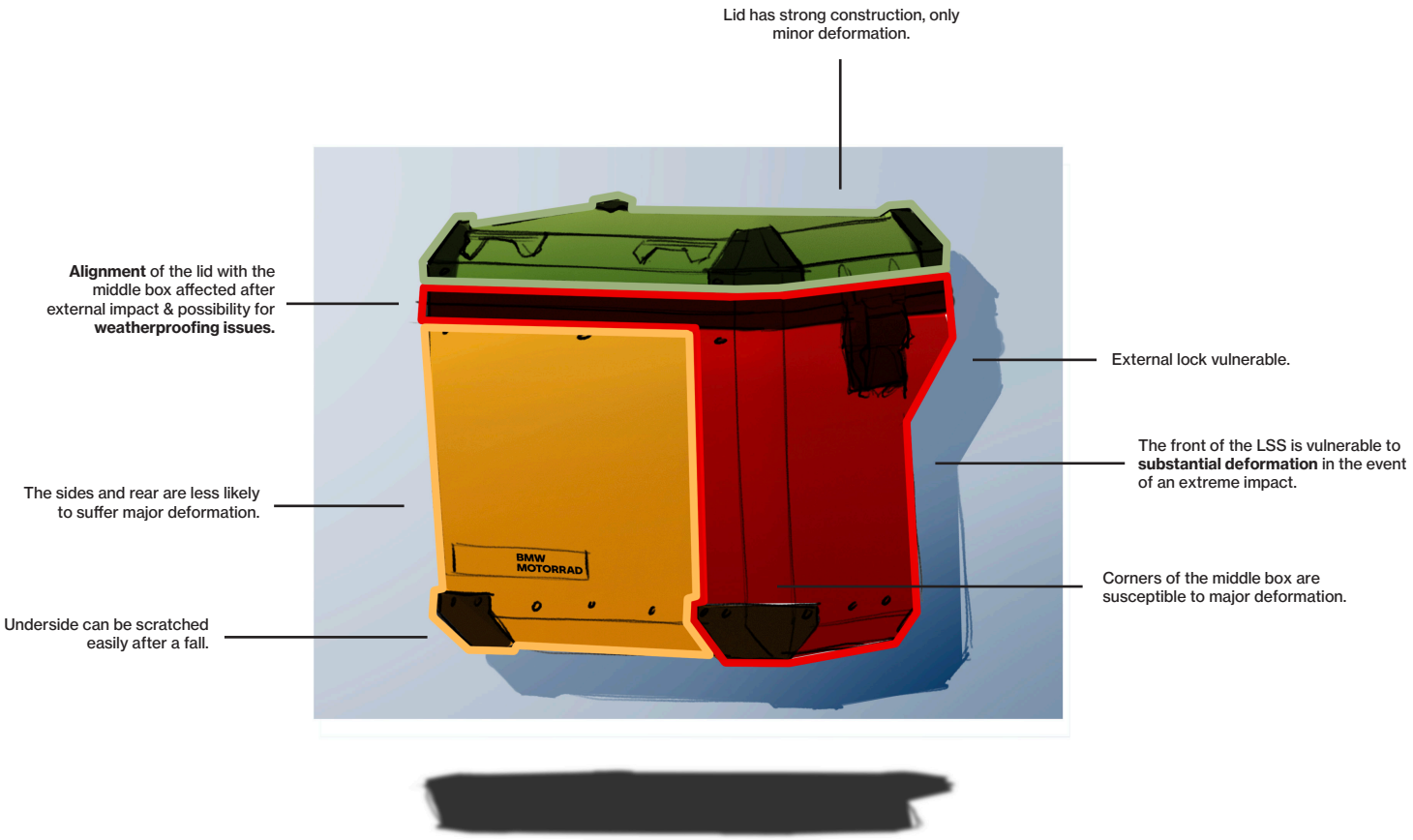


Figure 4.6 | Damage profile

KEY FINDINGS
LUGGAGE STORAGE SYSTEMS

KEY FINDING 6

Hard metal LSSs are designed to offer seven core functions: storage, weather resistance, quick access, protection, versatility, organisation, and security

RQ 1 *What are the main functions of a hard metal LSS?*

Hard metal LSSs are designed to store items securely and protect them from theft, weather damage and damage from falls and crashes. An LSS also protects the motorcycle in the event of a fall or accident.

These systems are robust and strong, but expensive, heavy, wide and difficult to straighten or repair if deformed compared to other types of LSS. Weather resistance has been identified as a particular weakness of these systems, particularly in the event of dents or other damage to the lid.

KEY FINDING 7

The LSS is prone to superficial damage, such as scratches.

RQ2 *Why are LSSs discarded?*

RQ2.1 *Which part of the a LSS is most susceptible to damage?*

Interviews, surveys and observations have shown that aluminium LSS are particularly susceptible to scratches. A significant proportion of owners are uncomfortable with these superficial scratches because they wish to keep their motorcycle, including the LSS, in 'as new' condition.

It should be noted that not all owners of hard metal LSS are bothered by scratches and dents. In fact, some owners do not mind them and see them as adding to the character of their motorcycle.

KEY FINDING 8

The LSS is susceptible to significant deformation of the middle panel in the event of an external impact, causing misalignment and waterproofing problems.

RQ2 *Why are LSSs discarded?*

RQ2.1 *Which part of the a LSS is most susceptible to damage?*

The aluminium middle panels lack reinforcements and/or folds and welds that are present in other parts of the case and contribute to its strength and rigidity. As a result, the middle panel deforms more than the other components, affecting the alignment of the lid with the pannier.

As the side panel deforms more than the lid, the two components no longer fit tightly together. This makes it difficult to close and creates a gaps that allows water and dust to enter the pannier, compromising its weatherproofing.

KEY FINDING 9

Stresses are transferred through the luggage rack.

RQ2 *Why are LSSs discarded?*

RQ2.1 *Which part of the a LSS is most susceptible to damage?*

In the event of damage, there are significant forces at play. A case study has shown that a fall to one side of the motorcycle can transfer stresses from the pannier to the luggage rack, subframe and other luggage racks, causing deformation of the other pannier. These stresses are transferred through the subframe, resulting in misalignment of the lid and weatherproofing problems on the other side.

CHAPTER 5

CIRCULAR ECONOMY

Prior chapters have provided an overview of the stakeholders, including BMW Motorrad and the GS rider, as well as the R 1300 GS Adventure and the luggage storage system options (LSS).

This chapter explores the circular economy in the context of mobility and LSSs, with the aim of evaluating the current LSS's ability to prolong the lifespan.

An analysis was conducted on the left side aluminium pannier from a BMW R 1200/1250 GS Adventure. The analysis identified the ease of maintenance, critical parts and actions, and their placement in the product architecture.

Content

CIRCULAR ECONOMY IN MOBILITY

The Circular Economy (CE) is becoming an increasingly important consideration for manufacturers due to additional legislation. R. Fings, BMW GS Product Manager (2024), suggests that while this interest may be significant for manufacturers, it is less so for customers.

BMW Motorrad customers prioritise robustness, innovation, quality and ease of use over sustainability. However, extending the lifespan of products through simple interventions can benefit customers, prevent premature replacement, and reduce waste.

Value hill model

R-strategies are key to transforming the linear economy into a circular one (Malooly & Daphne, 2023). A product adapted or designed for the circular economy will increase the customer's options when it comes to extending the life. As illustrated in Figure 5.1, this model incorporates all R-strategies in combination with the Value Hill model (Metabolic, 2024). An overview of all R-strategies is found in Appendix I.

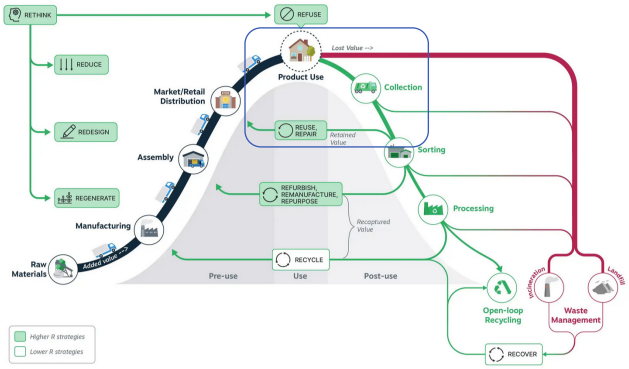


Figure 5.1 | Note: The Value Hill graphic is an adaptation of the Value Hill Model to include the 9R Framework. Buren, N., Demmers, M., Heijden, R., & Witlox,F. (2016). Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments. | Circle Economy (2016). Master Circular Business With The Value Hill. | Kirchherr, J., Reike, D. & Hekkert, M. (2017). Conceptualizing the Circular Economy: An Analysis of 114 Definitions. | Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring Innovation in the Product Chain. (Metabolic, 2024).

Value retension strategies

Extending the lifespan of aluminium LSSs is important since it reduces the need for the production of new products to replace the old, thus minimising impact on the environment.

Value retention is the first step after a product is used and no longer functions as intended. Intervening high up the value hill helps **retain value**. R-strategies **reuse** and **repair** focus on retaining value high up the hill.

Reuse

Reuse is defined as the process of another consumer using a discarded product that is still in good condition and able to perform its original function (e.g. second-hand) (Malooly & Daphne, 2023).

The sale of pre-owned motorcycles frequently includes LSS due to the fact that these systems are only compatible with that specific model. Furthermore, the requirements and preferences for LSS are subject to change, which results in these systems being replaced and resold on the secondary market.

Repair

The repair strategy involves the repair and maintenance of a defective product so that it can function again (Malooly & Daphne, 2023).

A product should be designed with parts that are replaceable and the replacement of these parts can be used to maintain, upgrade or extend the product (Cradle to Cradle Products Innovation Institute, 2023).

Consumer fatigue due to obsolescence

An aluminium LSS is a type of product that is purchased by the user for long-term use. External impacts and use marks can significantly reduce the expected lifespan of the product, potentially rendering it obsolete before the planned end-of-life cycle.

“Obsolescence refers to the process by which products, technologies, or systems lose their utility or value, often replaced by newer, more efficient alternatives” (Norman & Verganti, 2013).

Impact of obsolescence on the GS brand

Not only does obsolescence have a significant impact on the longevity of a product, but it also has an impact on the user experience, the brand image and the principles of sustainability (Alzaydi, 2024).

BMW GS motorcycle LSSs are designed to fit a specific model. According to Alzaydi (2024), this type of business model can lead to consumer fatigue and, in the long run, dissatisfaction with the product and the brand.

This is especially relevant for GS LSSs, where users are required to replace their LSS when switching motorcycles. The older LSS retains its functionality and economic value, but simply does not fit the luggage rack of the newer motorcycle. In interviews, BMW GS riders have expressed their disappointment at missing out on the opportunity to retrofit the older GS Adventure LSS to the newer R 1300 GSA.

Durability through repair

urability is one of the key characteristics of the R 1300 GSA. A product is durable if its degradation takes longer than similar, comparable products” (Hollander et al., 2017). According to Boulos et al. (2015), product durability and product life extension are closely related. Furthermore, Cordella et al. (2020) suggest that reliability and repair processes also influence the durability of a product.

It is possible to create a durable product by incorporating features that prevent damage, thereby slowing the degradation of its performance (Singh et al., 2019). Another way to create durability is to develop products with high physical and emotional durability, which can help prevent the product from becoming obsolete (Mesa et al., 2022).

Value of imperfection

Design for sustainability does not refer to a particular aesthetic or outer appearance for a product (Walker, 2009). In our consumption society, design relies heavily on ‘newness’. It is important that design starts embracing the natural ageing of products. In order to extend the product life cycle, it is essential to focus on enhancing user attachment through the strategic incorporation of imperfections, such as time- and use-related marks, into the design (Van Hinte, 2004).

Increase user involvement and attachment through repair

Rather than perceiving products as use-objects, it is possible to consider them as living entities that evolve in sync with their users (Ostuzzi et al., 2011). The repair process has the potential to enhance user involvement and emotional attachment by adding to the product’s existing appearance, thereby highlighting the scars that showcase past experiences. This process ultimately generates unique objects with strong personal characters.

The end result is a product that has greater ‘value’ for the user. This is because the user is willing to put in the work to repair and maintain the product when needed, which in turn prolongs its life cycle.

Battlescars on LSSs tell stories

Going back to the motorcycle LSS, a dent or scratch is a story and adds to the narrative and image of the person who owns and rides that motorcycle. However, this is only the case if the storage solution is designed to accept this storytelling through damage.

Design principles to increase value

The circular economy is a systemic shift which is only achieved when we rethink consumption (Berg, 2024). There are two interesting design philosophies that help to retain, maintain, and increase the value of a product.

Wabi-Sabi

Wabi-Sabi is a Japanese aesthetic philosophy (see Figure 5.2) that embraces the natural ageing of materials and products (e.g. leather bags, patina on vintage cars).

Rethinking the perception of new as being the same as good helps to see products in a different light. Wabi-Sabi helps to redefine beauty as imperfect and incomplete, just as nature is (Berg, 2024).

Kintsugi

Kintsugi is a Japanese repair technique with a philosophy (see Figure 5.3) that embraces brokenness, damage, imperfection and flaws.

Broken pottery is repaired by applying golden glue, creating a more beautiful and unique piece of pottery than before. After the repair, the golden glue exposes the scars, which have become the highlight of the new design (Berg, 2024). It encourages us to slow down and feel the satisfaction of repairing something, thereby increasing involvement and attachment to the product.

Figure 5.2 | Kintsugi - example of the repair technique.

Figure 5.3 | Wabi-Sabi - example of natural aging.

The concepts of repair and reuse can be employed to enhance user involvement and extend the value of products over time. It is beneficial to consider imperfections as narratives of past experiences, as this can help to accept flaws and view them as a positive addition. The following paragraph will analyse and evaluate the ease of implementation of the R-strategy repair.

GENTLE DISMANTLE

The gentle dismantle method assesses the extent to which a product can be dismantled without causing any permanent damage to its connections and/or components. The ease and gentleness of dismantling is an indication of the LSS's suitability for maintenance work.

The left aluminium BMW R 1200/1250 GS Adventure pannier has been disassembled using the gentle dismantle method. See Appendix K for setup and results, and the results in the form of a knolled picture can be seen in Figure 5.4.

Poor state of gentle dismantle

During the process of dismantling, it was found that the majority of parts could not be removed, since they are connected by non-reusable fasteners, such as rivets and glue. The use of these types of connectors has a significant negative impact on the ability to replace parts, repair the LSS, and/or perform maintenance.

Lock sub-assemblies easy accessible for maintenance and replacement

However, a limited number of parts are removable from the main assembly during the gentle dismantle, including three lock sub-assemblies. The state of these sub-assemblies being gently dismantled is excellent, making it easily maintainable for the user.

Challenging gentle dismantle

Overall, the state of gentle dismantle of the analysed LSS is poor. This creates a situation where maintenance and repair is difficult, with the exception of the lock sub-assemblies.

The next section identifies the most critical parts and actions in the analysed LSS.

Figure 5.4 | Knolled picture of the gentle dismantle.

HOTSPOT MAPPING

For the R-strategy repair to be effective, it is vital that parts and materials are easily accessible, replaceable and removable. Hotspot Mapping is a valuable tool that is used to identify which parts are the most valuable and how difficult it is to reach these parts (Flipsen, 2023).

The comprehensive hotspot results are outlined in Table 5.1. Further details regarding disassembly steps and times can be found in Appendix L.

Non-reusable connectors make disassembly time-consuming

The disassembly of the LSS is a lengthy and intricate process, involving 124 steps and 315 tasks. In addition, it is evident that the time required for disassembly is substantial (n=12,591 seconds). The lengthy disassembly process is primarily due to the use of a high number of non-reusable connectors (n=69), such as rivets, in the construction. This type of connection is both time-consuming and forces-intensive, and also requires the use of proprietary tools.

Use of proprietary tools makes roadside repair difficult

A total of eight distinct tools were used in the course of the Hotspot Mapping analysis, three of which, as defined by the EN45554 Norm, are considered to be non-basic tools and are thus classified as proprietary.

In the context of ADV motorcycles, should a roadside repair be required, it is important to note that proprietary tools will not be available. Therefore, it is essential to avoid using such tools, since their availability at the time of the repair is not guaranteed. An overview of the employed tools can be found in Appendix L.

Table 5.1 | Overall results of the Hotspot Mapping.

Overall Hotspot Results	
Time to disassemble	**12,591 seconds**
Number of tasks	**351 tasks**
Number of steps	**124 steps**
Number of tools	8 tools
Number of parts	**143 parts**
Number of main parts	50 parts
Number of parts in lock sub-assemblies	93 parts
Number of rivets	**69 rivets**

Hotspot indicators

In the hotspot mapping method (B. Flipsen, 2023), critical activities and critical parts are indicated.

Critical activities

Critical activities are those that are time consuming, are difficult to access and/or require non-standard tools for disassembly. A total of 16 activities were identified as time consuming. In addition, 51 activities were identified as critical activities. Almost all of these activities are related to the time-consuming removal of non-reusable connectors in the form of rivets.

Critical parts

Critical parts are defined as those parts that have a high priority in the core function of the product, a high economic value or a significant environmental impact. There are three types of critical parts.

Priority parts

Priority parts are identified through hotspot mapping analysis if they have a high probability of failure, require maintenance and/or contribute to the primary function of the product. The seven priority parts are shown in Figure 5.5 and a full description of each part can be found in Appendix M.

Environmental parts

Eleven environmental parts are labelled because their components are made of materials with a high environmental impact. It is therefore important to facilitate easy recovery of these materials at the end of their useful life so that they can be reused or recycled.

Economical parts

Economical parts have a high economic value. The LSS has eleven economical parts, marked with the economic indicator.

The three types of critical parts are used in the disassembly map to indicate target components.

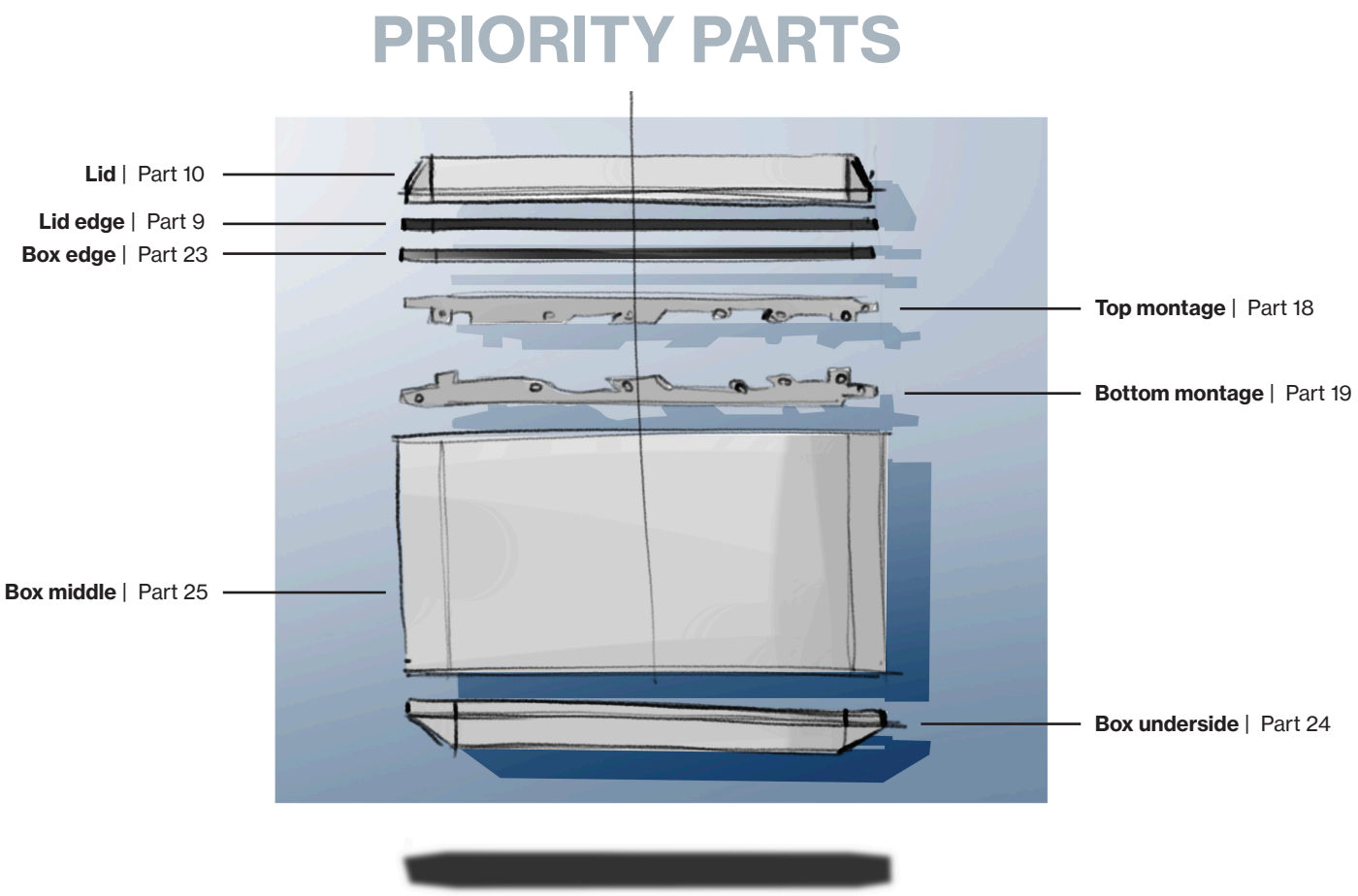


Figure 5.5 | Priority parts - with reference number to disassembly map.

DISASSEMBLY MAP

Designers and engineers can use the Disassembly Mapping method to evaluate existing and design future products for assembly and disassembly, which are important steps in enhancing repair (De Fazio et al., 2021).

Assembly and disassembly are nearly impossible

The disassembly map is structured horizontally with a maximum depth of six layers. Unfortunately, the priority parts are positioned in a location that requires a large number of dependent actions to be completed and a large number of parts to be removed before one priority part can be removed. In addition, the design uses a significant number of high force-intense and non-reusable connectors (indicated with the non-reusable penalty).

Some of the environmental and economical parts (indicators) are reached with less effort, making those easier to replace and recycle/reuse. However this is not the case for all of these parts, as some of them suffer from the same challenges as the priority parts.

Repair practices not possible

The disassembly map illustrates the difficulty of disassembling the aluminium LSS due to its architecture, dependencies, use of non-reusable high-force connections and use of proprietary tools. Replacement of critical parts is therefore not feasible, making it almost impossible to prolong life after damage to a priority part.

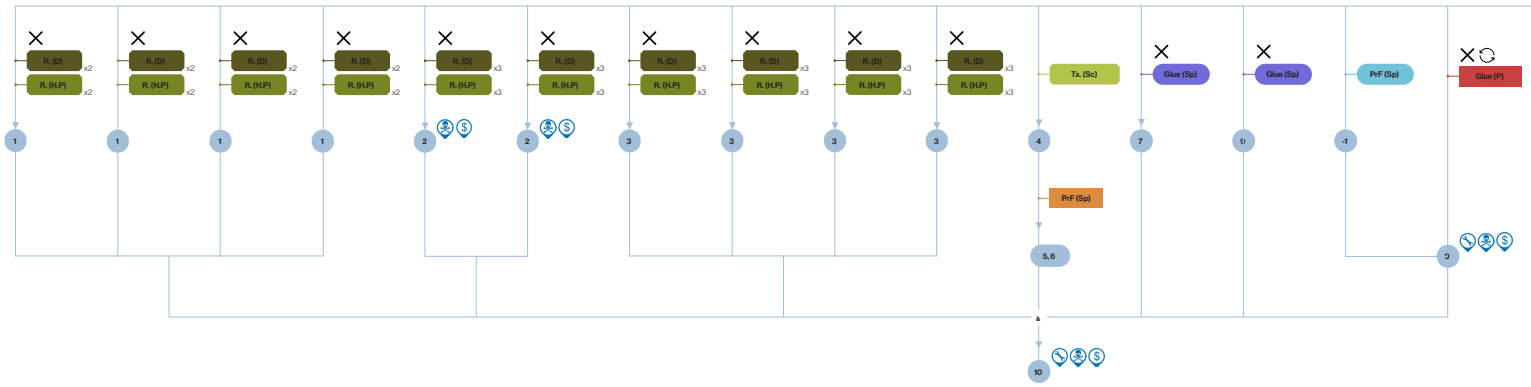
The disassembly map can be found in Figure 5.6 on the next page. The step following the disassembly map analyses the end-of-life of an aluminium LSS.

Reading guide disassembly map

The disassembly map is initiated with the fully assembled product at the top of the map. Each block represents an action that exerts an influence on the product. Multiple actions in sequence are annotated above each other, and result in a part being able to be removed after these actions have been completed. A part is removed when the part number is noted in the map.

It is important to note that some parts have dependencies on other actions/components, and thus, their removal is only possible once all the dependent actions have been executed.

DISASSEMBLY MAP



Legend

Motion type

Hand motion

Single motion tool

Multiple motion tool

Force intensity

Low Medium High

Penalties

= Product manipulation

= Low visibility/identifiability

= Uncommon tool

= Non-reusable connector

Target components

= Failure indicator (Priority part)

= Environmental indicator

= Economic indicator

Part Number List

-1	Internal lid rubber seal
0	Internal box BMW product number sticker
1	External lid luggage mounting brackets
2	External lid lock catching latch
3	External lid plastic corner protector
4	Metal spacer
5	Internal rubber ring (from cord holder)
6	Cord holder
7	Internal lid sticker - product details and attention
8	Internal lid sticker - maximum speed limit
9	Internal lid plastic edge
10	Pannier lid
11	External box aluminium corner protector
12	Internal box plastic corner rib structure
13	Metal spacer
14	Internal box plastic corner rib structure
15	Internal box aluminium structure
16	Metal spacer
17	External box aluminium central montage system
18	External box steel top montage system
19	External box steel bottom montage system
20	= part 16
21	External box plastic bottom cap
22	External box plastic corner protector
23	Internal box plastic edge
24	Box underside
25	Box side panel

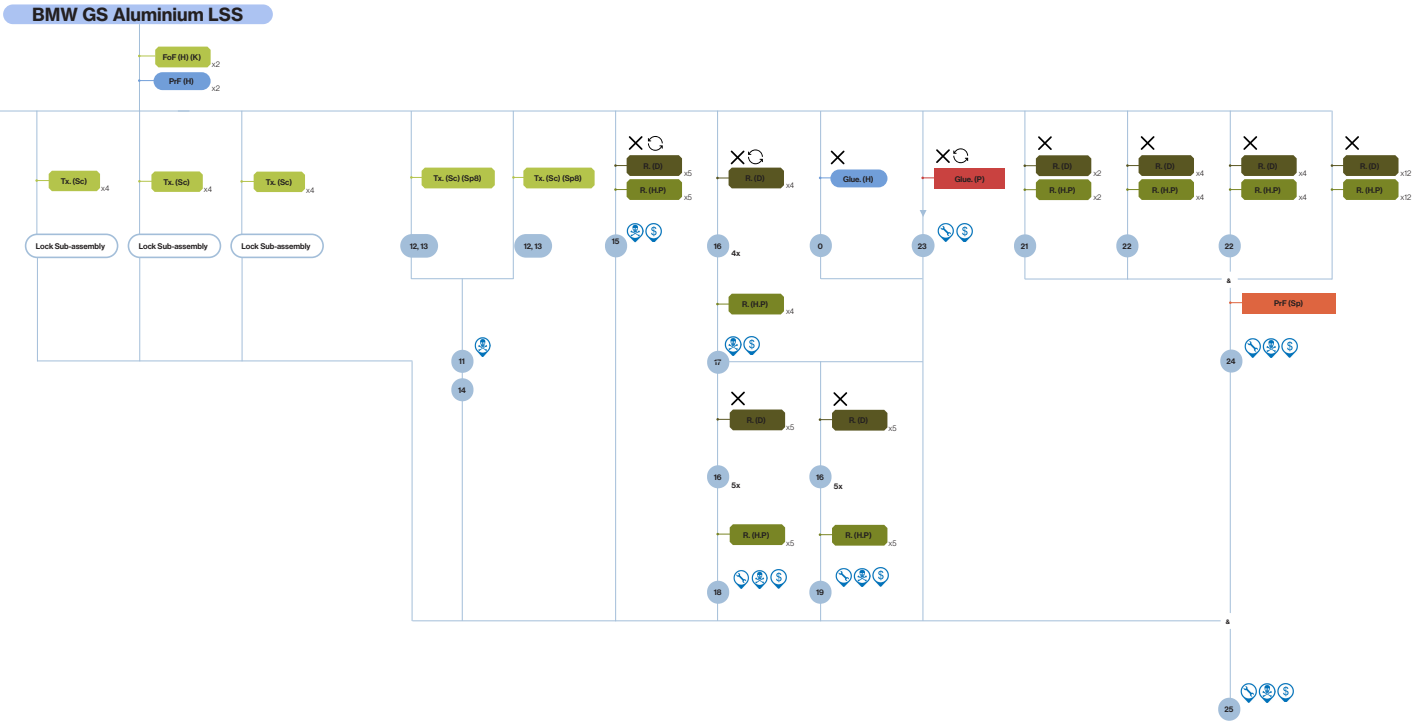


Figure 5.6 | Disassembly map - BMW R 1200/1250 GS Adventure aluminium right pannier of the LSS.

Type of Connector

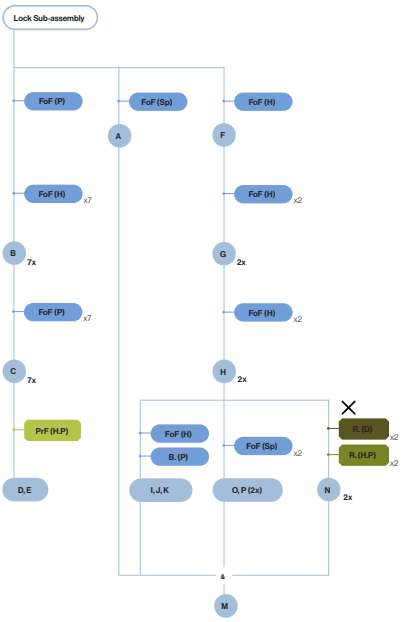
Rivet	R
Screwdriver Torx	Tx
Glue	Glue
Form Fit	FoF
Press Fit	PF

Type of Tool

Screwdriver	(Sc)
Hand	(H)
Drill	(D)
Hammer & Punch	(H.P)
Key	(K)
Pliers	(Pl)
Spudger	(Sp)
8mm Spanner	(8Sp)
Knive	ook K?

Sub-Assembly Lock Part Number List

A	Plastic push-on part
B	Lock plaques
C	Lock Springs
D	Lock main body
E	Lock top
F	Metal backplate
G	Plastic side panel
H	Long metal stick
I	Ball
J	Spring
K	Casing
L	Lock housing
M	Metal housing
N	Metal linkage with two holes
O	Plastic lock housing
P	Short metal stick



MASS BALANCE DIAGRAM

A Mass Balance Diagram (MBD), as shown in Figure 5.7, shows the weight [g], the price of the materials [EUR] and the environmental impact of the material [gCO2]. These factors are used to evaluate the impact of the materials used in the construction of the LSS. The Granta Edupack (2023) dataset is used for the properties.

Excellent recyclable LSS

The MBD graph shows that 85.8% of the LSS is made up of recyclable materials such as aluminium and stainless steel. The remaining non-recyclable materials (14.2%) are mainly the glass-filled PA6 thermoplastic used for the corner protectors. Switching to a recyclable thermoplastic reduces the environmental impact and increases recyclability, reducing the non-recyclable content to 0.45%.

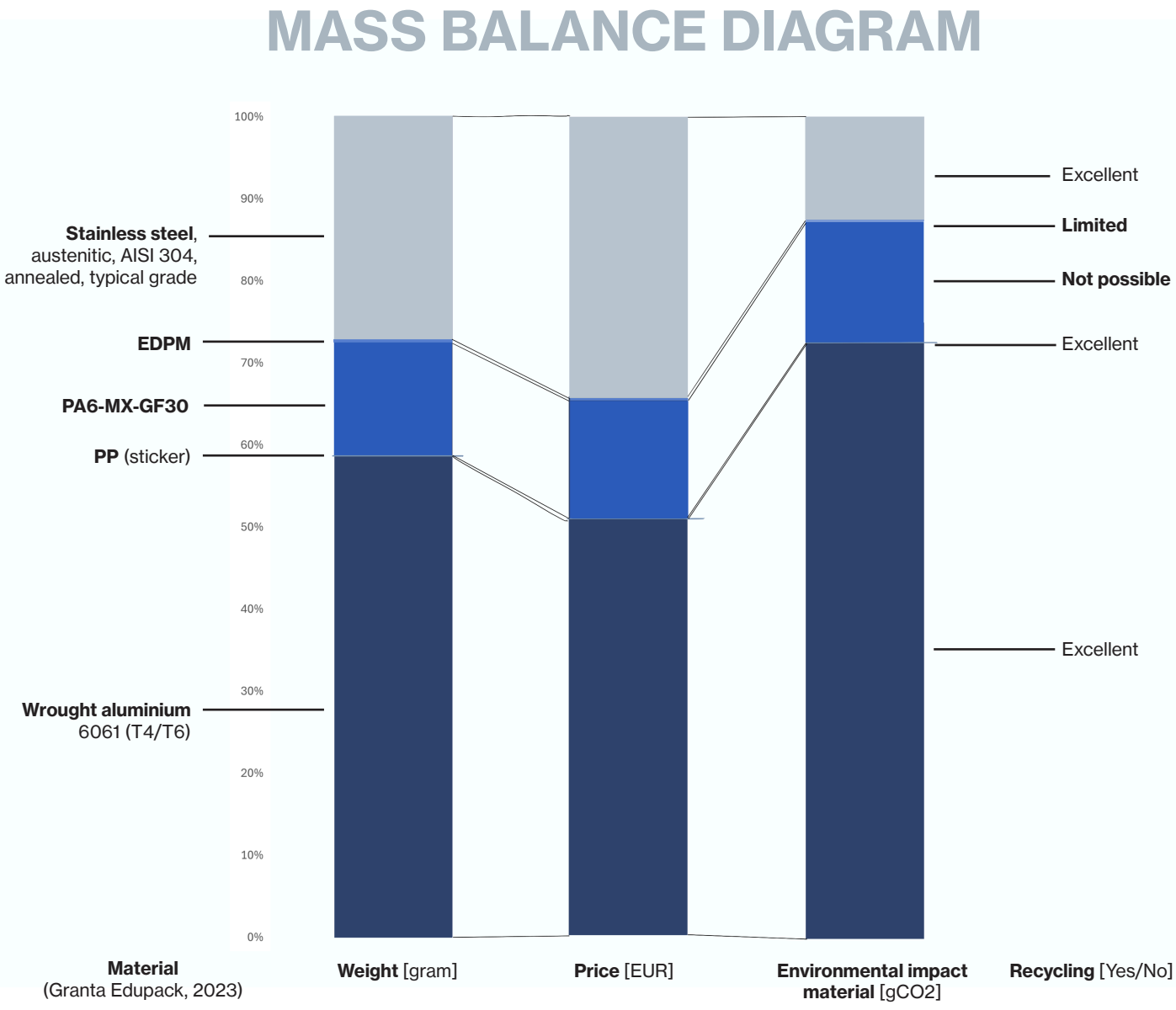


Figure 5.7 | Mass Balance Diagram - BMW R 1200/1250 GS Adventure right pannier

KEY FINDINGS
CIRCULAR ECONOMY

KEY FINDING 10

The LSS is nearly impossible to disassemble and reassemble due to the extensive use of high-force non-reversible connectors.

The BMW GS Adventure LSS uses a horizontally structured product architecture with many dependencies (Found in the Disassembly map). Combined with the high number of steps, critical activities, critical parts and high-force non-reusable connectors (n=69 rivets) involved in this LSS, disassembly and assembly is an almost impossible task. Only the three lock sub-assemblies are easily disassembled for maintenance and/or repair.

RQ3 What is the current state regarding the Circular Economy for a BMW GS Adventure LSS?

RQ3.1 What is the current state regarding disassembly and reassembly of a BMW GS Adventure LSS?

KEY FINDING 11

The removal of priority parts is challenging due to their location in the architecture and the high number of dependent parts.

Parts that require the most maintenance and/or have the highest risk of failure are called priority parts. Ideally, these parts should be easily accessible for replacement in order to increase the longevity and lifetime of the LSS. The hotspot mapping identified seven priority parts (see Figure 5.8).

These priority parts are not easily accessible due to their deep location in the product architecture. Furthermore, these parts are very large in size and have a large number of dependent parts connected to them.

It should also be noted that almost all of the priority parts are marked for their environmental and economic hotspots. This highlights the importance of being able to remove these parts for reuse, refurbishment, repair and/or recycling.

RQ3.2 What parts of the analysed LSS are most important? (Priority parts)
RQ3.3 How repairable/replaceable are the priority parts?

Figure 5.8 | Priority parts

CHAPTER 6

DESIGN DIRECTION

Now that the key findings have been distilled from the context and analysis, it is time to take those findings and create a design direction: Sacrificial Design.

This chapter starts with the key finding: design direction, that explains how the previous key findings lead to the design direction sacrificial design. This explanation is followed by an overview of the design direction and consequent five sacrificial strategies.

Content

KEY FINDING
DESIGN DIRECTION

KEY FINDING 12

The strategy of sacrificial design presents the user with a decision: to exhibit the evidence of previous adventures through visible battle scars or to restore the object to its original condition.

RQ4 How can we prolong the lifetime of a LSS?

RQ4.1 What strategy can be implemented to increase the lifespan of a LSS for BMW R 1300 GS and R 1300 GS Adventure motorcycles?

The objective is to develop and design a concept LSS that enables the user to easily prolong the lifespan of the product in both functional and aesthetic terms. At the same time, the aim is to steer the comfortable, adventurous status symbol image of the R 1300 GS Adventure closer towards its robust adventure identity.

Key findings

The key findings from the previous chapters provide a comprehensive overview of the R 1300 GSA identity and design language, the versatility of the GS rider, and the low-speed situations with external impacts where damage to the front and misalignment of the lid occur. GS riders' problem-solving mindset is evident in their positive approach to repairs, despite the fact that a number of them still refrain from repair practices. Finally, the technical analysis concluded that it is almost impossible to perform maintenance, disassemble or repair the aluminium LSS under review.

Creating an unique narrative trough repair practices

This demonstrates the GS rider's commitment to extending the lifespan of the LSS, which the LSS does not technically permit. Allowing the GS rider to engage will increase attachment to the LSS and BMW GS. This will enable them to express their own narrative through the battle scars of past experiences or the "new" and clean, repaired look.

Sacrificial design strategy

The design and engineering of easily replaceable external components that can withstand and absorb the forces of a low-speed external impact creates a situation where damage accumulates in those replaceable components, instead of in the main structure. The external components, which are easily replaceable, are designed to absorb and dampen impact. The external placement enables easy repair practices, allowing the GS rider to make an informed decision about whether to replace or not to replace the sacrificial parts of their LSS, creating a stronger connection to their LSS.

The strategy is called **Sacrificial Design** and will be further explained in this chapter.

SACRIFICIAL DESIGN AS A STRATEGY

As stated on the previous page, the key finding indicates that a design direction should increase durability, enabling GS riders to act in order to prolong the lifespan of their LSS, and focus more on sustainability in the context of the CE.

Sacrificial design

Sacrificial design is developed to involve the proactive incorporation of features designed to prevent damage to the primary structure, along with the straightforward replacement and repair of these features to withstand wear and tear (D. H. Hollander, 2018). The overall objective is to extend the lifespan of the LSS concept by sacrificing the easily replaceable outer features. The following page presents five sacrificial directions.

Retaining value through enhanced user interactions

The inclusion of sacrificial and repairable protective parts contributes to the value retention path of reuse and repair (value hill model). It prevents the LSS from being discarded when damaged, helping to retain the value for the GS rider and CE.

Increased user involvement through conscientious repair increases the attachment to the LSS as it carries the stories of imperfections and subsequent repair practices. For the CE, emotional attachment and involvement work in tandem with technical repairability to increase the lifespan and number of positive experiences a GS rider can have with their LSS setup.

Embracing imperfection: use-marks as a visual narrative

Battle scars (another way of describing usage marks) can add to the adventurous image of the GS Adventure motorcycle rider. By challenging the conventional notion that new equals good, it is possible to showcase past experiences with visual use marks.

The Japanese philosophy of Wabi-Sabi embraces the beauty of natural ageing and imperfection. The sacrificial design allows these imperfections to become part of the motorcycle's character. The ability to repair these sacrificial parts gives the owner a degree of control over the story they wish to tell with their motorcycle and LSS.

Now that the sacrificial design strategy has been clarified, the subsequent page will focus on the five directions within sacrificial design.

DESIGN DIRECTION

My aim is to create attachment and increase durability through the use of sacrificial design to prolong the lifespan of a luggage storage system on the BMW R 1300 GS Adventure.

SACRIFICIAL DIRECTIONS

Sacrificial design makes use of features that sacrifice themselves in the event of wear and/or low speed falls, reducing the risk of large deformations in the main structure. The location of these features in the product architecture, the ease of disassembly and the repairability of these parts are of high importance in this strategy.

Based on the sacrificial design direction derived from the research, five sacrificial design directions were created.

Combination of strategies

Most sacrificial design solutions involve a combination of sacrificial strategies, which actually increases their strength. The isolated functions of each of the five strategies are visually represented in Figure 6.1. Further visual reference material can be found in Appendix P.

Chapter 7 uses these sacrificial design directions to generate ideas and concepts.

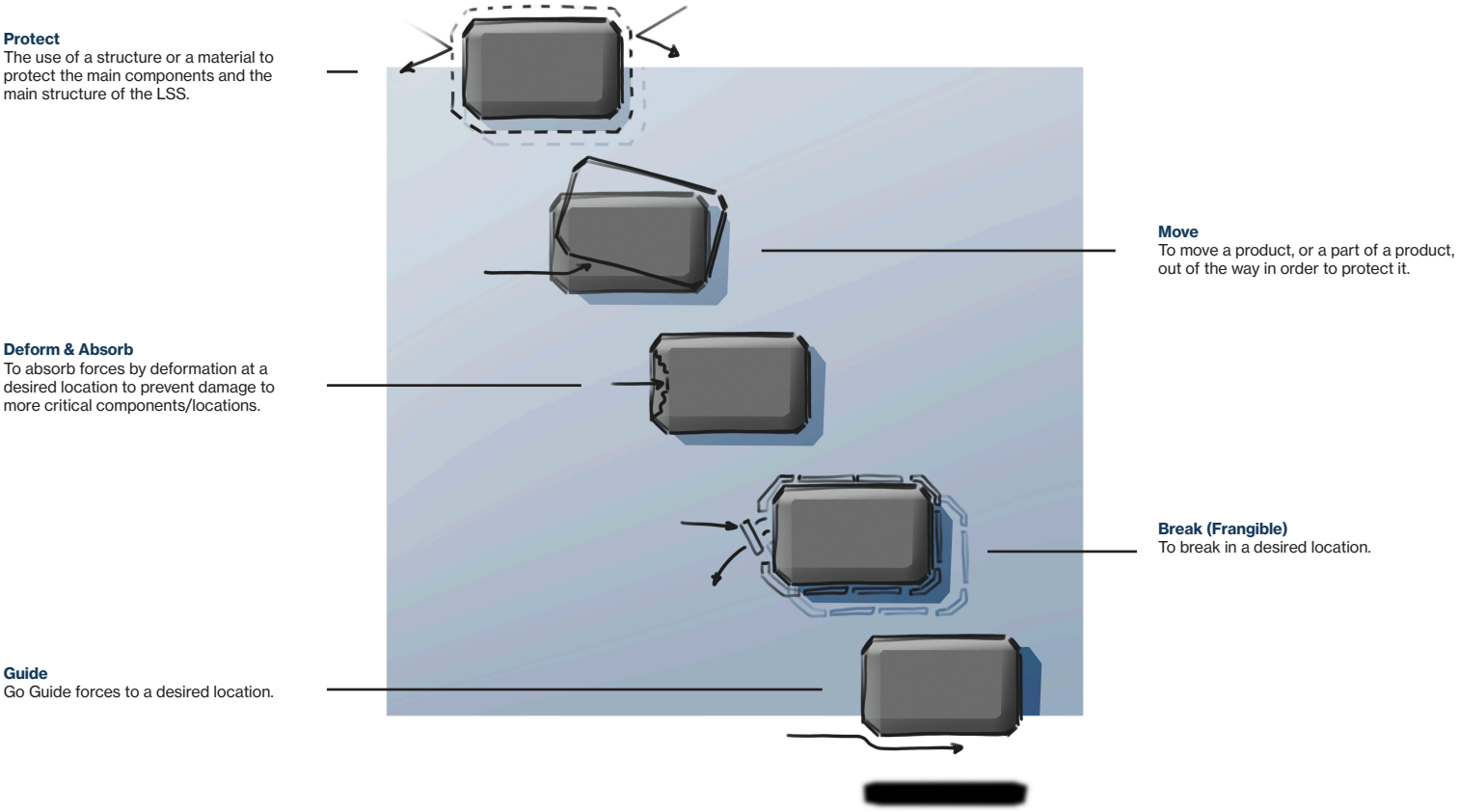


Figure 6.1 | Overview - Five sacrificial directions within sacrificial design.

DESIGN REQUIREMENTS

A BMW GS Adventure LSS is exposed to challenging conditions and is used by a versatile group of GS riders. To develop ideas and select concepts which, it is essential to have a clear set of requirements.

Main requirements

These requirements are based on the insights gained in the previous chapters, and incorporate the detailed understanding gained from the various analyses conducted. The main requirements are presented in Table 6.1 and the full list can be found in Appendix S.

Main wishes

There are also a number of wishes derived from the research described above, which can be found in table 6.2.

Table 6.1: List of the main requirements for the LSS.

Category	ID	Main Requirement
Storage Capacity	SC1	The LSS must have a luggage storage capacity of 30 Liters.
Durability	D2	The sacrificial parts must be able to absorb and protect the core functions of the LSS in when subjected to falls from standstill up to speeds of 30 km/h.
	D3	The LSS must be able to absorb impacts without major deformations when subjected to falls from standstill up to speeds of 30 km/h.
	D6	The sacrificial parts of the LSS must be able to withstand damage from the side, underside, and front.
Prolong Lifetime	PL2	Priority parts must be completely removable and replaceable.
	PL3	The absorbent and protective parts must be replaceable with the use of basic tools. (EN45554 Norm)
Rider Safety	RS1	It is vital that contact between the rider, and possibly the passenger, and the LSS is made with soft, deformable materials in order to reduce the risk of injury in the event of a fall or crash.
Modularity	M1	It is essential that the LSS functions effectively with and without the soft bag.
	M2	The LSS must be suitable for use as a camp chair, table or workbench.
Ergonomics	E1	The LSS must be used comfortably by a single rider in a seated and standing position.
	E2	The LSS must be used comfortably with a duo riding setup without the LSS intervening with the seating comfort of the rider and/or passenger.
Compatibility	C1	The LSS must be designed to securely fit on the luggage rack of the BMW R 1300 GS Adventure.
Design & Aesthetics	DA1	The LSS must fit in with the aesthetics of the BMW R 1300 GS Adventure's styling.

Table 6.2: List of the wishes for the LSS.

Category	ID	Wish
Weather Resistance	W1	The LSS should keep dust and water out in order to keep the luggage clean, dry, and safe as much as possible after the event of a fall or crash.
Prolong Lifetime	W2	Functional groups, like the electronics, should use clumping to be removable in sub-assemblies.
Ease of Installation and Removal	W3	In order to facilitate a straightforward installation process, it is recommended that alignment aids such as grooves or guide pins be incorporated.
	W4	It is important to ensure that the unit's weight is kept low in order to facilitate effortless handling during removal or installation.
Design and Aesthetics	W5	The battle scars from falls, crashes, and/or other types of damage should add to the visual storytelling of the LSS.
Storage	W6	The storage volume should be as large as possible

CHAPTER 7

IDEATION & CONCEPTUALISATION

The sacrificial design strategy, including the five design directions, is used to generate ideas and create concepts. The chapter begins with an overview of the four design phases, followed by an illustration of each phase. The second part of the chapter illustrates three concepts and ends with the selection of the concept that will be further developed.

Content

Overview of four ideation phases
Exploration | Hand sketches
Form study | Silhouettes
Initial ideas | Sacrificial design
Concept sketches | Sacrificial design

3 concepts
Selected concept
Validation

IDEATION PHASES

The numerous ideation sketch phases throughout the project have been grouped into four themes. The increase in complexity of ideas and visualisations is visible from one theme to the next.

Figure 7.1 below provides an overview of these themes, while the four full themes can be seen on the following pages.

EXPLORATION
HAND SKETCHES

Hand sketches are used for first ideation and exploration.

FORM STUDY
SILHOUETTES

The form collage '**DURABLE**' inspired three interesting side and three interesting front silhouettes.

INITIAL IDEAS
SACRIFICIAL DESIGN

Initial ideation following **'SACRIFICIAL DESIGN'** direction.

CONCEPT SKETCHES
SACRIFICIAL DESIGN

The five '**SACRIFICIAL DIRECTIONS**' were the basis for the concept drawings.

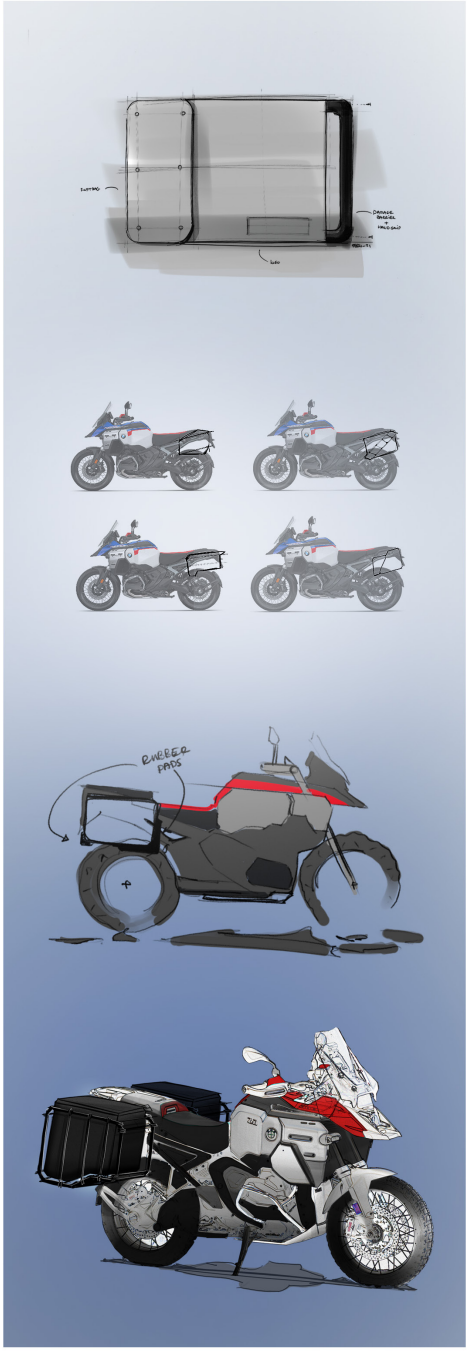
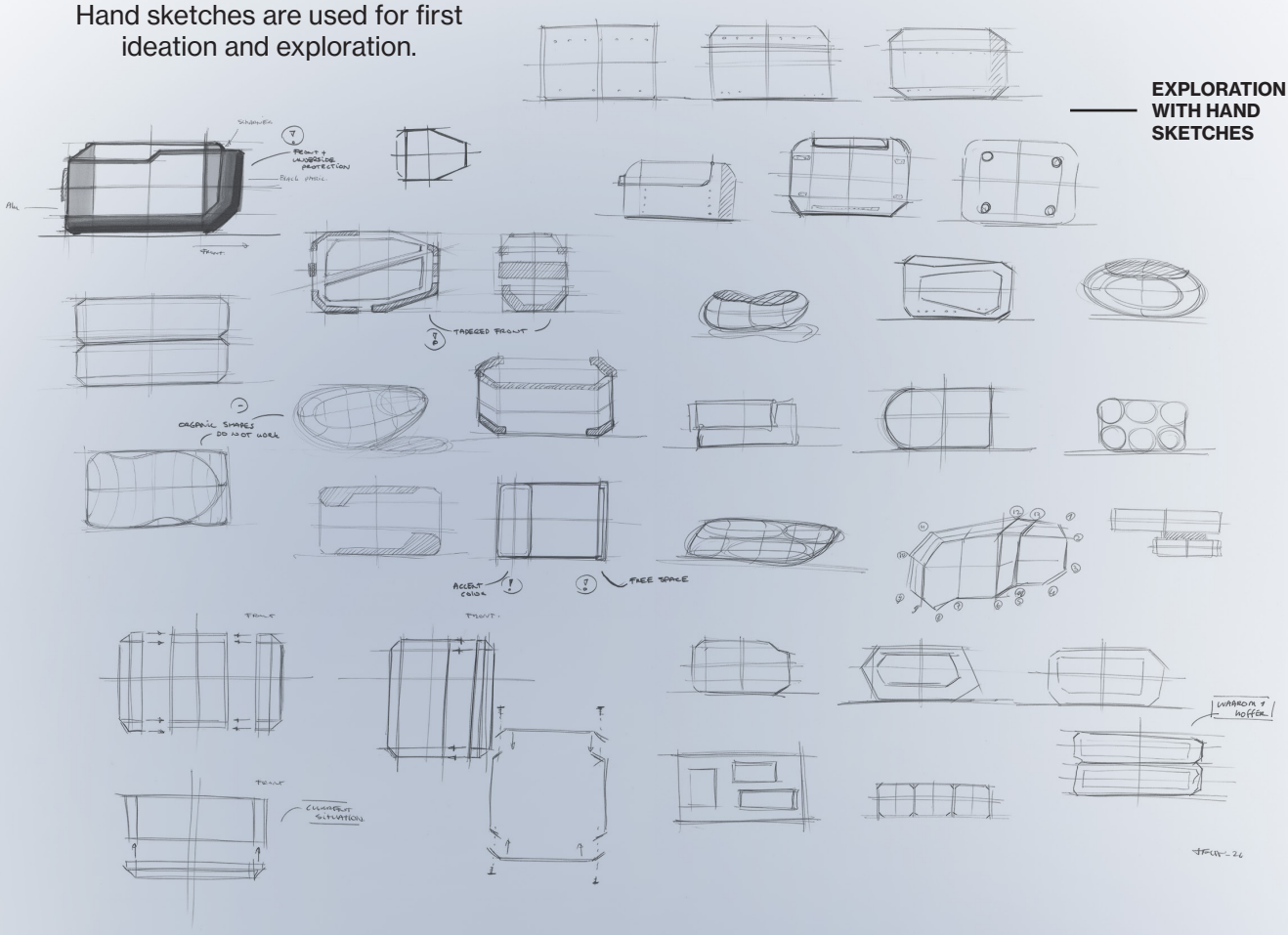


Figure 7.1 | Ideation sketch phases

EXPLORATION
HAND SKETCHES

Hand sketches are used for first ideation and exploration.

EXPLORATION WITH HAND SKETCHES



MOST PROMISING HAND SKETCHES FURTHER VISUALISED

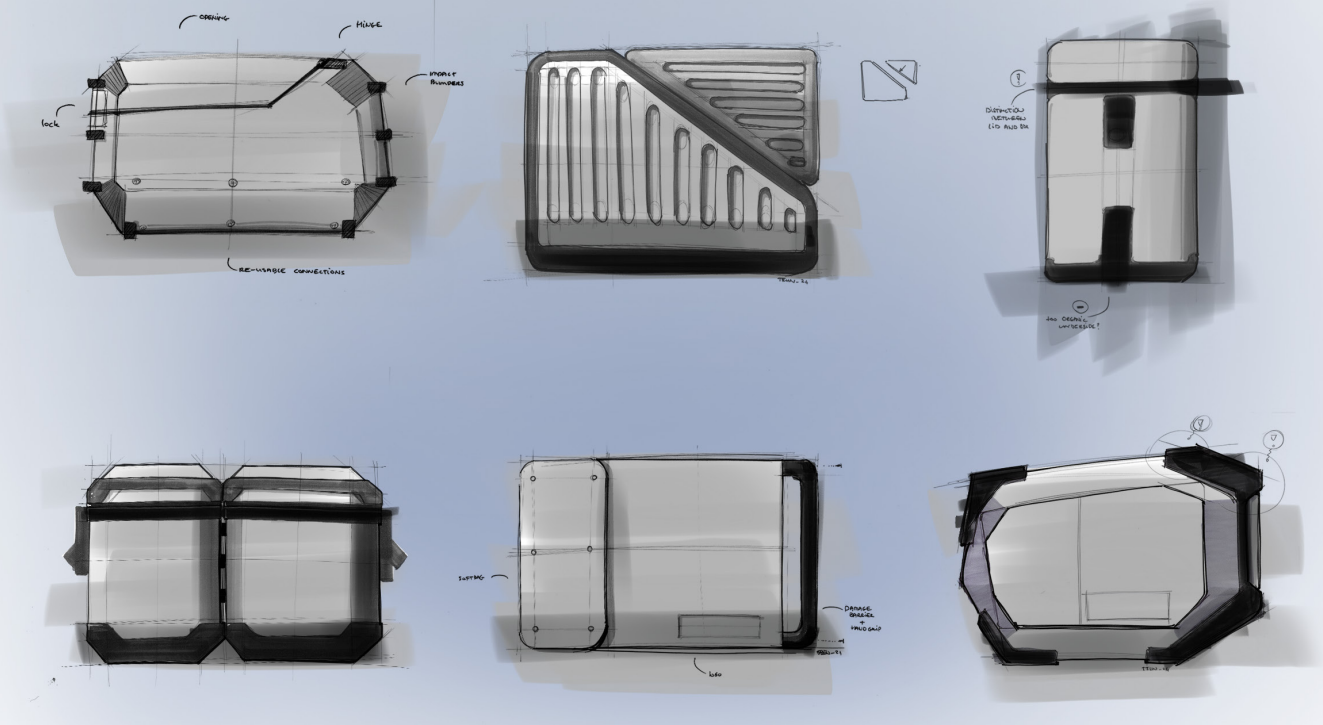
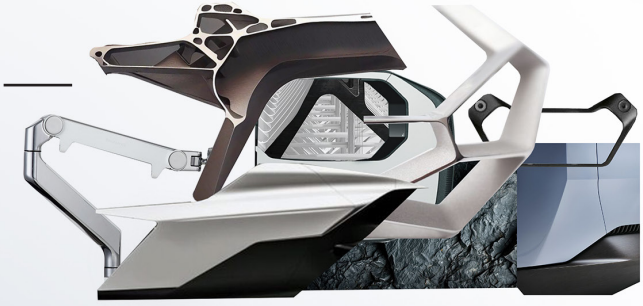


Figure 7.2 | Exploration - Hand Sketches

FORM STUDY
SILHOUETTES

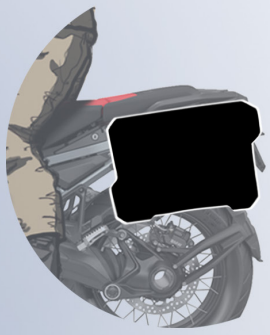
The form collage '**DURABLE**' inspired three interesting side and three interesting front silhouettes.

FORM COLLAGE
DURABLE



IDEAS BASED ON FORM COLLAGE

INTERESTING **SIDE SILHOUETTES**



INTERESTING **FRONT SILHOUETTES**

Figure 7.3 | From study silhouettes.

INITIAL IDEAS
SACRIFICIAL DESIGN

Initial ideation following **'SACRIFICIAL DESIGN'** direction.

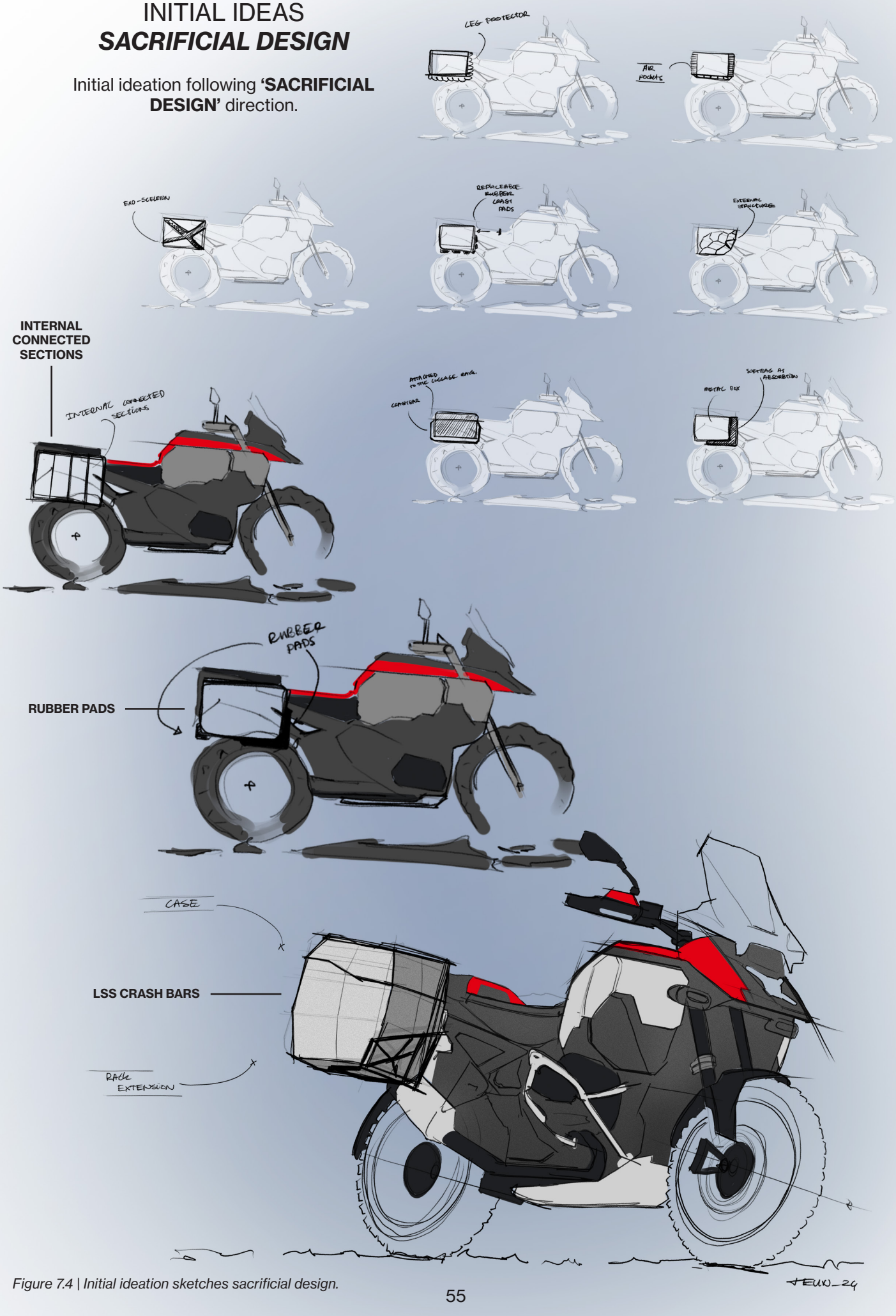


Figure 7.4 | Initial ideation sketches sacrificial design.

CONCEPT SKETCHES
SACRIFICIAL DESIGN

The five '**SACRIFICIAL DIRECTIONS**' were the basis for the concept drawings.

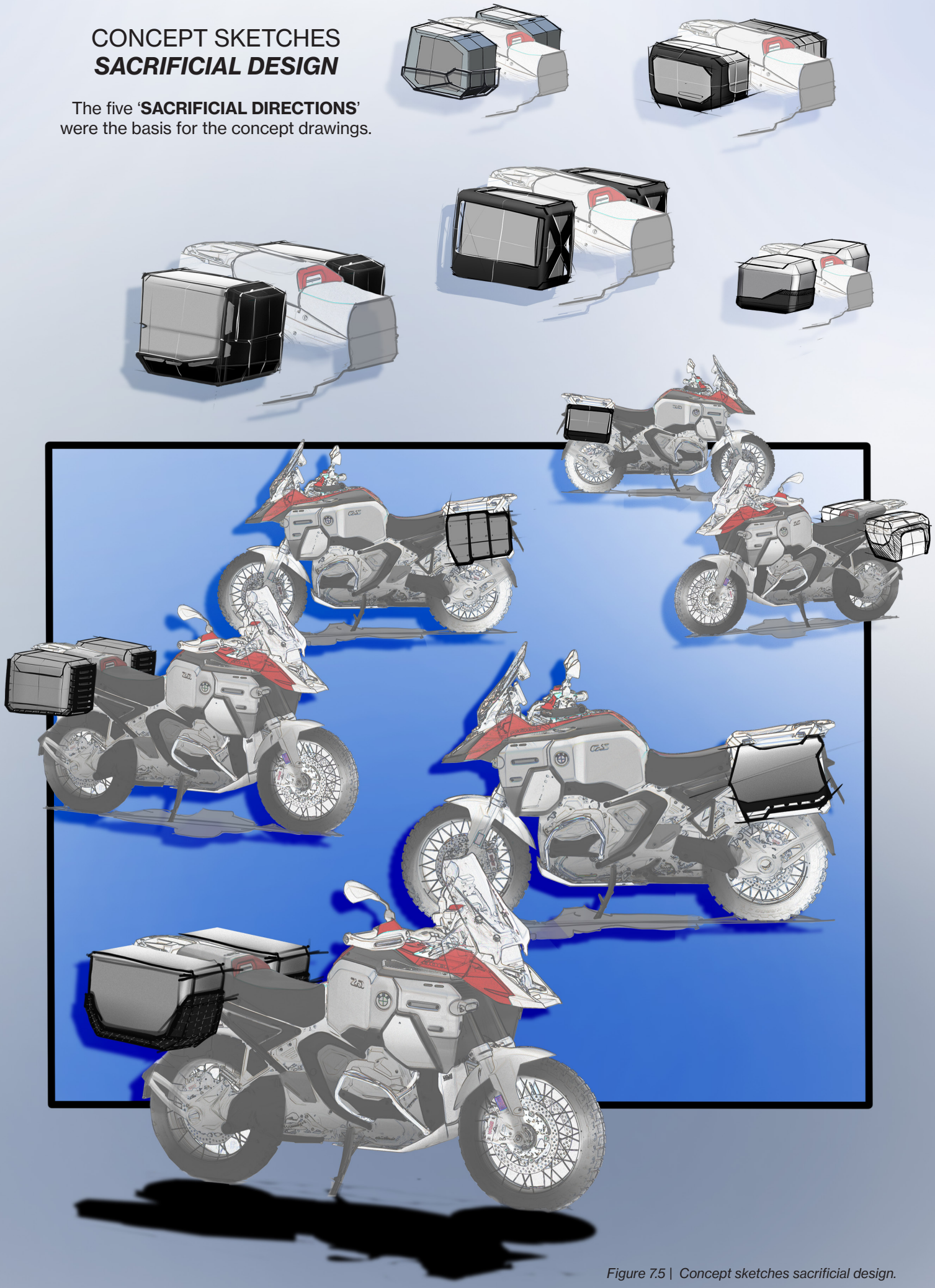


Figure 7.5 | Concept sketches sacrificial design.

CONCEPT SELECTION

A total of 26 sketches have been evaluated on their feasibility. This selection of feasable sketches have been rated using the weighted objectives method (Van Boeijen et al., 2020) resulting in three concepts. A full overview of the weighted objectives method can be found in Appendix Q.

This page provides a brief explanation of these concepts, which are further visualised on the next three pages.

CONCEPT A | **DEFORM & ABSORB**

BUMPER WRAP

The ‘BUMPER WRAP’ is a LSS with a rubber protective sleeve around its bottom part. This bottom section connects to the luggage rack rather than the LSS itself.

CONCEPT B | **GUIDE**

MESH-MATE

The open structure of the ‘MESH-MATE’ allows a modular mesh storage net to be placed , where items such as rain clothing can be stored. The open structure can also be used as a handgrip to manoeuvre the motorcycle.

CONCEPT C | **BREAK \ PROTECT**

GS PROTERRA

The protective layer with air pockets and the additional sacrificial soft bag provide an absorption zone for the most vulnerable areas of the ‘GS PROTERRA’.

CONCEPT A | **DEFORM & ABSORB**

BUMPER WRAP

The ‘BUMPER WRAP’ is a LSS with a rubber protective sleeve around its bottom part. This bottom section connects to the luggage rack rather than the LSS itself.

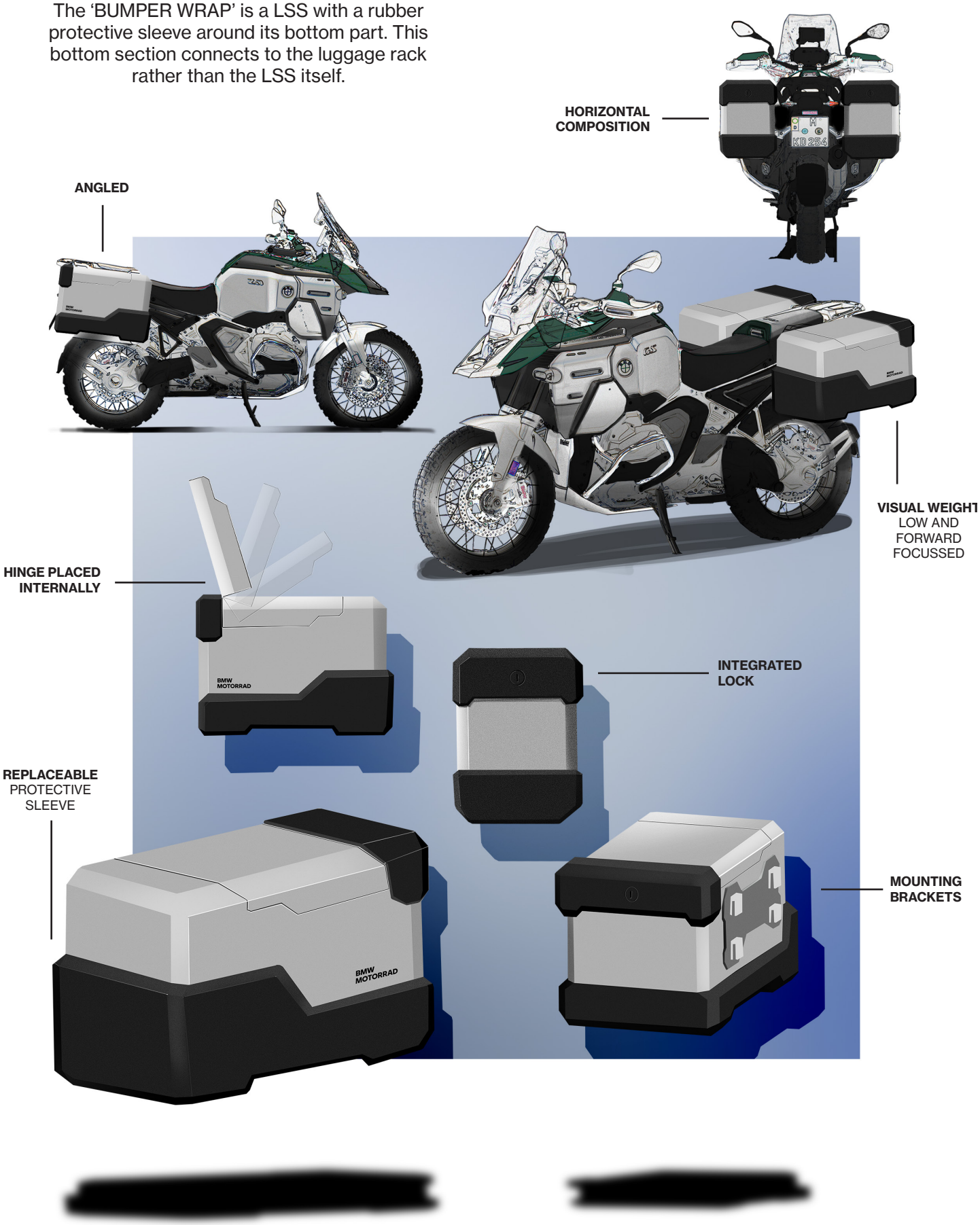


Figure 7.6 | Concept sketch A.

CONCEPT B | **GUIDE**

MESH-MATE

The open structure of the ‘MESH-MATE’ allows a modular mesh storage net to be placed , where items such as rain clothing can be stored. The open structure can also be used as a handgrip to manoeuvre the motorcycle.

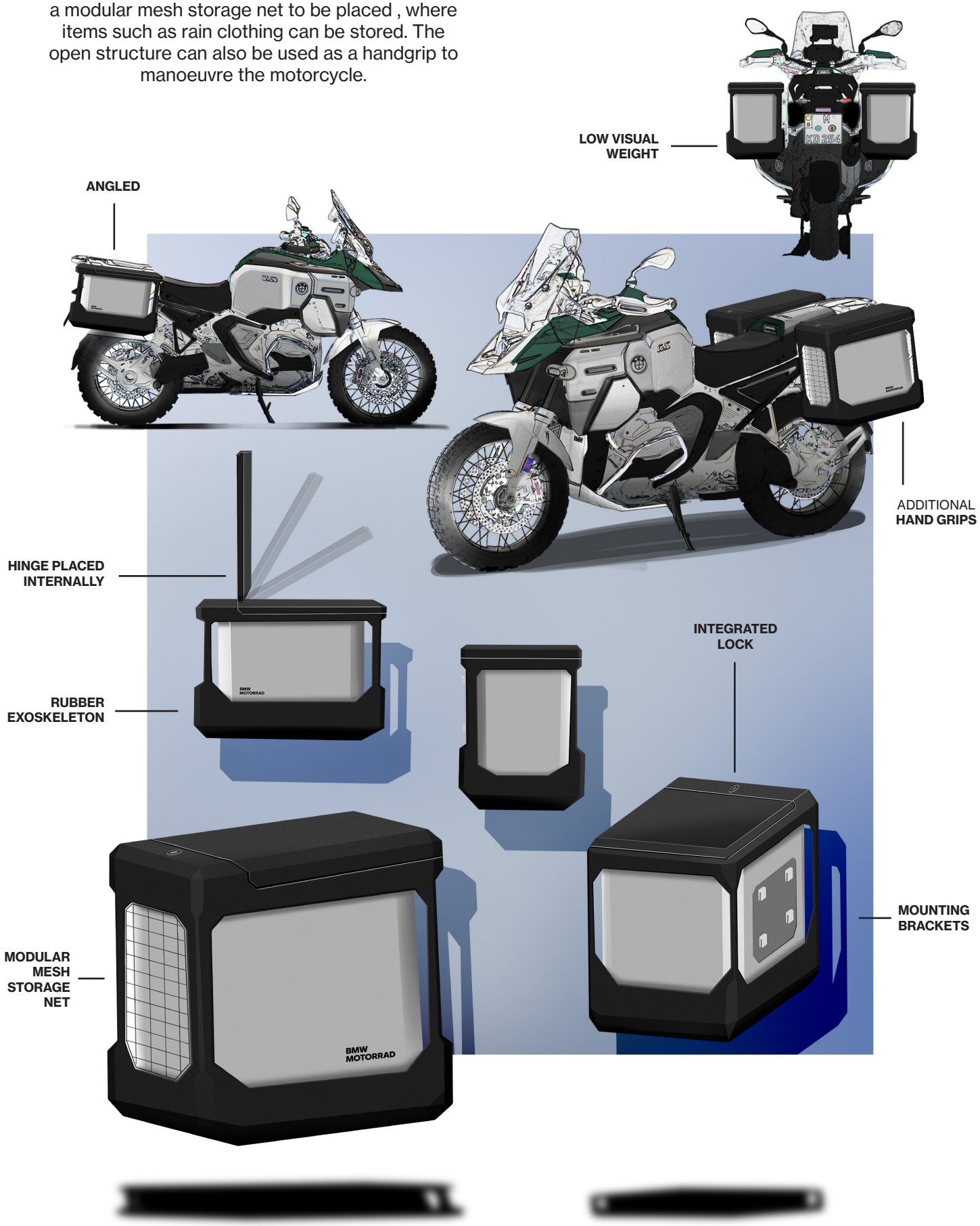


Figure 7.7 | Concept sketch B.

CONCEPT C | **BREAK \ PROTECT**

GS PROTERRA

The protective layer with air pockets and the additional sacrificial soft bag provide an absorption zone for the most vulnerable areas of the ‘GS PROTERRA’.

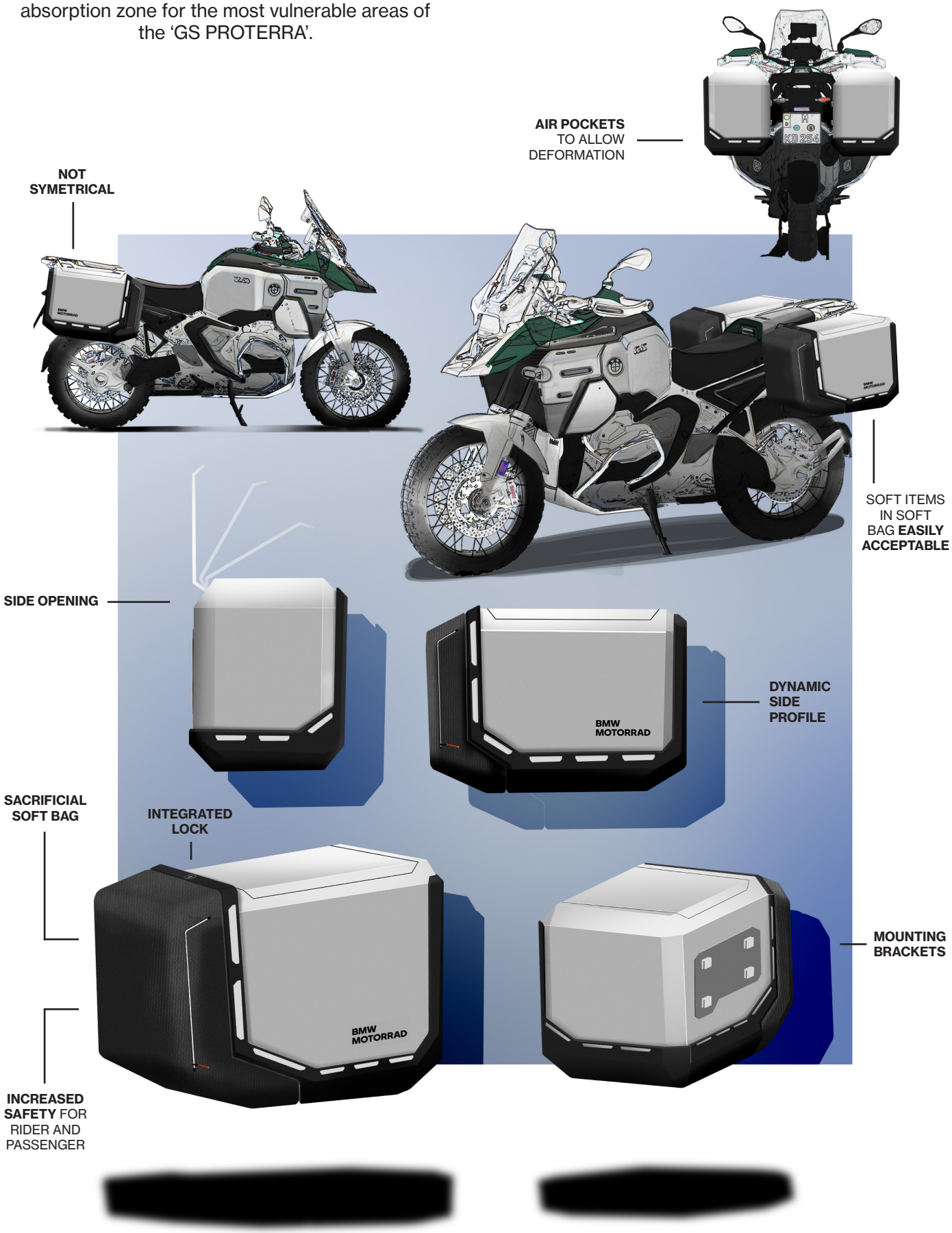


Figure 7.8 | Concept sketch C.

SELECTED CONCEPT

BMW GS PROTERRA
LUGGAGE STORAGE SYSTEM

The GS Proterra (see Figure 7.9 and Figure 7.8 on the previous page) is an aluminium LSS surrounded by strategically placed sacrificial parts. These parts are designed to absorb, deform and break in order to protect the aluminium core structure and the valuables inside.

Sacrificial parts

The sacrificial parts, located at the front, sides and rear of the GS Proterra, protect the aluminium core structure by sacrificing themselves as the first point of contact with external objects. These soft rubber parts are connected to the core structure with reusable connectors, which make disassembly easy and facilitate life-prolonging procedures.

Increased rider safety

The sacrificial parts are made of a soft, deformable material. This reduces the risk of injury to the lower body in the event of a impact, compared to harder materials such as aluminium and hard plastics. This feature increases safety for the rider and passenger.

Additional storage

The storage capacity can be increased further for solo riders with an optional additional modular soft luggage solution. When attached to the front of the GS Proterra, this luggage solution provides additional protection for the rider when storing soft items.

Montage

The GS Proterra is attached to the luggage rack of the R 1300 GS Adventure.

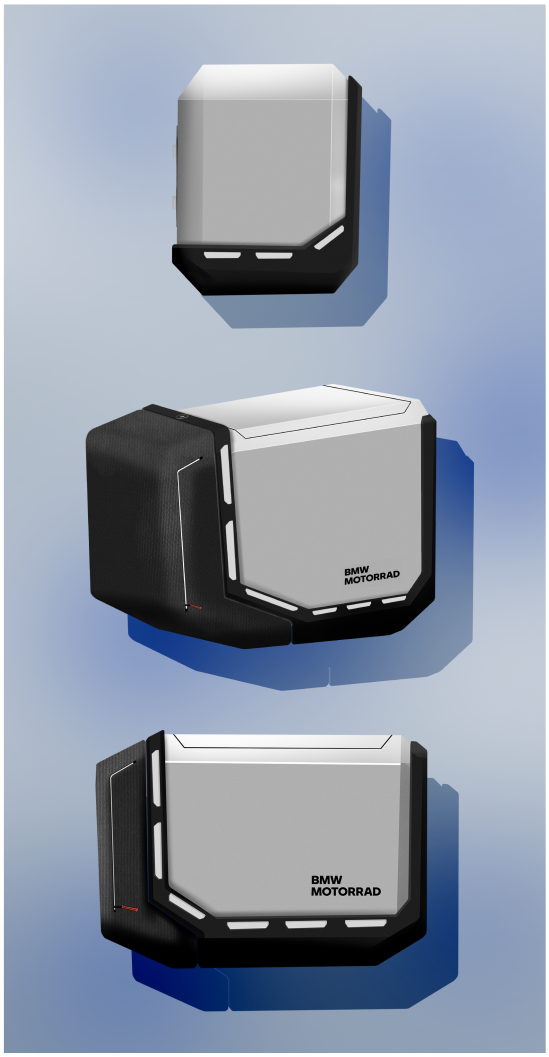
Features

The GS Proterra is equipped with a variety of features, including locks, handles, hinges and electronic components. These electronic components include a light and a USB charger.

Exterior finish

The GS Proterra's non-symmetrical design is intended to create a more robust and durable effect at the front and a lighter effect at the rear. The exterior finish is brushed aluminium, complemented by a darker contrasting semi-soft rubber material located on the lower part of the LSS.

The abbreviation GS Proterra stands for '**PRO**tection all-**TER**rain **A**luminium' and protecting the earth (Terra) at the same time.



[redacted]

Figure 7.9 | Selection of sketches - GS Proterra LSS

VALIDATION OF CONCEPT

Interview with Reiner Fings

BMW Motorrrad GS product manager
+20 years of experience with BMW Motorrad and BMW GS.

The GS Proterra concept was discussed during an interview with Reiner Fings, BMW Motorrad GS product manager.

Integrated storage

"When you go on a real travel, it's really, really helpful to have this additional storage around—not in your pockets or on your clothing, but integrated in the storage of the motorbike."

Reiner mentions the impact of successful well-integrated storage solutions in the adventure motorcycle community: *"We're selling, let's say, around 80% of that stuff within the bike. It is so successful a product. It's working really good."* This underlines the strong market demand for integrated LSS and highlights the potential of the concept to appeal to a wide range of BMW GS owners.

Emphasis on usability, robustness and flexibility

The design provides functionality, usability and flexibility. Reiner emphasizes the importance of focussing on functionality and usability in the first instance, and seeing the sacrificial features and repairability as an added secondary benefit:

"if you focus on the usability, and then enclose robustness and flexibility, you are not so far away to have a design which is clear, and which gives you on the second read clear information about the benefit of the replaceable parts."

He continues by acknowledging the idea of sacrificial features and appreciating the added bonus of the design feature.

Addressing real-world problems

The design approach is to solve practical problems faced by adventure riders, including challenges with wear-and-tear, falls, crashes and usability in different conditions. Reiner explains that many people think of crashes in extreme terms, resulting in injury, serious injury or death. The reality is that everyday riding and adventure riding carries with it the potential for accidents, but often with far less extreme outcomes.

"Few people truly understand the challenges faced by motorcycle manufacturers, particularly in terms of crash resilience. (...) In my understanding, your design has to fit perfect with the customer perspective and has to pick up the real problems that might be caused when using a motorbike."

It shows that the design addresses real-world scenarios such as low-speed motorcycle crashes and the wear and tear that comes with frequent use, ensuring that it meets the needs of customers in different riding environments.

CHAPTER 8

DESIGN DETAIL

The selected concept is developed into the final concept: **BMW GS Proterra**. The development of the luggage storage system is documented in the design detail chapter.

Content

Design detail | BMW Motorrad
Design detail | GS Riders
Design detail | Luggage storage system
Design detail | Circular economy
Design detail | Styling

Validation of sacrificial parts

BMW MOTORRAD DESIGN DETAIL

The BMW GS Proterra utilises the latest iteration of the BMW GS Adventure luggage rack, which is also featured on the R 1300 GS Adventure.

MONTAGE TO THE R 1300 GS ADVENTURE

The GS Proterra is mounted in the slots of the luggage rack's mounting bracket. The lock that secures the GS Proterra to the luggage rack is compatible with the R 1300 GSA luggage storage system. Furthermore, BMW Motorrad is developing an adapter plate that will enable the aluminium LSS to be fitted to the standard R 1300 GS, facilitating the sharing of LSSs across the R 1300 platform (Fings, 2024).

Figure 8.1 shows the luggage rack of the R 1300 GS Adventure.

Sharing mounting brackets and electronics

The mounting brackets and electronic connections are similar to those used in the R 1300 GS Adventure LSS. These parts have already been developed by BMW Motorrad and are ready to be implemented in the Proterra concept.

Using the same components for multiple LSSs reduces the number of spare parts required and simplifies repair practices, thus reducing the environmental impact.

The GS Proterra is securely fastened to the luggage rack.

Locking the LSS to the luggage rack prevents theft while allowing for easy disassembly and assembly of the LSS on the motorcycle. The location of this lock is indicated in Figure 8.1.

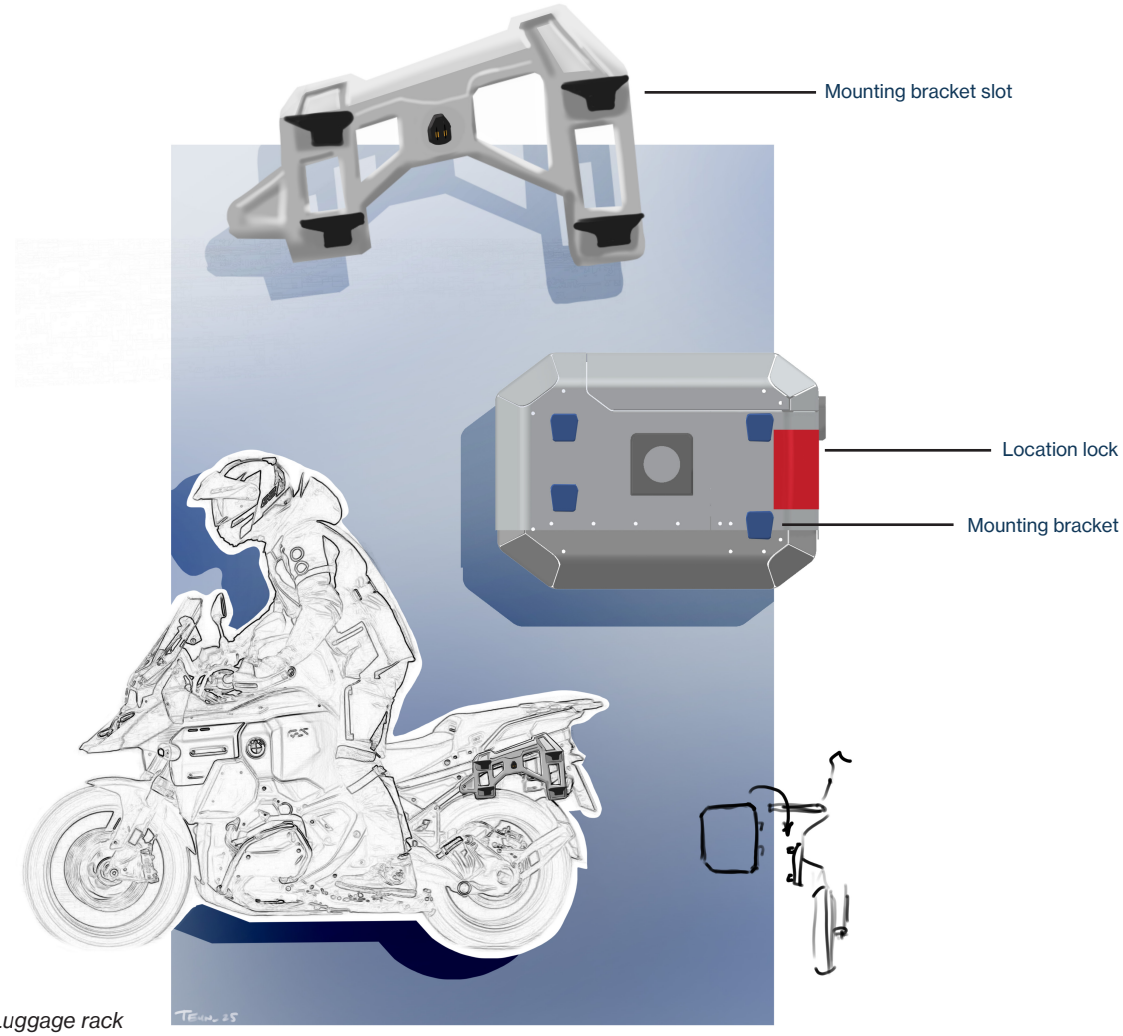


Figure 8.1 | Montage - Luggage rack R 1300 GS Adventure.

ELECTRONICS

The GS Proterra concept uses the same integrated electronics as the R 1300 GS and GS Adventure LSSs to provide charging and lighting functions. Figure 8.2 shows a block diagram of the electronics. Figure 8.3 visualises the electric connection between the LSS and luggage rack.

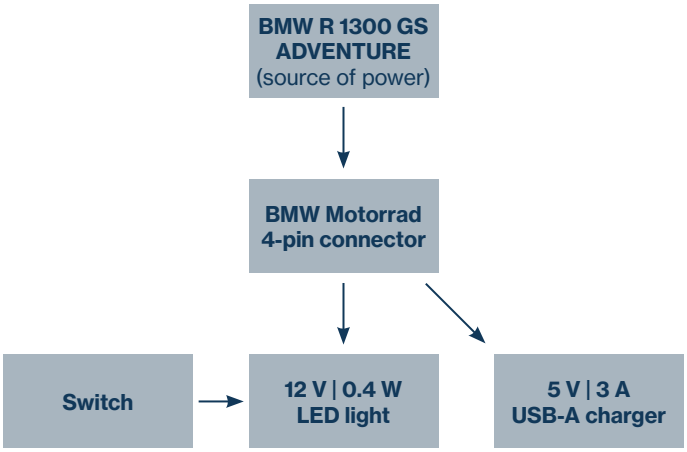


Figure 8.2 | Block diagram - Electronics in the GS Proterra.

Charging

The GS Proterra's electronics use the R 1300 GSA's electrical system, eliminating the need for additional fuses. The system has a maximum output of 15 W, with USB-A charging providing up to 5 V and 3 A (BMW Motorrad, 2023).

The USB connector can be easily replaced with a USB-C charging port. This reduces the risk of technical obsolescence, providing the GS Proterra with a future-proof, upgradeable electrical system.

Interior lighting

A built-in switch activates the interior light when the lid of the GS Proterra concept is opened. The light is powered by a 0.4W LED bulb that runs off the motorcycle's 12V system.

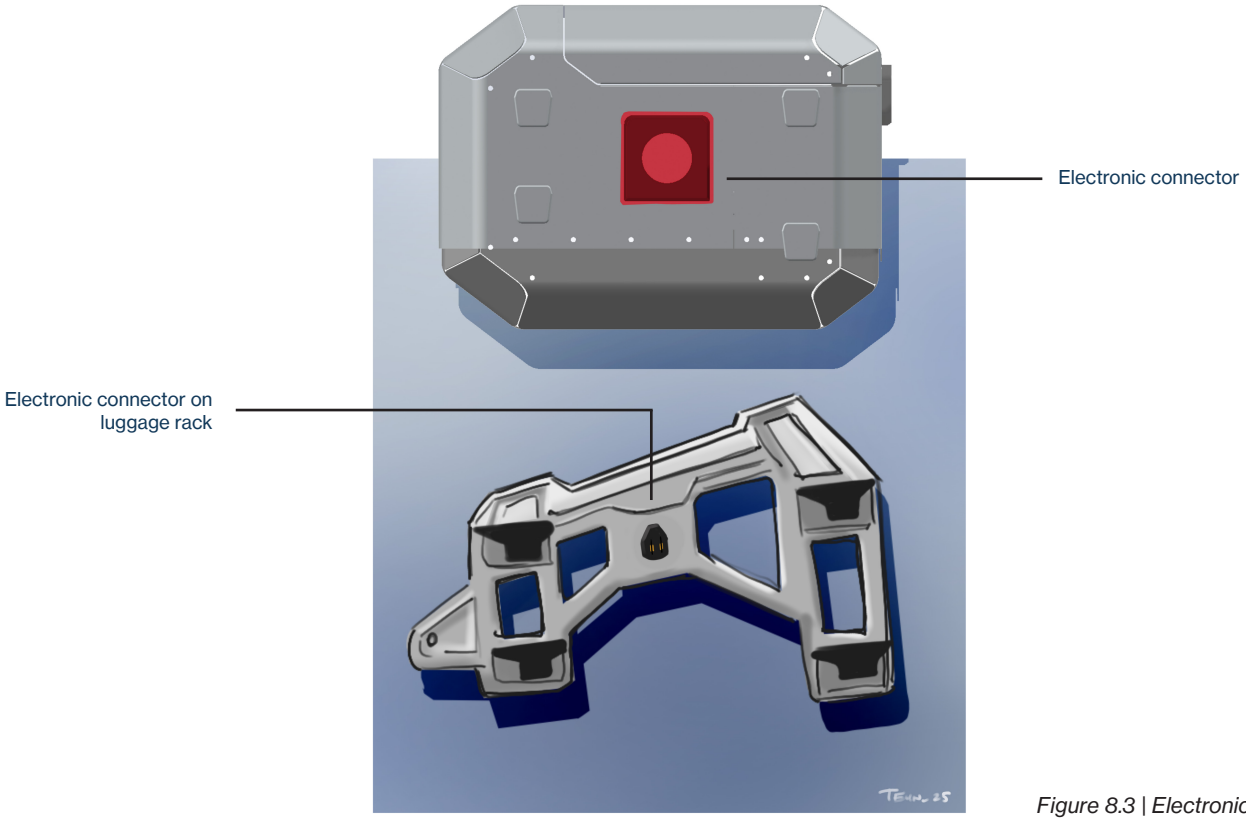


Figure 8.3 | Electronics - Overview system.

GS RIDERS
DESIGN DETAIL

Rider ergonomics and comfort are closely related in motorcycles. It is essential for a positive riding experience that the location and maximum dimensions of the LSS are chosen wisely so as not to interfere with the rider and passenger, while at the same time providing as much storage space as possible.

ERGONOMICS

As discussed in the previous paragraph, the GS Proterra uses the luggage rack of the R 1300 GSA and is therefore bounded to its location and type of mounting brackets.

The GS Proterra utilizes the maximum ergonomic dimensions to provide a large storage volume. The maximum dimensions of the GS Proterra are dictated by three main ergonomic situations: Solo riding sitting, solo riding standing, and duo riding. These three types of ergonomic situations are shown in Figure 8.4.

Storage expansion for solo riding situations

In solo-riding conditions, the storage capacity can be increased by adding a soft luggage storage system in front of the GS Proterra. This soft LSS acts as an extra layer of impact absorption, thus increasing protection for both rider and passenger. The front-facing location is ideal for storing items that require frequent and quick access, such as rain clothing.

Due to the placement of the luggage rack, in combination with the location of the foot pegs of the passenger, it is not possible to comfortably fit the soft luggage extension in duo configuration. The add-on is, therefore, an optional extension. The following page provides further information on this soft luggage extension.

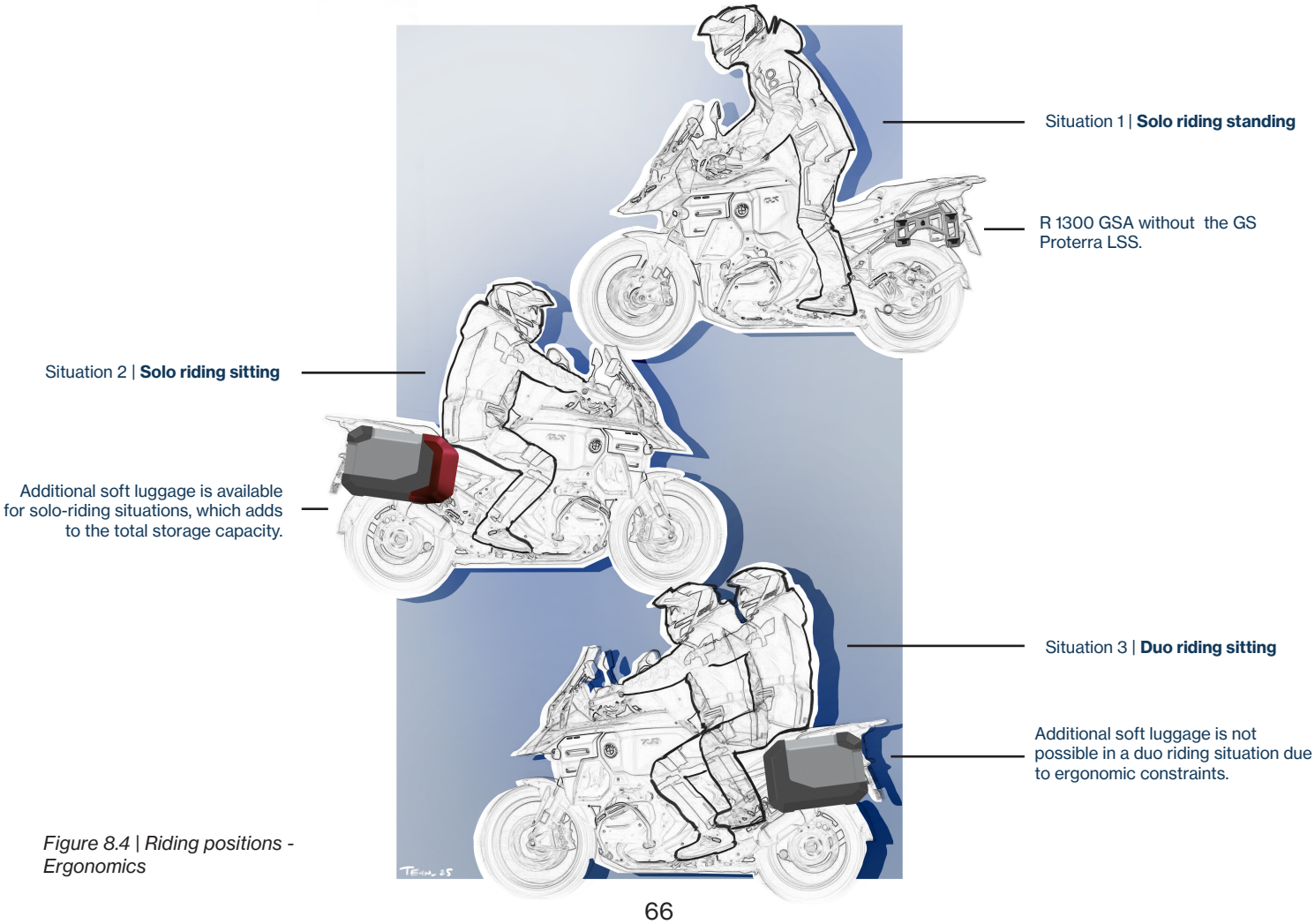


Figure 8.4 | Riding positions - Ergonomics

SOLO RIDING LUGGAGE EXTENSION

The solo riding luggage extension is manufactured from a robust yet flexible fabric, which allows it to deform and absorb impact forces while protecting the rider's legs. Figure 8.5 illustrates the location, shape, and montage of the soft luggage extension.

Rider dynamics

The forward location of the luggage extension is beneficial for the dynamic handling of the motorcycle, as it lowers and moves the centre of gravity forward.

Shape

The form-fit shape of the soft luggage extension makes optimal use of the available space while also adding to the dynamic styling of the GS Proterra.

Uncomplicated and straightforward montage

The luggage extension brackets can be mounted by the rider using the existing connections that are used by the sacrificial parts. The soft luggage extension can be efficiently and quickly attached to the front of the GS Proterra without the need for tools.

Increased rider safety

The soft luggage extension adds a deformable layer that increases the forces the GS Proterra can absorb in an external impact. At the same time, it should be noted that the risk and severity of injury to the rider's legs is reduced, especially when the bag is filled with soft and deformable items such as rain gear, clothing and/or a spare set of gloves.

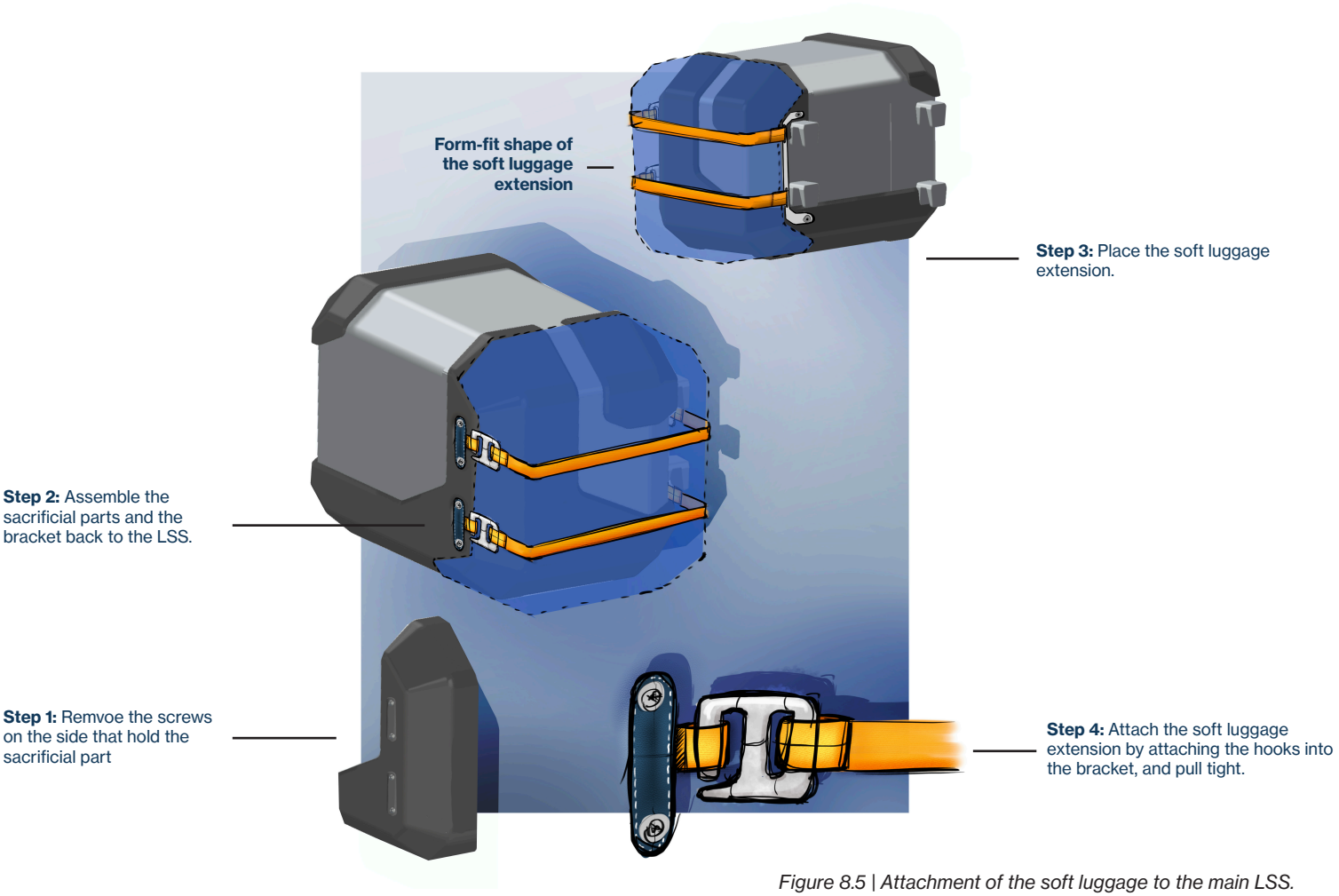


Figure 8.5 | Attachment of the soft luggage to the main LSS.

LUGGAGE STORAGE SYSTEM DESIGN DETAIL

The previous paragraphs provided a comprehensive overview of the luggage rack and its electronics, as well as the ergonomic design of the GS Proterra. This paragraph focuses on the core aluminium structure features, and materials of the GS Proterra.

CONSTRUCTION CORE STRUCTURE

The analysed aluminium LSS formed the basis for the development of the GS Proterra. The construction consists of three components: the lid, the middle and the bottom. A number of improvements have been made, allowing for added strength and increased ease of disassembly, which consequently prolongs the life of the GS Proterra.

Figure 8.6 shows the key decisions for the core structure of the GS Proterra.

Construction allows for lifespan extension

The addition of external sacrificial parts, which will be further explained later in this chapter, that deform and absorb the forces reduces the stresses on the core structure. This reduces the risk and severity of plastic deformation of the core structure, which is the main cause of misalignment of the lid and subsequent weatherproofing problems.

When combined with the key decisions from Figure 8.6, it creates a stronger, stiffer and above all easier-to-disassemble GS Proterra LSS. This feature enables GS riders to prolong the product's lifespan in the event of damage.

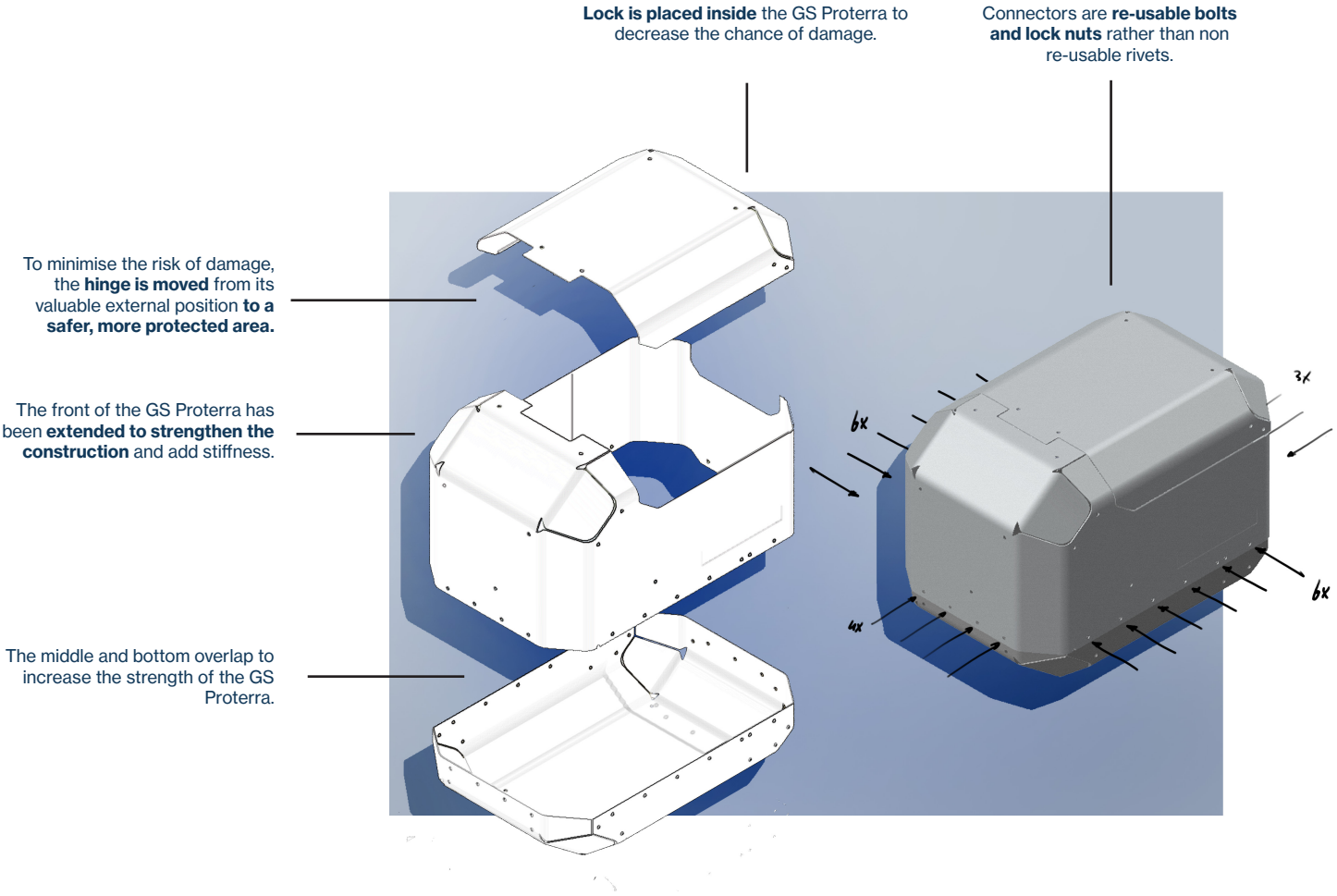


Figure 8.6 | Construction - Core structure with the key decisions.

FEATURES

The GS Proterra's hinge, lock and handle are essential features that allow the GS rider to use the LSS efficiently and intuitively. As can be seen in Figure 8.7, these features enable the GS rider to lock, unlock, open and close the GS Proterra.

Clumped sub-assemblies make repairs easy

The features are organised and clumped into one sub-assembly per feature, facilitating the removal of these sub-assemblies with minimal effort.

Once removed from the main assembly, repairs are easier since access and visibility are far superior outside the LSS than inside it. This further streamlines the disassembly and repair process.

Placement

The three consecutive steps to open the LSS is visualized in Figure 8.7.

STEP 1 | Lock

The lock mechanism is positioned slightly inside the hand grip to protect it from the weather and initial rear impact forces. This asymmetrical position leaves enough space to comfortably open the LSS with the handle.

STEP 2 | Handle

Flipping the handle upwards disengages the locking pins, allowing the GS rider to open the lid. The size of the handle has been tested when wearing motorcycle gloves to ensure it functions properly.

STEP 3 | Opening

As can be seen in Figure 8.7, the hinge is located inside the concept LSS and is mounted under the overhanging middle side panel. This internal location creates a smooth exterior surface that can be used for various tasks when not in use for riding, e.g. as a camp chair, table or workbench.

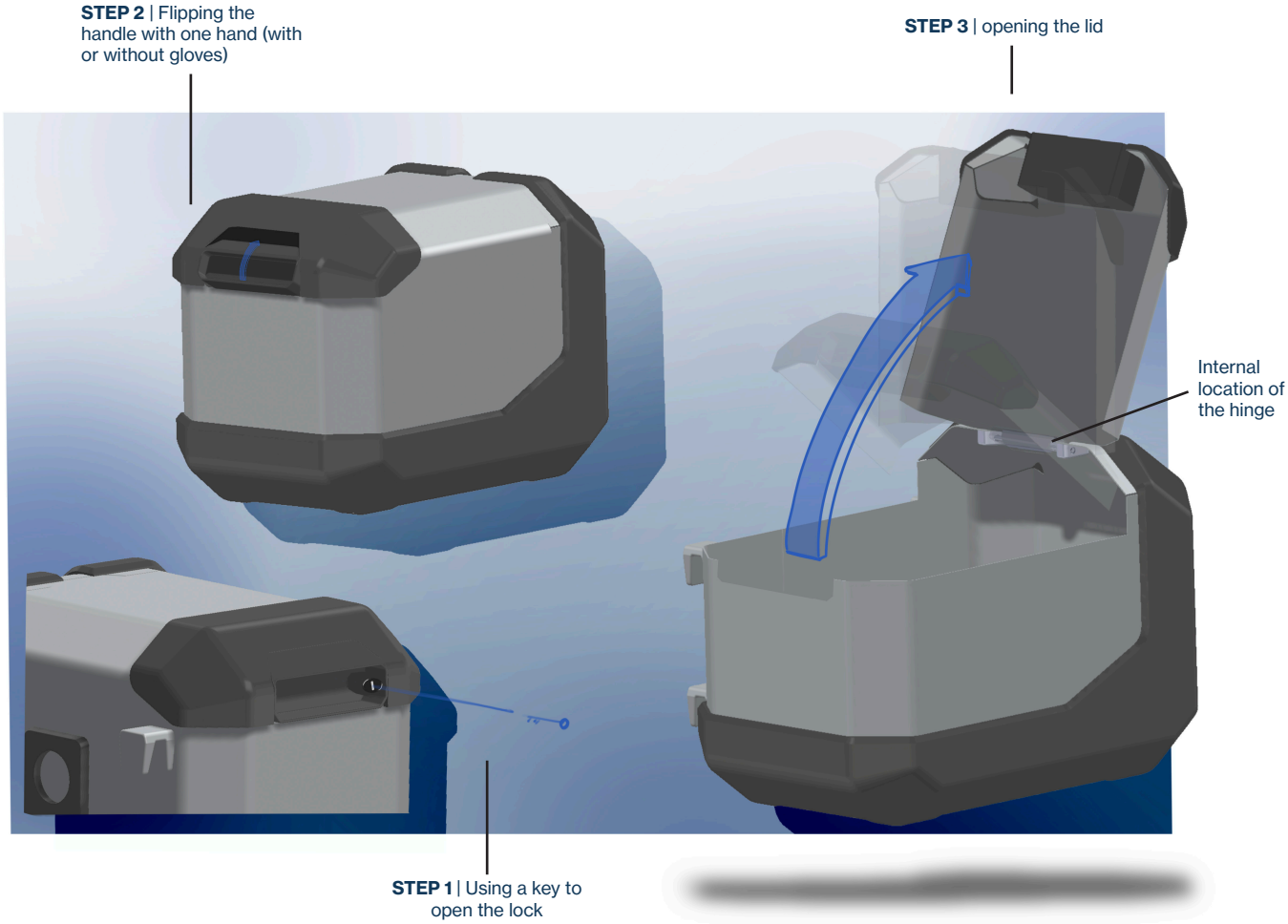


Figure 8.7 | Features

MATERIALS

The reasoning behind the choice of the materials for the core construction and sacrificial parts is discussed below. The exact mechanical properties can be seen in Appendix T.

Absorbent and deformable sacrificial parts | TPU

The sacrificial parts used in the GS Proterra are made from TPU, which allows for excellent absorption of external impact forces through deformation.

TPU (thermoplastic polyurethane elastomer) possesses excellent elastic recovery, effective damping properties and high heat resistance. It is both strong and resilient, with high tensile strength, yet soft due to its low Young's modulus. In addition, it is highly impact and tear resistant, exhibits excellent chemical and oil resistance, and is highly recyclable (Granta Edupack, 2023; Omnexus, 2025).

Proven effectiveness against damage

BASF's Elastollan AC 55D10 HPM is a TPU and can be produced by extrusion or injection moulding (Granta Edupack, 2023). Additionally, no surface treatment is required, as the material can be pigmented in dark brown and grey colours and is scratch and UV resistant, see Figure 8.9. The materials' effectiveness has been demonstrated through its use in the 'airbumps' that protect the exterior of the Citroën Cactus (SAE, 2018).

Strong yet light core construction | Aluminium 6061

The Proterra LSS is constructed from 6061 aluminium, a material that offers a balance of high strength and low weight.

The strength of Al 6061 is characterised by its high tensile strength and yield strength. The material possesses a high Young's modulus, which contributes to its hardness, and has excellent corrosion resistance to salt water, fresh water, acids and UV radiation. Additionally, Al-6061 offers excellent hot and cold formability, is highly weldable, can be effectively formed using metal pressing techniques and is highly recyclable (Granta Edupack, 2023).

Matt anodised material finish

The majority of metals require a surface treatment to prevent corrosion and create a preferable finish. The aluminium used in the GS Proterra will be anodised, a process in which an oxide layer is formed through an electrochemical process (Comhan Aluminium, 2018). Anodising is a sustainable process that treats the surface of the aluminium to make it ultra-durable, scratch-resistant and low-maintenance (Alumet, 2025).

The anodised aluminium's material finish is characterised by a matt etched appearance. The various finishes can be observed in Figure 8.10. The finish creates a tough and durable expression, fitting perfectly with the durable character of the GS Proterra and the robust and adventurous brand identity of BMW GS.

Figure 8.9 | Material finish TPU - example from Citroën Cactus (BASF, n.d.)

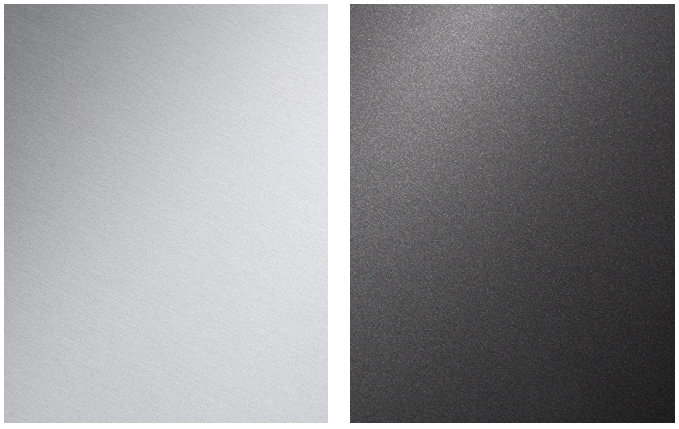


Figure 8.10 | Material finish aluminium - Black (Alumet, n.d.-a) and Natural (Alumet, n.d.-b)

CIRCULAR ECONOMY DESIGN DETAIL

The sacrificial parts are strategically positioned around the GS Proterra LSS. This paragraph explains the three core functions of the sacrificial parts and how they can be easily disassembled to prolong their lifespan in future situations. An overview of the sacrificial parts can be seen in Figure 8.11.

Sacrificial parts protect and guide through elastic deformation.

Firstly, the sacrificial parts protect the areas of the LSS that are susceptible to damage in static and dynamic situations up to 30 km/h. Secondly, the material properties of TPU enable impact forces to be dispersed through the elastic deformation of the sacrificial parts, thereby minimising their effect on the plastic deformation of the aluminium core structure. Finally, the sacrificial parts guide objects such as branches, small stones, sand, insects and unlucky birds that may come into contact with the LSS away from its visible aluminium parts.

Longevity as a hidden value proposition

The GS owner may not initially consider the ability to prolong their lifespan to be most important, but it is a hidden quality that can have a positive lasting effect on the perception of the GS Proterra long after its initial purchase. This approach enhances the product's longevity and demonstrates BMW Motorrad's ingenuity, innovation and long-term CE thinking strategy.

The next page goes into more detail about the division and ease of disassembly of the sacrificial parts.

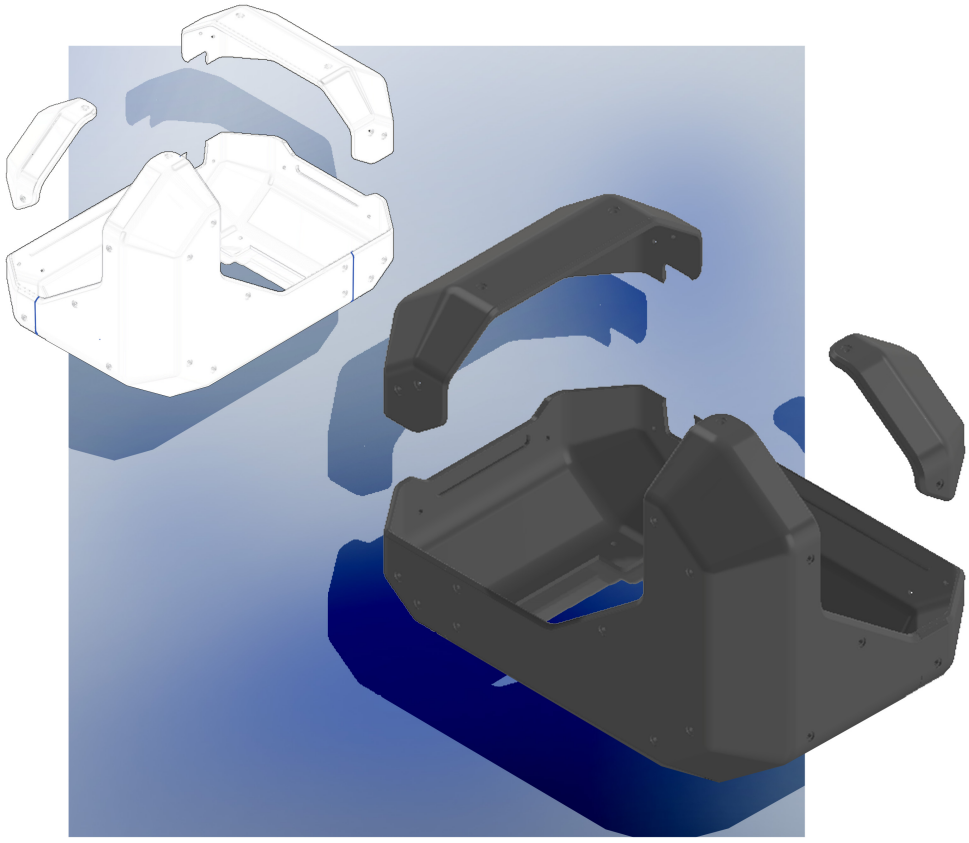


Figure 8.11 | Sacrificial parts - Overview sacrificial parts

DISASSEMBLY OF SACRIFICIAL PARTS

As discussed on the previous page, ease of disassembly is crucial for prolonging the lifespan of the GS Proterra LSS successfully. The LSS can be fully disassembled and reassembled using standard tools only, allowing for roadside repairs.

The sacrificial parts consist of five different parts. These can be seen in the exploded view of Figure 8.12.

Location of sacrificial parts

The sacrificial parts are strategically placed on the underside, front, and side of the LSS and are connected using nuts and bolts. This adds to the visual appeal of the R 1300 GS Adventure's multi-tool ruggedness. Research from the analysis phase showed that these areas of the LSS were most vulnerable, so protecting the core structure from the initial impact forces reduces the risk of permanent plastic deformations, which can lead to misalignment issues with regard to weatherproofing.

Weatherproofing

According to aluminium LSS owners, weatherproofing, particularly waterproofing, is one of the main concerns following an impact that has resulted in permanent deformation of the LSS structure. The strategic placement of the hinge feature and protective parts, combined with the ease of disassembly, reduces the likelihood of misalignment compared to the analysed LSS. This, coupled with the clear visibility of the reusable joints and the use of common tools, creates an environment with a low threshold for self-engagement in the repair process.

Priority parts

The priority parts are easier to replace as the connectors require less force to remove. However, it is very important that the fasteners are tightened to the specified torque specification to ensure a secure and strong connection.

Additional conditions

For repairability to work effectively, a few boundary conditions should be met. These boundary conditions include the availability of spare parts and sacrificial parts, the easy access to repair manuals, BMW Motorrad technical support, a dealer supported repair program, informing the owner of the GS Proterra LSS of the option of repair, and the precise sectioning of the sacrificial parts in order to make it economically interesting for the user to engage in these repair practices.

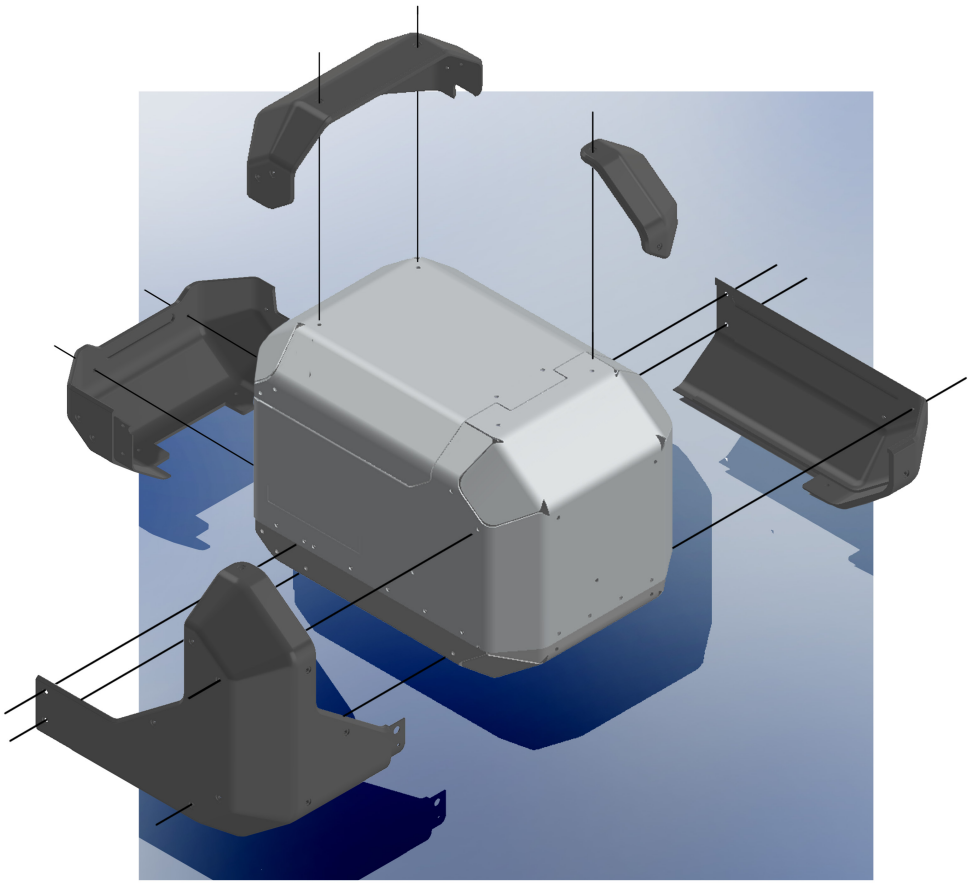


Figure 8.12 | Sacrificial parts - Overview location and montage of sacrificial parts.

DEVELOPING THE SACRIFICIAL PARTS

LOW-FIDELITY PROTOTYPING

Multiple low-fidelity prototypes were made during this project to test the shapes, mechanisms and locations of the sacrificial parts, as well as their styling in 3D.

This paragraph dives into the development of the sacrificial parts. It ends with a validation on ease of disassembly of these sacrificial parts.

FINDING PROPORTIONS

The most promising shapes from the initial ideation phase were cut out of cardboard; an old Yamaha was used as a reference for a motorcycle (see Figure 8.13). However, this motorcycle is 40 years older, as well as being smaller, lighter and lower than the R 1300 GS Adventure.

Using an underlayer in Photoshop was a more effective way of finding the right measurements and proportions, as can be seen in the ideation sketches earlier in this report.

Figure 8.13 | Low-fidelity prototyping using a motorcycle.

PROPORTIONS BASED ON THE OLDER LSS

A prototype was constructed using the existing luggage storage system to determine the proportions of the sacrificial parts (white) and the aluminium parts (black). Furthermore, cutlines (blue/yellow) for the lid were explored, as well as the location and shape of the sacrificial soft luggage extension. The prototype can be seen in Figures 8.14 and 8.15.

In order for the asymmetrical, smooth-flowing design with sacrificial parts to work, the dimensions of the LSS must be altered to create a wider, lower main shape.

Figure 8.14 & 8.15 | Low-fidelity prototyping based on the existing LSS.

FOAM MODEL

A foam model was constructed using the lower and wider dimensions. Cardboard strips were placed on the model, evaluated, changed and reattached to create protection in locations that were most susceptible to damage according to the damage profile.

After reflections and discussions, multiple iterations of ideas were tested using this method and the lessons were implemented into the project.

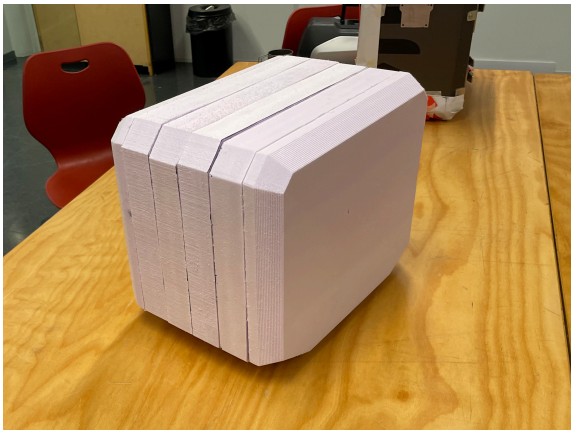
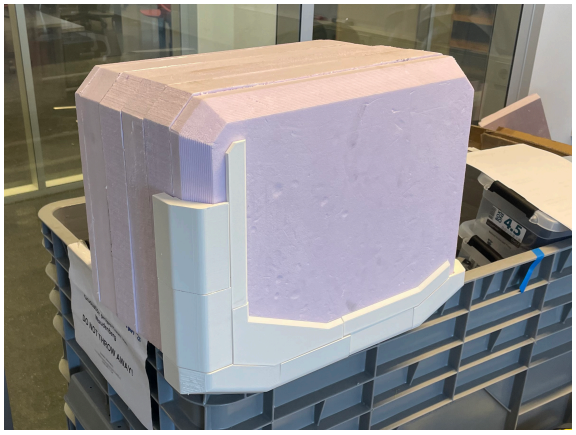


Figure 8.16, 8.17 & 8.18 | Cardboard on foam prototyping.

3D PRINTED SACRIFICIAL PARTS

Early CAD models were turned into quick prototypes using 3D printing, which made it possible to discuss and iterate the technical choices.

However, the base model was deemed too square and the 3D-printed parts appeared bulky. Taking pictures and sketching over these helped to further develop the styling of the concept LSS.



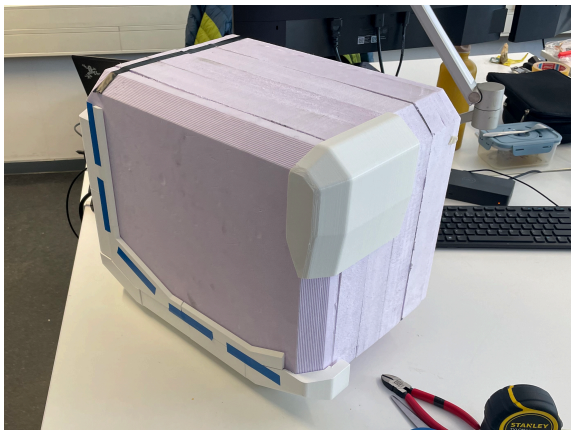
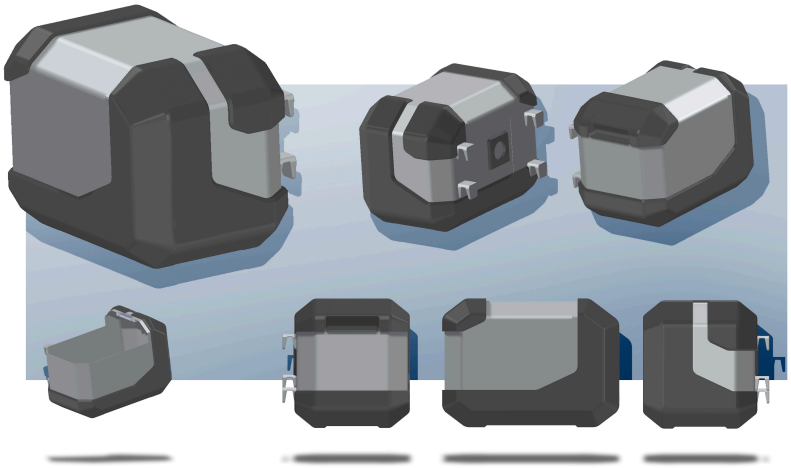


Figure 8.19, 8.20 & 8.21 | 3D printed sacrificial parts on foam.

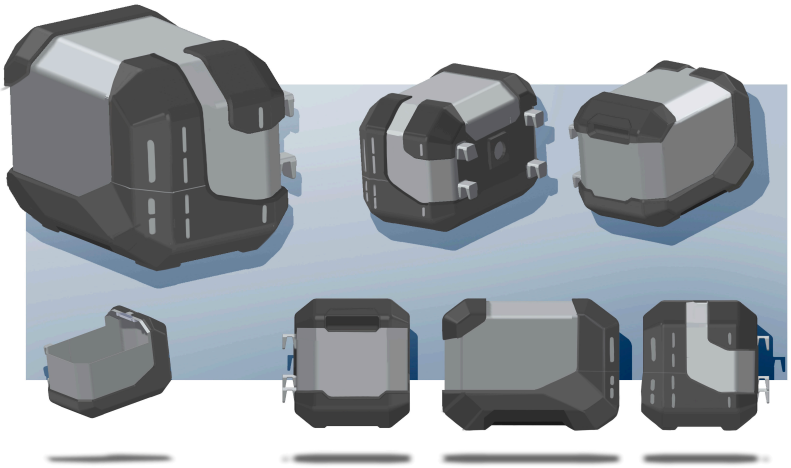
STYLING
DESIGN DETAIL

After receiving feedback on the design of the GS Proterra, changes were made to the styling. Multiple iterations were created during this process, including those with strategically placed cut-outs, as can be seen in Figure 8.22.

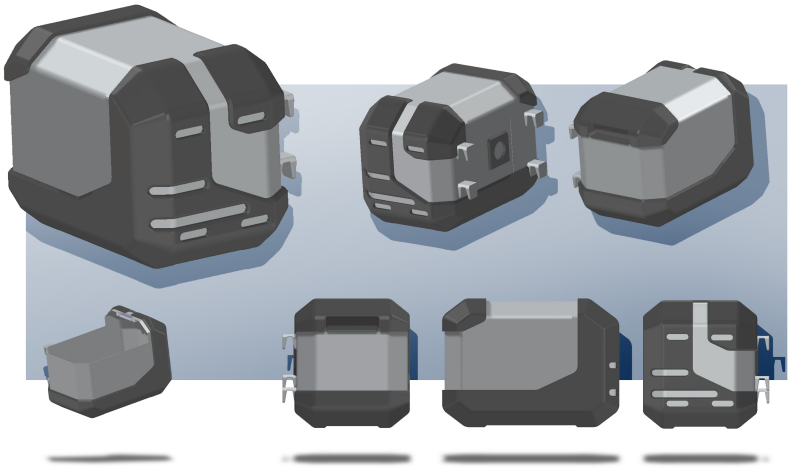
Figure 8.23 on the next page shows the final ideation and simplification of the styling of the final concept.



A | Base design without cut-outs



B | Vertical cut-outs



B | Horizontal cut-outs

Figure 8.22: Iterations of cut-outs for the GS Proterra.

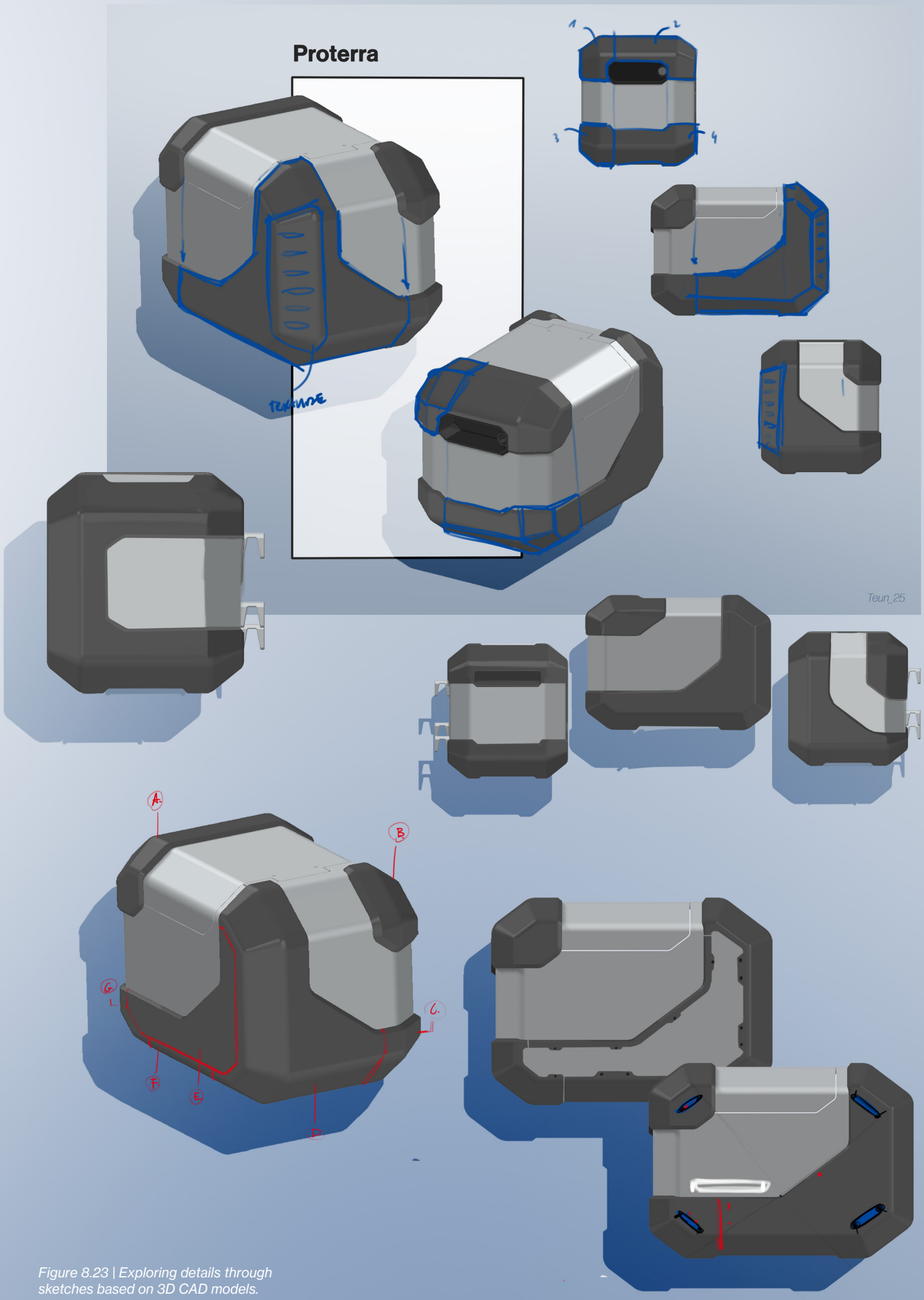


Figure 8.23 | Exploring details through sketches based on 3D CAD models.

VALIDATION OF SACRIFICIAL PARTS

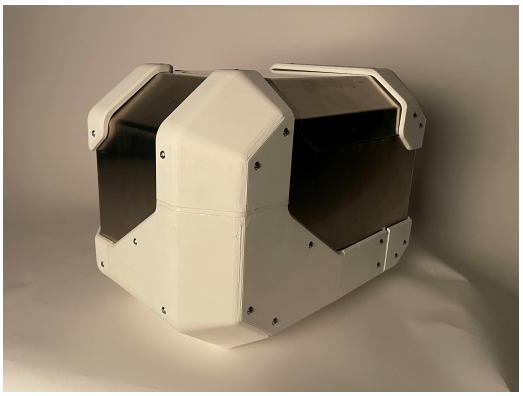
HIGH-FIDELITY PROTOTYPING

Sacrificial parts can only prolong the lifespan after damage if a GS rider can easily disassemble and reassemble each of the five parts.

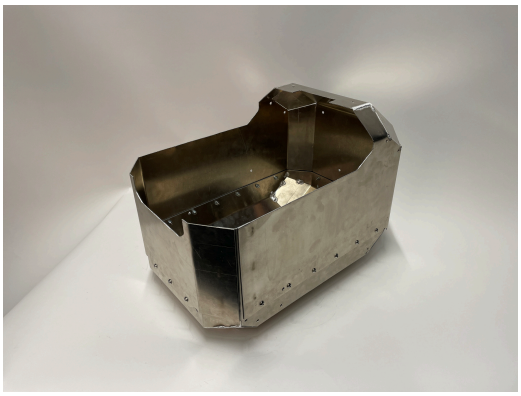
Validation setup

The concept has been validated by the ease with which it can be repaired, as demonstrated in this disassembly validation. The process can be viewed via the images on this and the subsequent page.

FINAL PROTOTYPE | **FULLY ASSEMBLED**

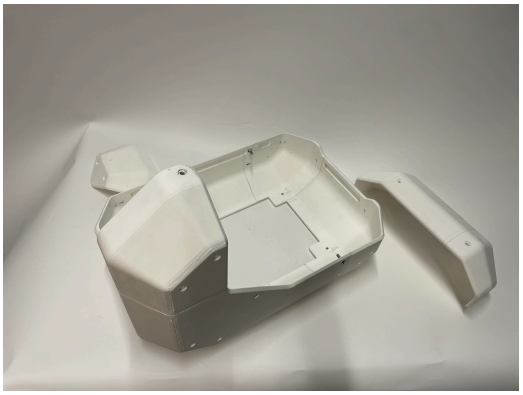


FINAL PROTOTYPE | **ALUMINIUM CORE STRUCTURE**



FINAL PROTOTYPE | **ALL SACRIFICIAL PARTS**

SEE NEXT PAGE FOR DISASSEMBLY OF ALL SACRIFICIAL PARTS



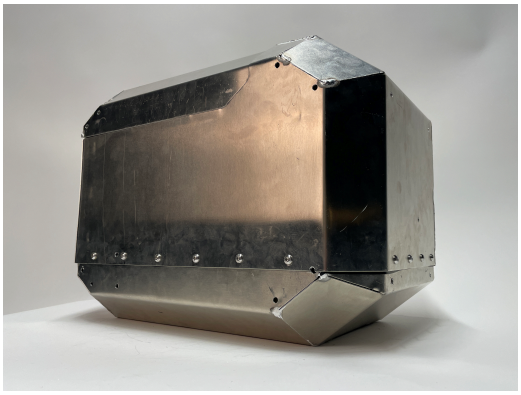
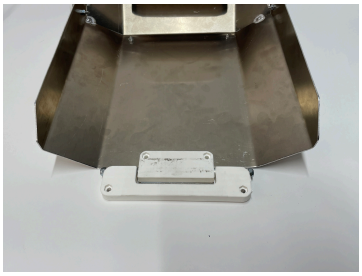


Figure 8.24 | Overview of the final high-fidelity prototype of the BMW GS Proterra LSS concept.

REMOVAL OF THE LID

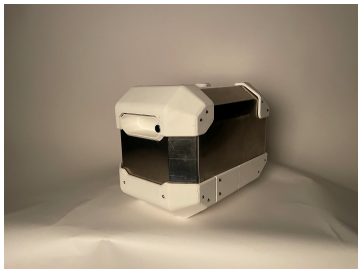
HINGE SYSTEM

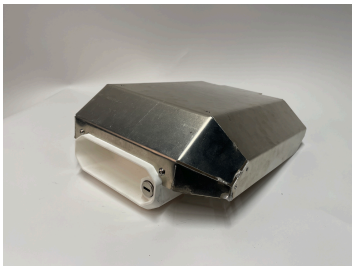
2X M5 12MM



REMOVAL OF THE HANDLE LID

2X M5 20MM





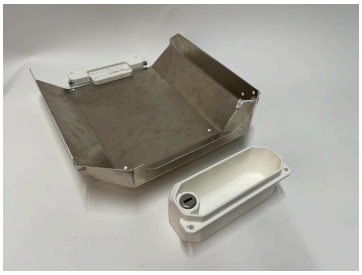


Figure 8.25 | Disassembly of the lid and handle.

DISASSEMBLY OF ALL SACRIFICIAL PARTS

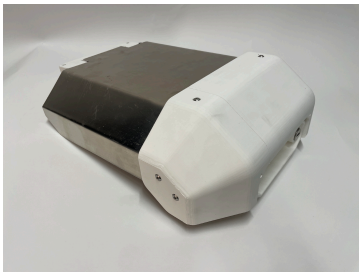
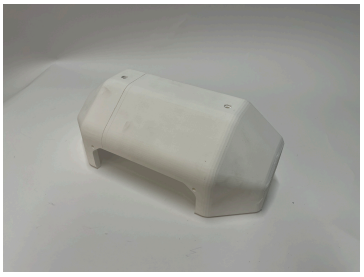
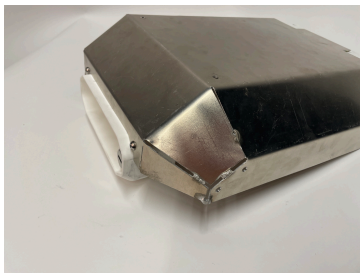
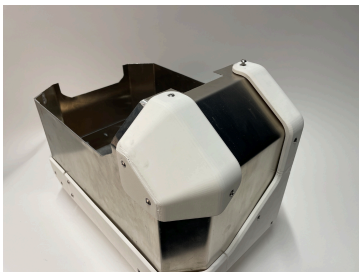
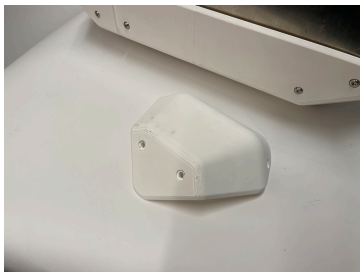
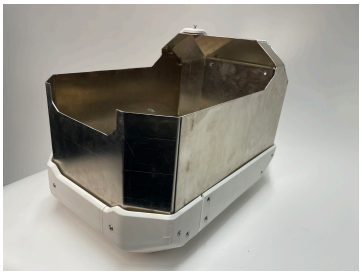
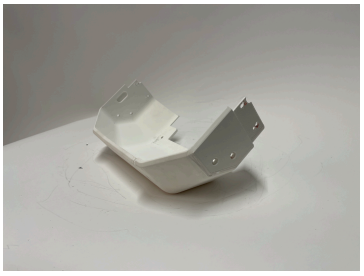
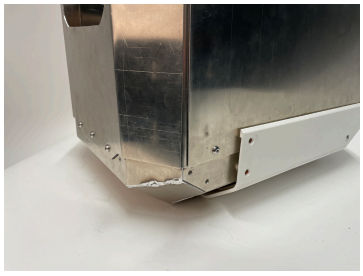
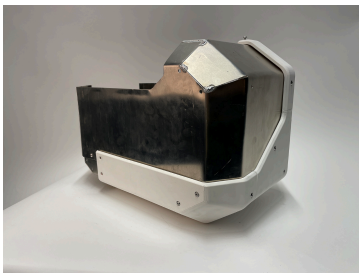
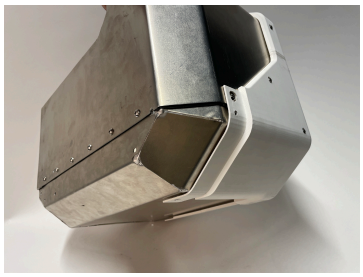
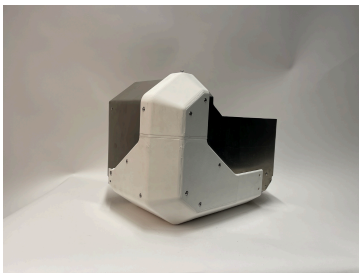
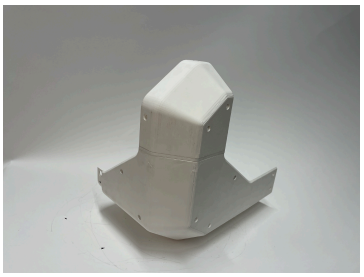
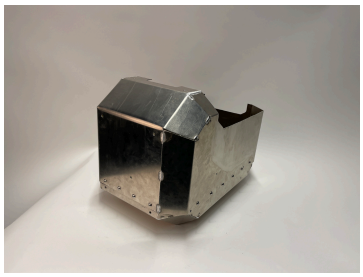
	ASSEMBLY BEFORE REMOVAL OF PART	REMOVED PART	MAIN ASSEMBLY AFTER REMOVAL
REMOVAL OF THE REAR SACRIFICIAL PART FROM THE LID 6X M5 12MM			
REMOVAL OF THE FRONT CORNER SACRIFICIAL PART 4X M5 12MM			
REMOVAL OF THE REAR MAIN SACRIFICIAL PART 12X M5 12MM			
REMOVAL OF THE INSIDE MAIN SACRIFICIAL PART 4X M5 12MM			
REMOVAL OF THE OUTSIDE MAIN SACRIFICIAL PART 10X M5 12MM			

Figure 8.26 | Disassembly of the five sacrificial parts from the BMW GS Proterra LSS concept.

Easy disassembly
It can be concluded that disassembly of the sacrificial parts is easy since there GS Proterra uses only one type of connections, and all connections are re-usable and easy to reach. Even the aluminium core structure can be disassembled using the same tools (19x M5).

CHAPTER 9

FINAL DESIGN

All the details have been developed, including the luggage rack connection to the R 1300 GSA, the ergonomics, the construction, the materials, and the design of the sacrificial parts. These have been tested using low- and high-fidelity prototypes, and the styling has been updated in the design detailing.

This chapter introduces the final concept. The BMW GS Proterra is an all-terrain aluminium luggage storage system that enables the GS rider to create adventures that last a lifetime.

Figure 8.1 | BMW R 1300 GS Adventure with the BMW GS Proterra luggage storage system on an adventure.

PROLONG THE LIFESPAN

The BMW GS Proterra luggage storage system enables GS riders to engage in value retention practices. The GS rider is therefore able to prolong the lifespan of their GS Proterra LSS by engaging in easy repair practices.

INCREASED SAFETY

The strategic placement and mechanical properties of the sacrificial parts enhance the safety of the rider and passenger while safeguarding the aluminium core structure and valuable luggage inside the BMW GS Proterra LSS.

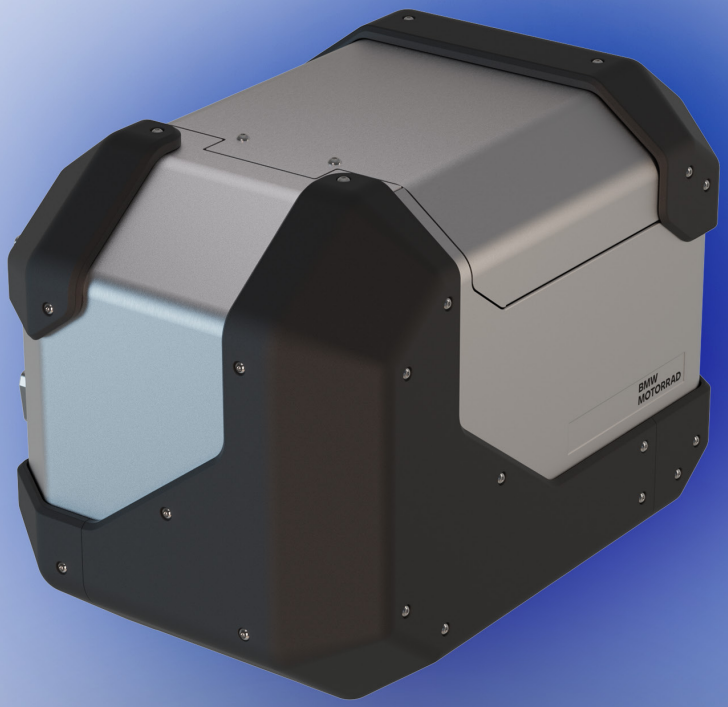


Figure 8.2 | Front of the GS Proterra concept.

REDUCED RISK OF DAMAGE TO VULNERABLE PARTS

The placement of the most vulnerable features safely inside, while attaching easily replaceable sacrificial parts on the outside, is prioritised in the GS Proterra's architecture. The GS rider is able to replace these external sacrificial parts with great ease.

EXPRESS YOUR NARRATIVE !

GS riders can express their preferred narrative through the appearance of their GS Proterra. They can either keep the signs of wear and tear as trophies of past experiences or replace the sacrificial parts to maintain a 'new' and clean appearance.

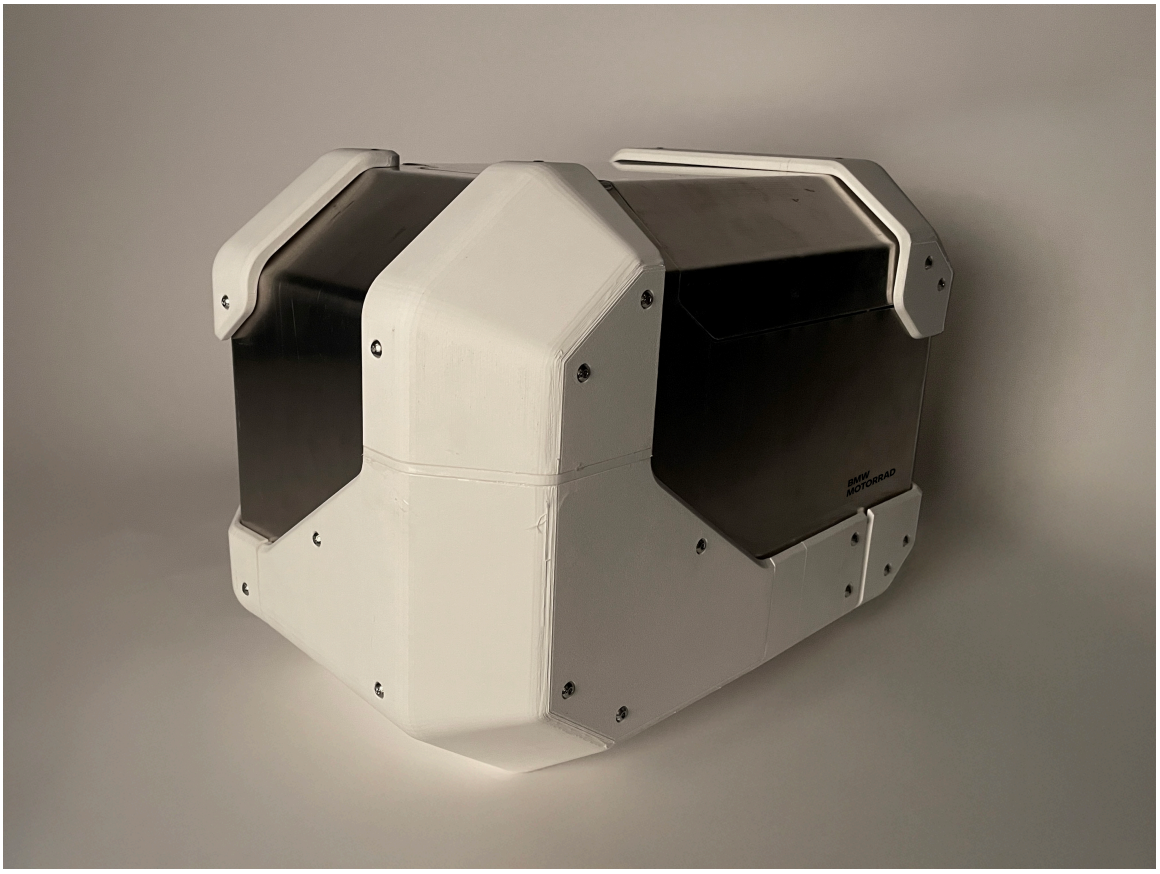


Figure 8.3 | Front of the GS Proterra concept.

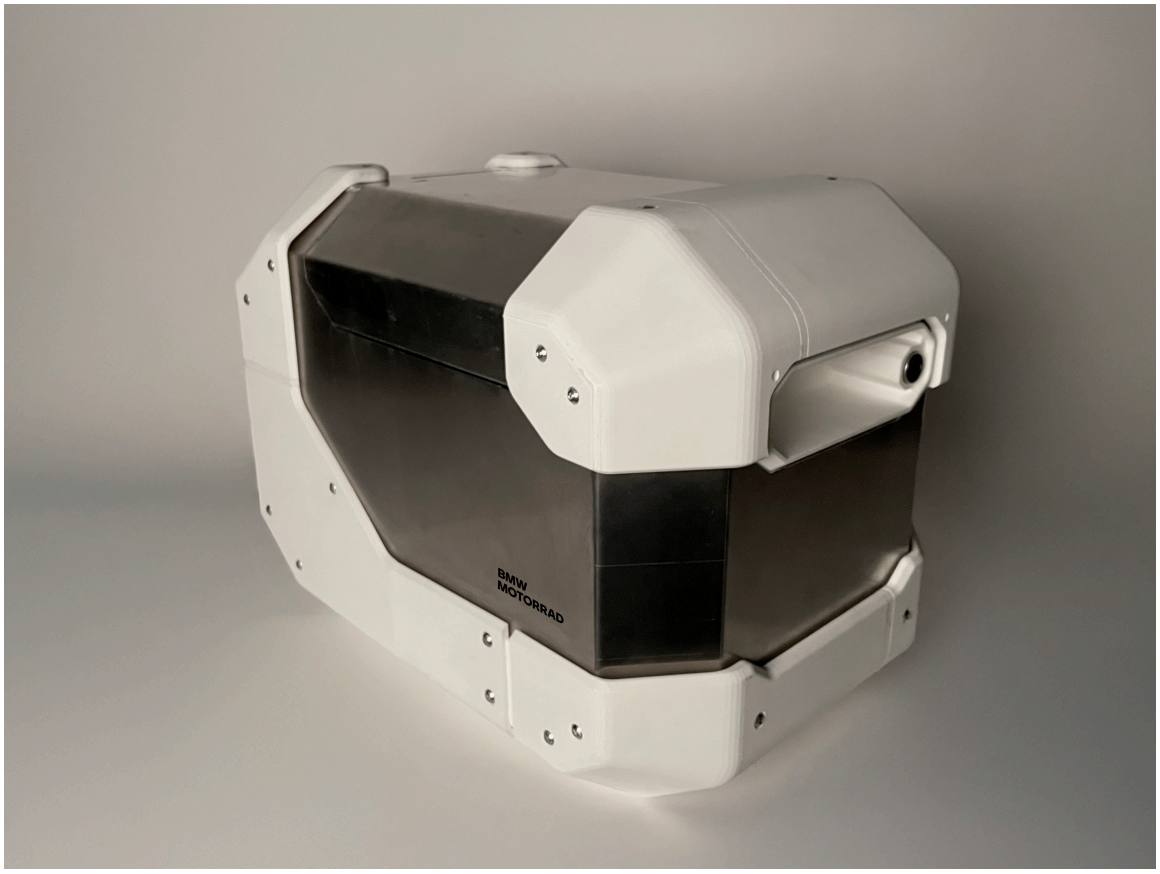


Figure 8.4 | Rear of the GS Proterra concept.

Figure 8.5 | Opening of the lid of the GS Proterra concept.

Figure 8.6 | Inside of the GS Proterra concept.

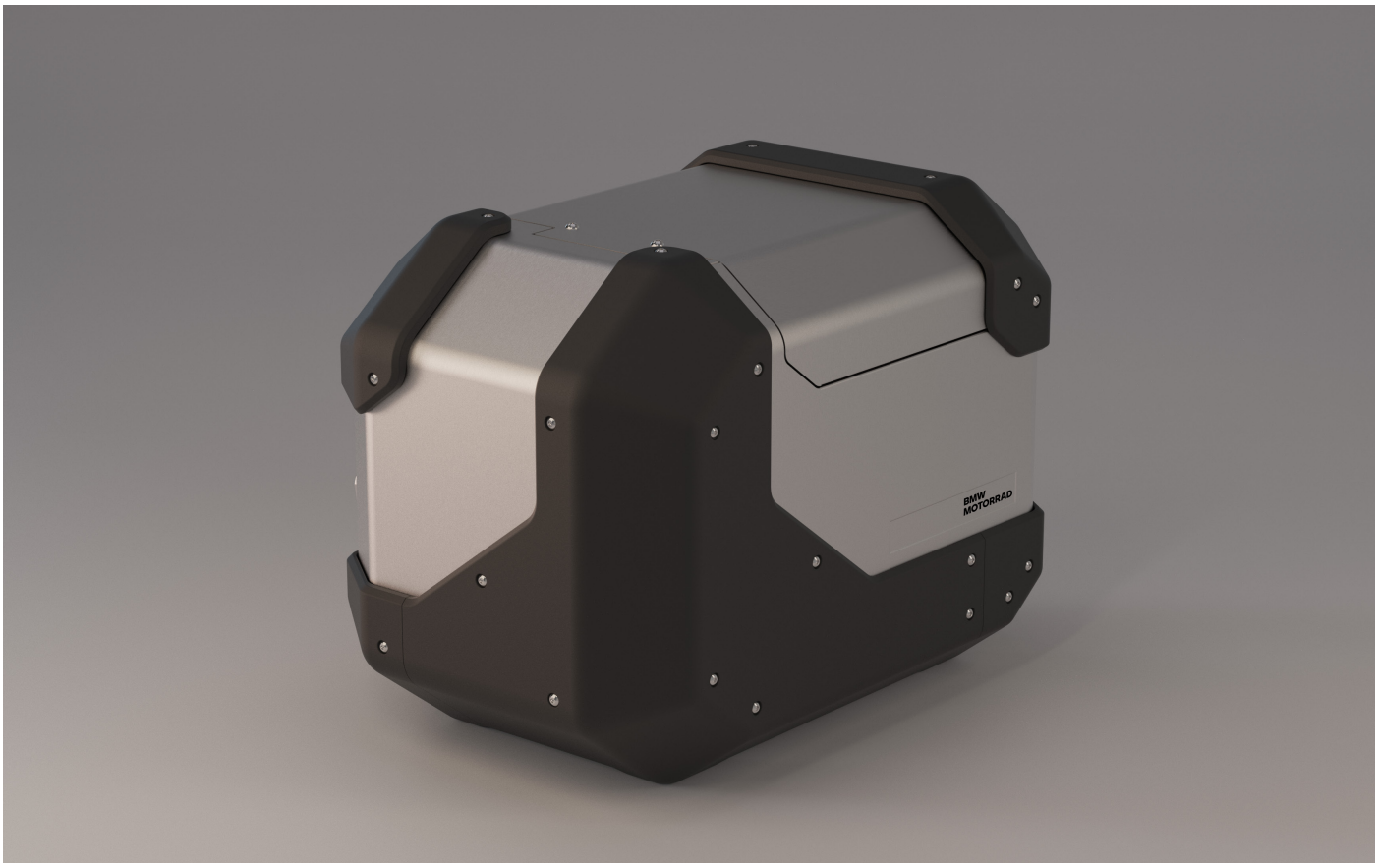


Figure 8.7 | Front of the GS Proterra concept.

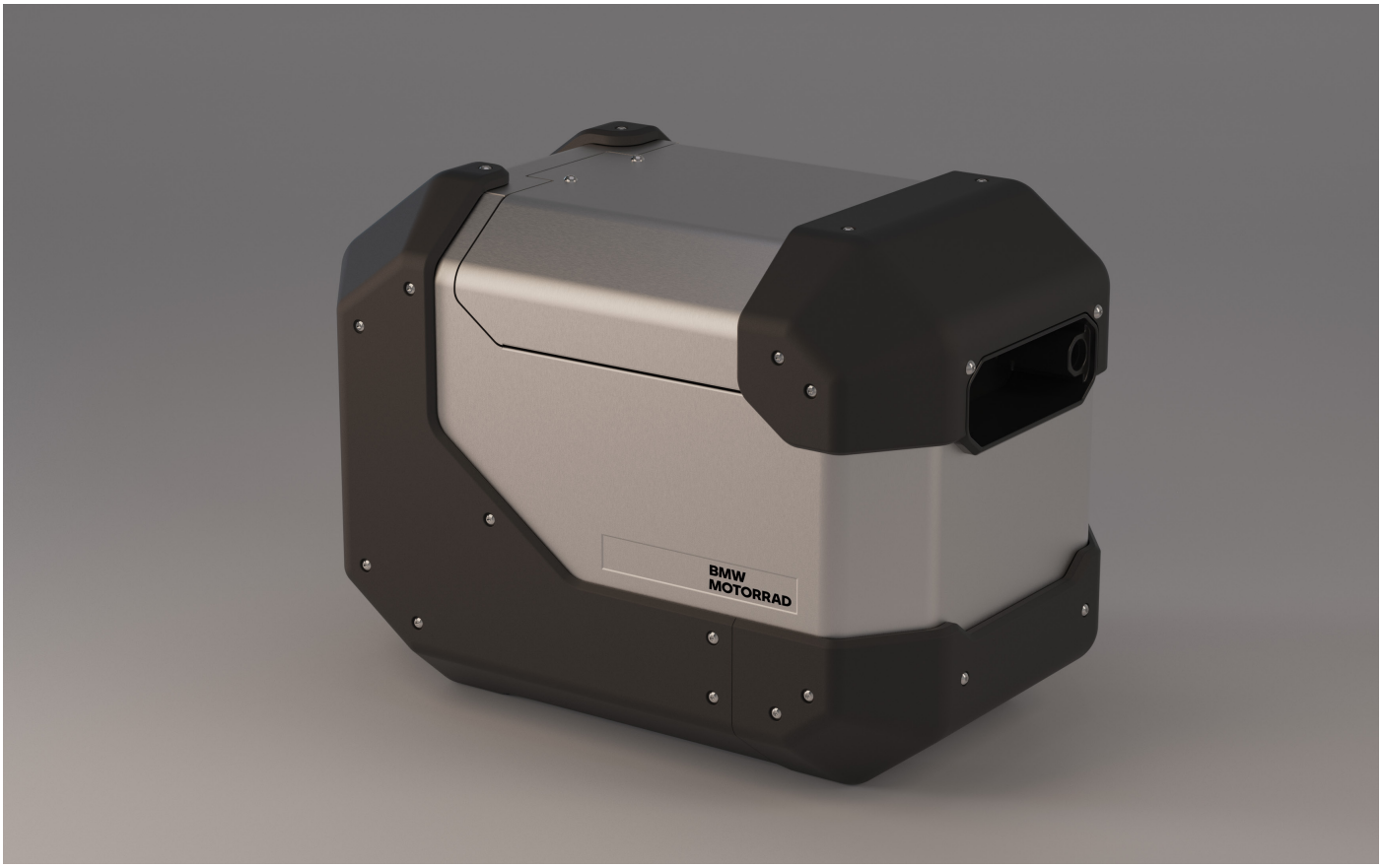


Figure 8.8 | Rear of the GS Proterra concept.

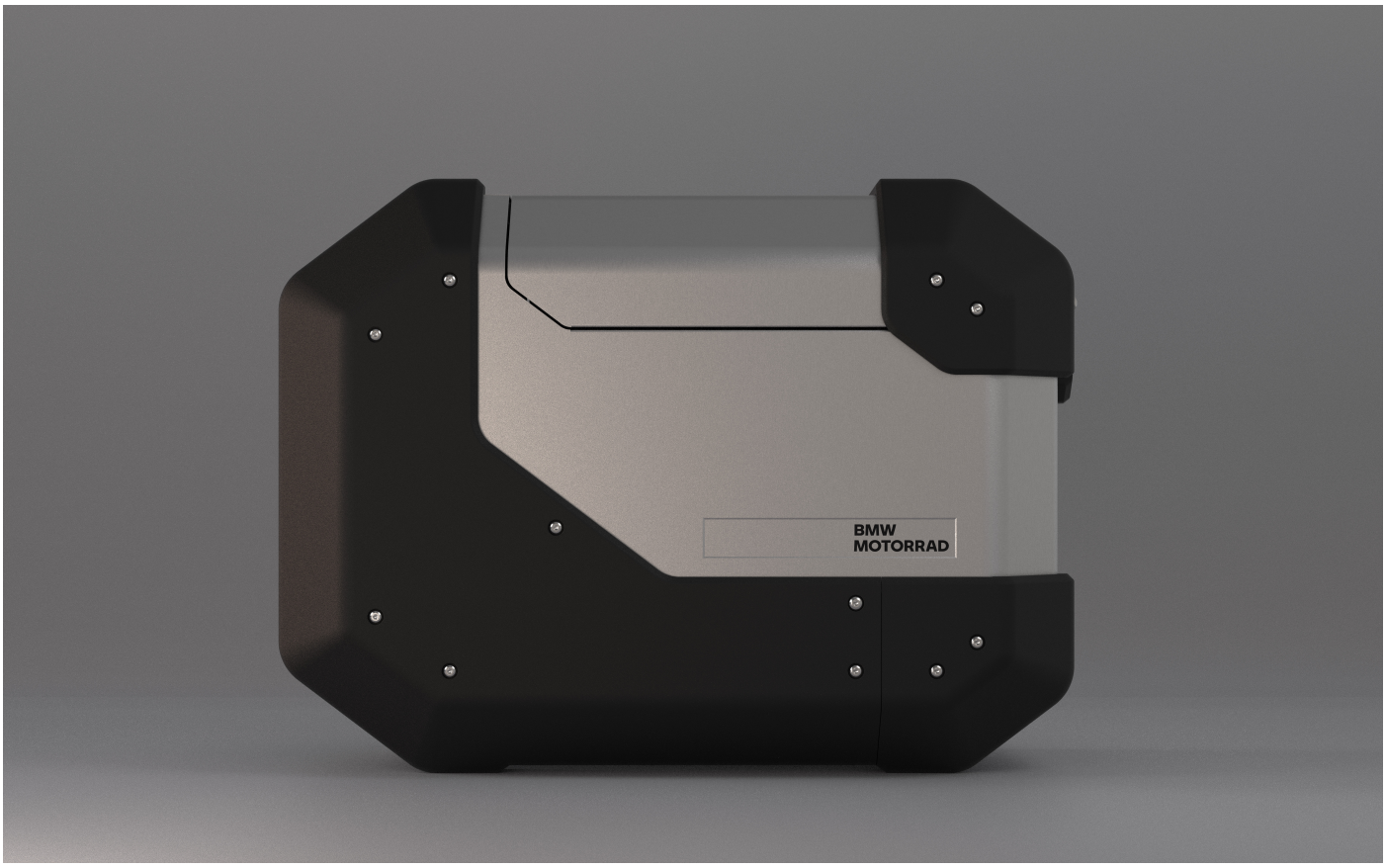


Figure 8.9 | Side of the GS Proterra concept.

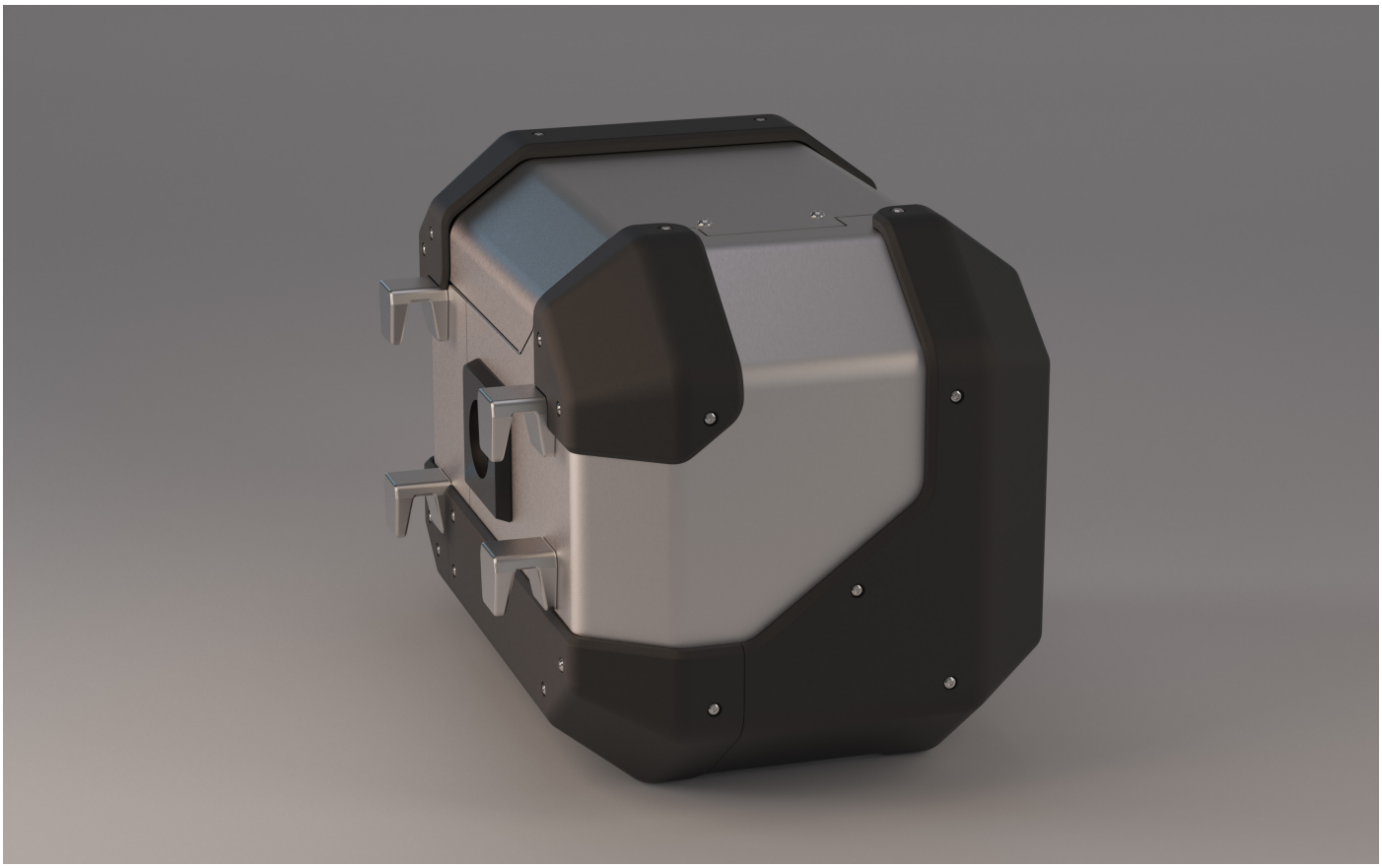


Figure 8.10 | Backside visualized from the front of the GS Proterra concept.

EXPLODED VIEW | **CORE ALUMINIUM STRUCTURE**

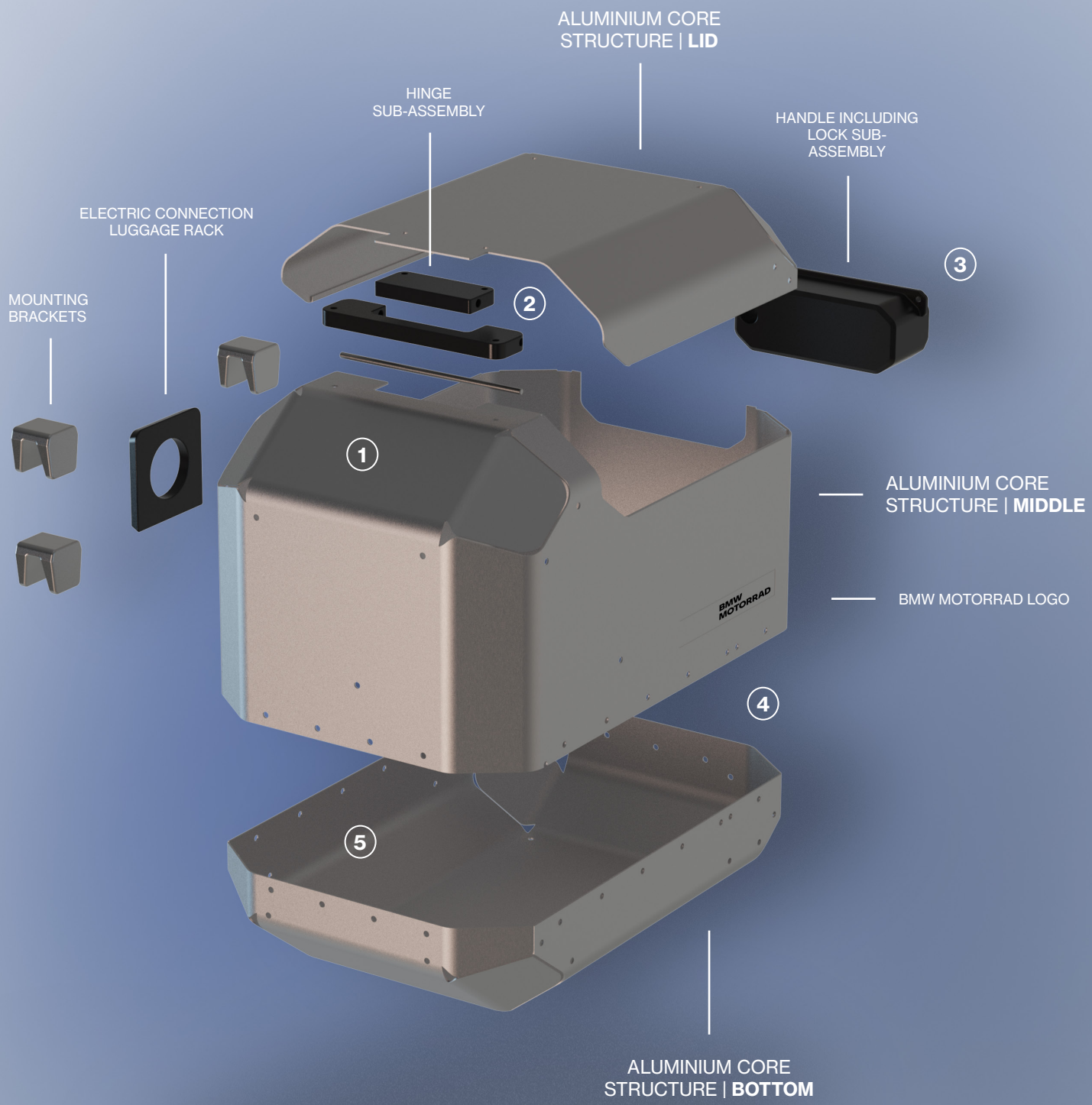


Figure 8.11 | Exploded view GS Proterra aluminium core structure including features.

CORE ALUMINIUM STRUCTURE

The GS Proterra's strong, light and stiff aluminium core structure ensures all belongings stay dry, safe and protected. The core structure consists of three parts, as shown in Figure 8.11. This paragraph discusses the main design arguments concerning technical construction.

MAIN DESIGN ARGUMENTS **TECHNICAL CONSTRUCTION**

1. The middle aluminium core structure stretches across the whole front of the GS Proterra. This increases stiffness and moves the more vulnerable split line for the lid toward a location less affected by front-facing external impacts.

2. The hinge sub-assembly was positioned in a location marked as vulnerable in the damage overview. It has now been moved to a safer internal location.

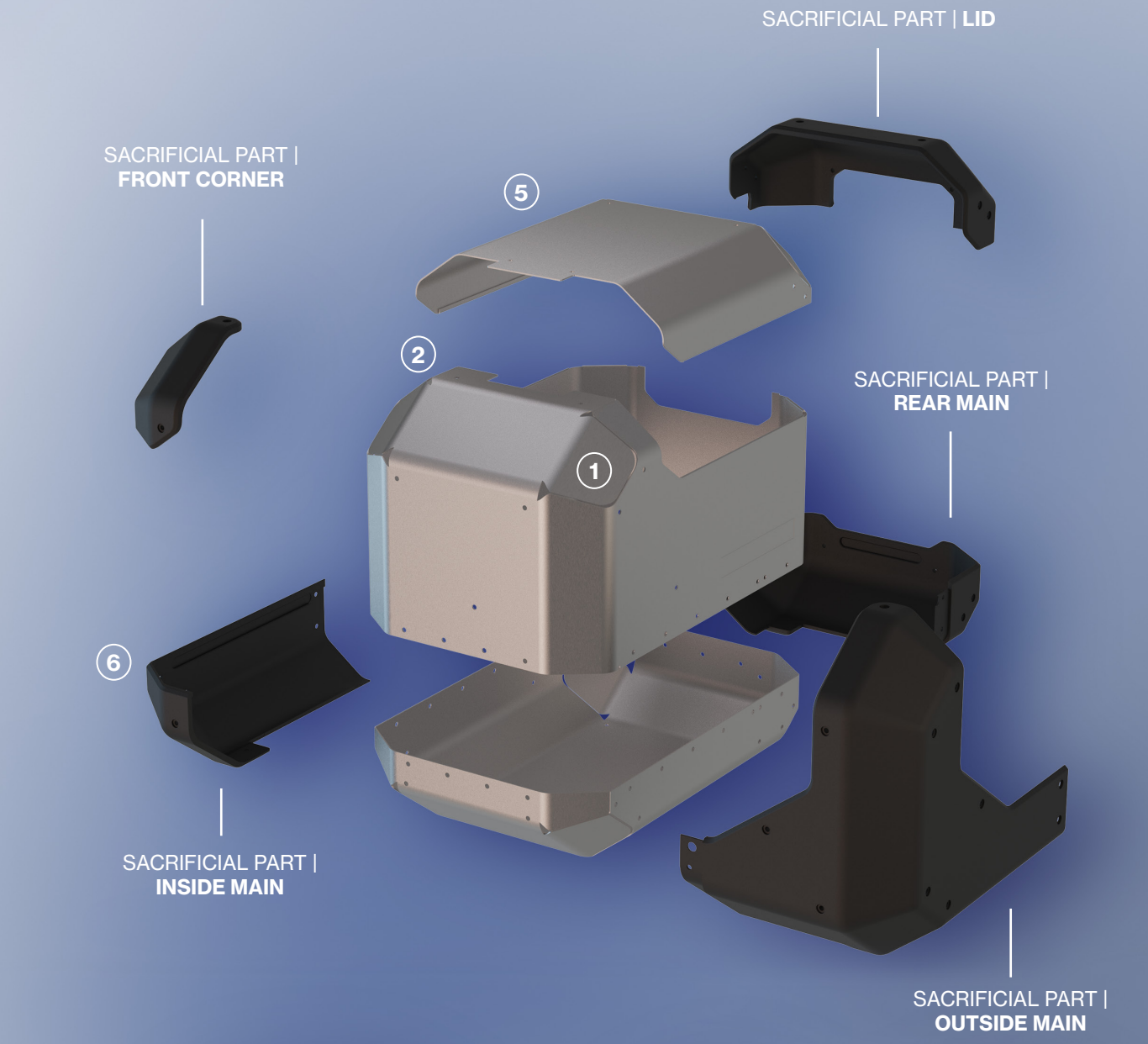
3. The handle, including the lock sub-assembly, has been placed inside the lid. This reduces the risk of damage from direct external rear impacts and protects it from weather conditions.

4. GS owners can completely disassemble the core construction to facilitate easy repair practices. Additionally, the type of connections used in the construction can be reused.

5. The re-usable connections used between the bottom and middle of the aluminium core structure are encapsulated behind the sacrificial parts. This creates a snug fit and increases the GS Proterra's weatherproofing capabilities.

   The details of the sacrificial parts are discussed in the next paragraph.

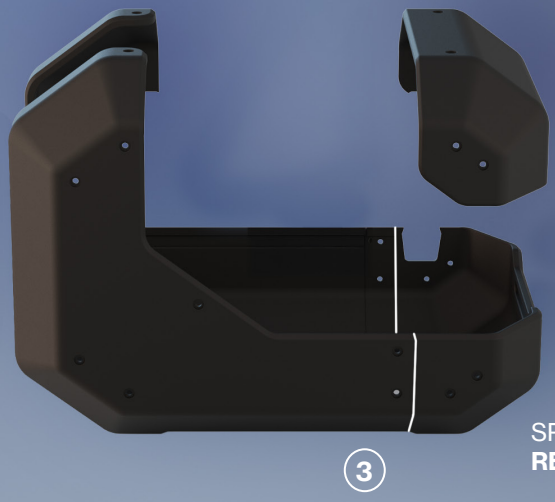
EXPLODED VIEW | **SACRIFICIAL PARTS**



FRONT VIEW

SPLIT LINE **FRONT**

SIDE VIEW



SPLIT LINE **REAR**

Figure 8.12 | Exploded view GS Proterra aluminium core structure and the five sacrificial parts and the front and side views of the sacrificial parts.

SACRIFICIAL PARTS

The sacrifical TPU parts are designed to absorb external impact forces by dispersing and deforming the sacrificial parts. The forces that reach the aluminium core structure are significantly reduced, leading to less plastic deformation of the aluminium core structure.

This paragraph discusses the main design arguments concerning the sacrificial parts.

MAIN DESIGN ARGUMENTS
SACRIFICIAL PARTS

1. The corners of the core structure are welded and the sacrificial parts conceal these welds, creating a clean image.

2. However, there is one exception as far as visible welds go. The two welds on top of the GS Proterra are added to increase the durable character and create a link with the visible welds on the tank of the R 1300 GSA.

3. The sacrificial parts are divided into five sections by strategically placed cut lines. Three of these sections form the lower main body. The GS Proterra owner only has to replace the damaged part instead of the whole sacrificial body, which is a more cost-effective solution and decreases the impact on the environment.

4. There are four small legs that stick out from the bottom to ensure stable placement when the GS Proterra is detached from the motorcycle.

5. The flat surface on top of the GS Proterra allows the LSS to be used as a camp chair, table or workbench.

6. The sacrificial parts have two thicknesses, with the front, rear and underside being thicker (11 mm) to better absorb forces, while the sides and top are thinner (5 mm) to reduce the total weight of the GS Proterra.

   The styling details and arguments are discussed in the next paragraph.

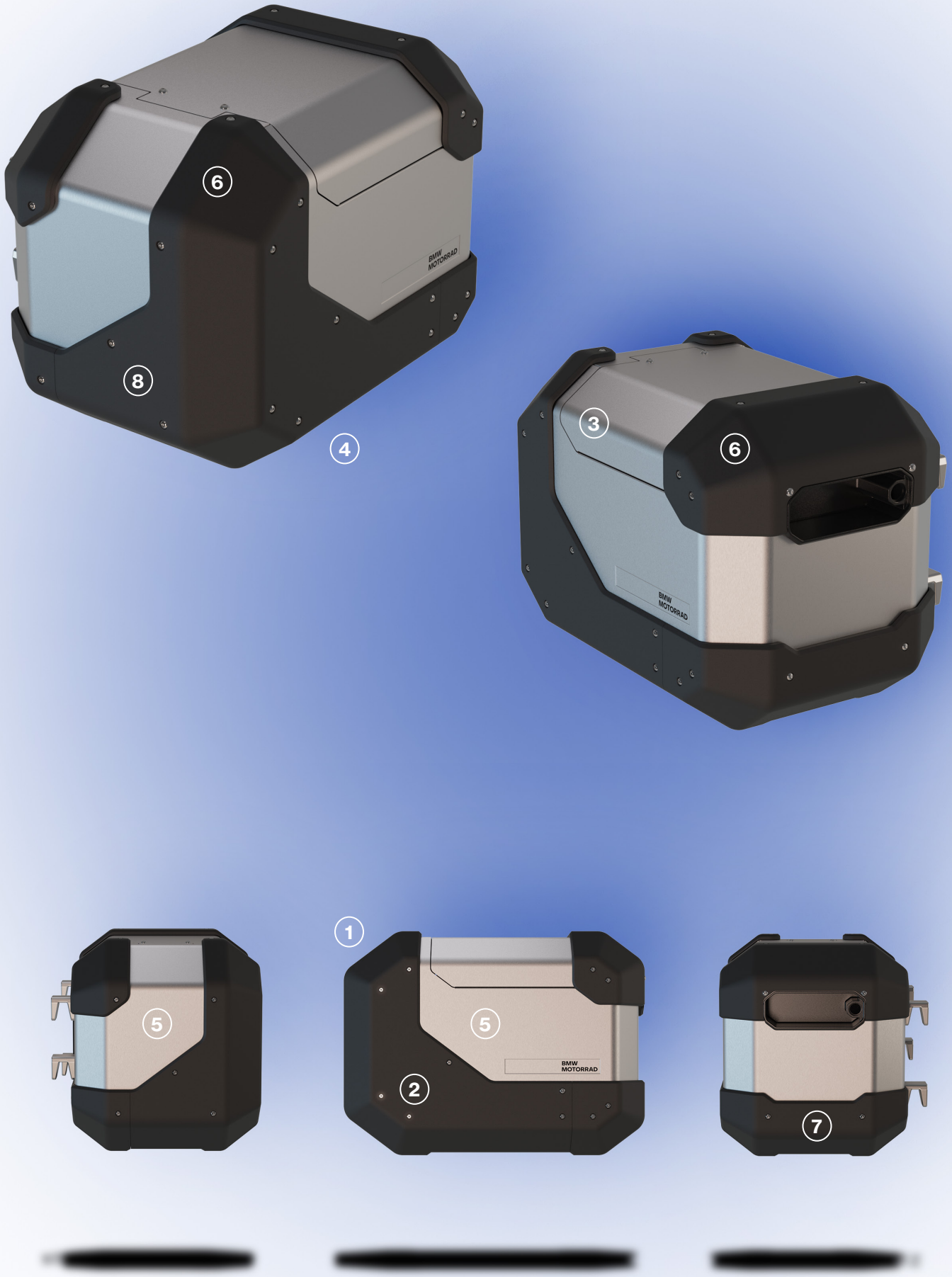


Figure 8.13 | Styling of the BMW GS Proterra.

STYLING OF THE BMW GS PROTERRA

The BMW GS Proterra's design showcases the durability, longevity, quality and strength of its luggage storage system. The Proterra's design approach uses asymmetrical shapes to highlight the LSS's dynamics and flexibility.

This paragraph analyses the main design choices, as can be seen in Figure 8.13.

MAIN DESIGN ARGUMENTS **STYLING**

1. The GS Proterra's 37-degree corners and chamfers give the LSS a tough, durable and reliable yet dynamic appearance.

2. The visible connectors on the side profile are set at an angle of under 37 degrees, which adds to the coherence and calmness of the design. Furthermore, they offer a fresh take on the rivets found in earlier models, while maintaining a visual link to the rich history of aluminium GS LSSs.

3. The cut line between the main body and the lid is at a 37-degree angle.

4. The visual weight of the GS Proterra is positioned low and towards the front, which makes the rear and top appear lighter. This reduces the overall visual weight of the LSS.

5. The proportions of the negative space (aluminium) are 1:1 in the front view and 2:1 in the side view. This creates a sense of coherence and repetition, as well as a clear flow of the lighter material between the darker, contrasting sacrificial parts. This is particularly evident from the side.

6. The chamfer at the front is larger than the chamfer at the rear. This asymmetry creates a grounded yet dynamic side profile. From the front, it aligns with the aesthetics of the R 1300 GSA, while from the rear, it provides a sleeker, more horizontal finish.

7. The rear of the GS Proterra features a repetitive pattern derived from the handle opening, which helps to create a sense of coherence.

8. The reusable connectors of the GS Proterra add to the 'multi-tool' and robust styling of the R1300GS Adventure. The LSS's repairability is indicated by these visible connectors.

Figure 8.14 | BMW R 1300 GSA with the BMW GS Proterra luggage storage system - One pannier of the GS Proterra is opened.

INCREASED SAFETY

The sacrificial parts protect the GS rider's and passenger's feet and legs. Contact with a soft deformable material rather than harder aluminium disperse the forces and results in less severe injuries.

EXPRESS YOUR NARRATIVE !

GS riders are a versatile group of ADV motorcycle enthusiasts. The option to replace sacrificial parts gives these riders a choice: do I repair in order to maintain a clean and new look to my motorcycle, or do I keep the dents and scratches as battle scars to reminder themselves of past adventures and experiences. The GS Proterra allows the GS rider to choose it's own narrative through the option to repair.

DECREASED CHANCE OF DAMAGE TO VULNERABLE COMPONENTS

The product architecture and construction of the GS Proterra allows for the most vulnerable components to be placed in a protective internal location. These components, including locks, hinges, and electronics, as well as valuable belongings placed inside the LSS, are protected by the externally placed sacrificial parts.

Additionally, the aluminium core structure, which is marked as a priority part, is also protected by the sacrificial parts. This reduces the need to go deep inside the product architecture when carrying out repairs.

PROLONG THE LIFESPAN THROUGH REPAIR

The sacrificial parts can be easily replaced due to their division and re-usable type of connection to the aluminium core structure. Since these parts absorb the forces of an external impact, the need to replace a priority part is decreased. The GS rider can now easily disassemble damaged sacrificial parts, and replace them to retain value and prolong the lifespan of their GS Proterra LSS.

CHAPTER 10

EVALUATION

Now that the final concept has been presented, it is time to evaluate it, along with the recommendations, and finally reflect on the project from a personal perspective.

Content

Evaluation of the final concept
Recommendations
Personal reflection

EVALUATION OF THE FINAL CONCEPT

The final concept is evaluated by testing it against the main programme of requirements from chapter 6. The full programme of requirements can be accessed in Appendix S.

General requirements

The final concept meets the set dimensions, however its total weight of 6.3 kg exceeds the programme of requirements limit of 5.5 kg. The excess can be allocated to the sacrificial parts that add 2.6 kg of weight to the final concept. Development of strategically placed cut-outs on the inside of the sacrificial parts should reduce the weight and increase the forces that can be absorbed by deformation.

Storage capacity

The final concept has a 41-litre capacity and can comfortably store up to 10 kilograms of luggage. This project investigated the extension of storage capacity. Due to time constraints, this part was not included in the final concept.

Durability

The strategic location of the sacrificial parts and the ability to repair using only conventional tools makes the final concept more durable compared to the analysed LSS. I was unable to test the final concept in real-world situations involving vibrations and external impacts during this project. The final concept should be tested to ensure it can absorb the forces of at least five external impacts at speeds of up to 30 km/h without major deformations to the core aluminium structure.

Prolong lifespan

The final design is constructed using only re-usable connections that are completely removable and replaceable using basic tools (EN45554), in contrast to the analysed LSS. Furthermore, the sacrificial parts attached to the final concept absorb impact forces through deformation, limiting the forces that contribute to the plastic deformation of the aluminium core structure.

The location of these replaceable sacrificial parts, combined with the reusable connections, allows for easy repair practices close to the surface of the final concept. This makes it much easier for GS riders to start to engage in repair practices, which ultimately increases the lifespan of their LSS.

However, while this works flawlessly in theory, user testing, including observations, should be used to see if the same results concerning the repair behaviour of GS riders are observed.

Rider safety

The location of the sacrificial parts, combined with the soft, deformable mechanical properties of the material, increases rider and passenger safety. However, the increased safety is an assumption based on location and mechanical properties of the material that comes into contact with the rider and/or passenger when comparing the analysed LSS with the final concept. Real-world testing needs to be done to confirm these assumptions.

Modularity

The versatile nature of the GS rider is a perfect fit for the additional use cases of the final concept. When not being used to transport or store items, the final concept can be used as a camp chair, table or workbench thanks to its mostly flat top. However, the final concept should be developed further to include additional brackets that allow users to expand the storage volume.

Compatibility

The final concept fits on the existing luggage rack attached to the BMW R 1300 GS Adventure. The addition of an adaptor plate is the key to making the final concept compatible with the normal R 1300 GS. This will reduce functional obsolescence and allow GS riders to easily switch between GS models while keeping their LSS, including its stories that it tells through its use-marks.

Ergonomics

Due to the set parameters for the location of the final concept on the luggage rack of the R 1300 GS Adventure, flexibility of placement was limited. The final concept provides comfort for solo riding, whether standing or sitting, as well as in a two-up configuration, although without the soft luggage extension when carrying a passenger. Real world testing and user feedback should confirm the ergonomic comfort of the final concept.

Design & Aesthetics

The final concept's robust, durable and repairable aesthetic fits perfectly with the adventurous identity of the BMW GS. The new aesthetics of the GS shift its comfortable 'status symbol' image towards the identity of the BMW GS. The visible screws resemble the rivets of the previous LSS, helping to maintain the heritage while providing a modern, sustainable and repairable design.

However, more attention should be given to the design details, including the patterns and logos. Furthermore, the sacrificial part attached to the lid is still a large, flat area. Applying textures or logos to this part could make it more interesting and help it to fit in with the rest of the final design's aesthetics.

Ultimately, I am convinced that the styling and material finishes of the final concept add to the adventurous and robust aesthetic of the R 1300 GS Adventure.

RECOMMENDATIONS

A number of recommendations surfaced while the project was being finalised, which are worth further developing when continuing the development of the GS Proterra LSS. The main recommendations are discussed below.

User validation

Feedback from users of the aluminium BMW GS LSS is a valuable source of insight. It can reveal the benefits of increased safety and a longer product lifespan, as well as highlighting the importance of repair and maintenance practices. This user perspective can also shed light on the visual aspects and practical applications of repair methods, which are crucial for maximising the product's lifespan.

Due to time constraints, there has been less user contact than intended at the end of the project. Final validation with the physical prototype and final renders gives users a better understanding of the final concept and provides clearer feedback.

Sacrificial parts

The precise construction of sacrificial components to ensure optimal force absorption in the material should be further calculated and developed. Simultaneously, the total weight of the sacrificial parts should be reduced by applying patterns and cut-outs/holes to the internal surfaces.

Soft luggage extension

The soft solo rider luggage extension discussed in Chapter 8 was not developed into the final concept due to time constraints. However, the idea of adding luggage extension possibilities in combination with an added layer of absorbent material to dampen and absorb forces is powerful and should be further developed when continuing with this project.

Weatherproofing

The weatherproof seal around the edges of the lid and the middle box should be improved to make it fully waterproof and dustproof. Furthermore, the construction of the bottom and middle box should be further developed to create a weatherproof seal without the use of adhesives or other non-reversible connections.

Development of features

A number of features were designed during the course of the project. A simplified version of these features was added to the CAD model. This was to demonstrate how this would function. When further developing the GS Proterra concept, it is important to consider refining these features. These features include locks, handle, hinge mechanism, integration of electronic components, montage on the luggage rack, tolerances, production methods, cost estimation and material finishes.

FEM simulations and real world testing

FEM simulations and real-world tests should be performed on the effectiveness of changes to the aluminium core structure and the function of the sacrificial parts in absorbing forces and preventing damage to the aluminium core structure. Additionally, the ability to absorb at least five impacts at a maximum speed of 30 km/h should be simulated and tested with physical prototypes.

Develop a BMW Motorrad repair support network

The essential support network behind the prolong lifetime strategy, including maintenance manuals, spare parts availability, and a BMW Motorrad repair service, is not included in the scope of this project. These are an essential part of implementing this strategy successfully and should be further developed.

PERSONAL REFLECTION

This final paragraph provides a personal reflection on the experiences and challenges encountered during the project, as well as the personal growth achieved.

Research and context analysis

The project started with an extensive context analysis and technical analysis. I was able to gain a better understanding of multiple sustainable and repairable methods and apply them to the current LSS. While the results of these separate methods were very clear, combining them created a lot of factors that all seemed important. Combined with the factors from the context analysis, it became difficult for me to find a clear direction given all these contextual factors.

Communication

During this first phase, my communication with my supervisory team was sometimes incoherent and vague. My 180-degree turns from meeting to meeting made it very difficult for others to follow my thought process. Talking to other students and experts helped me identify the most important factors that influenced my design direction.

This made me realise that working in a group helps me find a clear narrative. I do not enjoy the solo work I have been doing for this project and I function better in a team environment where it is possible to build on each other's thoughts, rather than running around in circles in my head.

Confidence

My communication style has become clearer and more confident throughout the project. Whereas initially I would ask for too much general feedback, I have learned to ask more precise questions, resulting in more in-depth answers.

Furthermore, I have learned the importance of using the right visual representation in meetings with stakeholders. Adding shading and other visual effects is not very time-consuming, yet adds significantly to the persuasive power of an idea or sketch.

Form study

Another challenge that I have overcome is the form study phase, which took place just after my midterm meeting. During this phase, I created numerous sketches and selected the ones that suited my form collage best. Unfortunately, the collage did not effectively communicate the chosen keyword, resulting in a selection of incoherent sketches. I realised that I lacked experience in both form study and creating collages based on a desired character. This caused me to struggle during this phase, but it also gave me the opportunity to gain experience in these areas.

Ideation

One of my primary goals was to improve my drawing skills, particularly my digital drawing skills, as these were quite limited at the beginning of the project. Throughout the project, I learnt many new techniques and gained more creative confidence. Ideally, I would have liked to spend more time on each phase in order to produce a greater variety of detailed sketches.

Nevertheless, I am very satisfied with the quality of the sketches, especially given the short timeframe of this project and the fact that this is my first time dedicating such a long period of time to a motorcycle design project.

Styling

I have worked on automotive projects before, but this was the first time I had worked on a large automotive project independently. While it was challenging, I found it rewarding when I realised how many new skills I had learned during the project. I would like to continue developing my styling skills in future projects.

Prototyping

From the midterm onward, I created multiple prototypes. These ranged from low-fidelity cardboard cut-outs to high-fidelity aluminium luggage storage systems, including the designed sacrificial parts. I gained valuable insights from creating these prototypes, while at the same time expanding my skillset.

Unfortunately, due to time constraints, I have not been able to use my prototype to its fullest extent to validate my final concept with the end user. I have found that I enjoy building prototypes and that this process helps me reflect on the choices I have made.

Research-Through-Design Method

During the project, I applied a research-thought-design method. This approach involved using physical and digital drawings, as well as low- and high-fidelity prototypes and CAD models, to generate knowledge. This method produced tangible outcomes that I could evaluate and refine. However, I also found this method to be very flexible, which meant that it lacked a clear direction in some parts of the process.

Project management

From the beginning, I have maintained regular communication with all the stakeholders involved in this project, and have planned and reviewed priorities as the circumstances of the project changed. During the process, a few phases took more time than expected, resulting in my graduation taking longer than initially planned. However, I can now say that these challenging phases have contributed to my growth as a designer.

BMW Motorrad and TU Delft

Communication between BMW Motorrad and TU Delft was smooth throughout the project. However, discussions concerning the sketches, ideas and styling were difficult in the visualisation phases of the project due to them taking place in the digital domain. Sadly, I was unable to visit BMW Motorrad while the project was ongoing. If I had been able to, I would have gained a lot of new skills.

Final result

Looking at the final concept, there are still many areas that I would like to improve and develop further. Ultimately, however, I am able to convey my main message through my final concept, and I am very proud of it. I have learnt many new skills and improved existing ones while creating a visually interesting LSS concept to add to my portfolio. Through this project, I aimed to demonstrate my versatility as a designer, a goal that I believe I have achieved with my final result.

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APPENDIX

Appendix A | Adventure motorcycles

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Teun van Woudenberg **Student number**

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

Project title Design of a repairable motorcycle luggage storage system for BMW Motorrad GS Adventure motorcycles.

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

Introduction

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

The project is situated within the domain of automotive design, innovation, and sustainability, with a particular emphasis on the implementation of R-strategies, including repairability, in the context of luggage systems for BMW Motorrad GS Adventure models.

BMW's GS Adventure models are renowned for its versitility in both on- and off-road riding, making it a popular choice for everyone from commuters to long-distance travelers. Luggage systems are essential for the storage and transportation of personal belongings during these journeys. A typical luggage system consists of a luggage rack, two panniers, and a top case. The positioning of luggage systems on the exterior of the motorcycle renders them susceptible to damage, including scratches and dents. Unfortunately, this too often results in the replacement of an entire case. A repair-focused luggage system facilitates the replacement of the damaged parts, thereby extending the lifespan of the luggage system.

The main stakeholders are BMW Motorrad and the users of the product, namely riders and passengers. For BMW Motorrad, interest lies in design and creation of valuable insights concerning sustainability and repairability in the context of luggage systems. The users are interested in its usability, practicality, easthetics, and the possibilty of repairing their luggage system.

Opportunities include researching repairability in the context of motorcycle luggage systems, the creation of an understanding of the target group's concerns regarding repair, and a redesign of the current luggage system in a way that makes repairability visible and aesthetically pleasing. Limitations may arise in the user's willingness to engage in repairs and the increased complexity of the luggage system.

→ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 BMW R 1250 GS Adventure aluminium panniers and top case (Picture: www.bmwmotorrad.nl)

image / figure 2 BMW R 1250 GSA motorcycles with aluminium cases parked in Delft (Picture: Teun van Woudenberg).

TUDelft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

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

Upon initial observation, the current luggage system for the BMW GS Adventure appears to be constructed with a number of non-reversible connections. These types of connections present a challenge when attempting to disassemble, repair, and reassemble the luggage system in a way that maintains all of its core functions, such as waterproofing and dustproofing, at optimal levels.
Furthermore, the cost of purchasing these systems is considerable. The implementation of R-strategies, such as repairability, can effectively prolong the lifespan of these systems, thus reducing their impact on the environment and the costs for the user. In addition, dents and scratches can be seen as aesthetically unpleasing and 'broken'. There is an opportunity to make repairability part of the design in an aesthetically pleasing way.
The primary objective of BMW Motorrad is to guarantee that the luggage system is capable of functioning at an optimal level for an extended period of time and that it can be utilised in a multitude of ways to suit the diverse requirements of motorcycle users. Such applications include commuting, day rides and long-distance travel. In addition, the automotive industry is increasingly focused on sustainability. The redesign can therefore act as a showcase for sustainable and repairable luggage systems, and the lessons learned could be applied to future projects for BMW Motorrad.

Assignment

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

Design a sustainable and repairable motorcycle luggage storage system for the BMW GS Adventure motorcycles, ensuring optimal user experience and prolonging the functional lifespan.

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

The project will adopt a research-through-design approach. As a result, the emphasis will be on the ideation, conceptualisation, prototyping, and validation of the concepts through the utilisation of prototypes. In addition, the project will use a human-centred design approach, starting from the future transport needs of the target group.
The project will start with an examination of the context and the existing luggage system, using models such as disassembly and hotspot mapping, which will form the basis of the first ideation phase.
The research phase will generate information to provide insights into solutions to increase the sustainability of these luggage systems, after which ideation and concept development will result in the generation of multiple concepts that will be presented at the midterm meeting. This will then be followed by the prototyping and final iteration of the selected concept. On day 60, a design freeze will be implemented to ensure that sufficient time is allocated for the construction and testing of prototypes, as well as finalise details, colour and trim, and the final model.

Project planning and key moments

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

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

Kick off meeting	9 Sep 2024
Mid-term evaluation	22 Nov 2024
Green light meeting	11 Feb 2025
Graduation ceremony	24 Mar 2025

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

Part of project scheduled part-time	✓
For how many project weeks	25
Number of project days per week	4,0

Comments:
Part-time graduation.

Motivation and personal ambitions

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

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

I have selected this project due to my enthusiasm for automotive design and the desire to expand my expertise in this domain by specialising in motorcycle design. Furthermore, I am passionate about motorcycles because I ride and own a BMW GS motorcycle.Additionally, I am interested in pursuing a deeper understanding of sustainable and repairable design principles, with the aim of integrating these concepts into a motorcycle design.

The objective of this project is to gain in-depth knowledge about the motorcycle design industry, enhance my drawing skills, and expand my skillset regarding the construction of low- and high-fidelity prototypes and the use of these to validate and evaluate concepts.

It is my intention to demonstrate that I am an all-round designer that utilizes visual communication, including drawing, and prototypes in the design process. Furthermore, I am interested in exploring the suitability of the motorcycle design industry as a potential career path and I would like to add this motorcycle design project to my experience and portfolio.

Appendix B | Adventure motorcycles

Adventure motorcycles are also abbreviated as ADV and are used to describe adventure motorcycles and adventure riding in the motorcycle community (ADVMotoSkillZ, 2023).

As mentioned in the GS history, the ADV movement and market started with the BMW R 80 GS. ADV motorcycles are very versatile and are characterised by a number of aspects:

Increasingly popular
This segment has been around for decades, and the growing popularity of the ADV segment can be attributed to a number of factors. People are looking for new ways to explore new horizons. ADV motorcycles are the do-it-all motorcycles and therefore satisfy this need for exploration combined with the ability to customise one's own adventure (Kusek, 2023).

Size and weight
Adventure motorcycles often have a stronger frame, a stronger sub-frame, a larger fuel tank and additional protection. All these additions result in a heavier and larger motorcycle compared to other types of motorcycles (The Rise of the Adventure Motorcycle, 2024).

High cost
These motorcycles can get you anywhere, but are often more expensive than road motorcycles (The Rise of the Adventure Motorcycle, 2024).

Do-it-all machines
The strength of ADV motorcycles is that they are very versatile, other motorcycles may be better suited to certain situations, but these machines can do everything from off-road to on-road (The Rise of the Adventure Motorcycle, 2024).

Highly customisable
There is a huge range of aftermarket accessories available for this segment of motorcycles, allowing riders to customise their ADV motorcycles to suit their personal needs and desires (The Rise of the Adventure Motorcycle, 2024).

Comfortable
Adventure motorcycles have a higher comfort rating than dual sport or off-road motorcycles, making them suitable for a wide range of activities (e.g. touring and/or daily commuting).

Appendix C | 2025 BMW Product portfolio

BMW Motorrad's porfolio can be subdivided in seven categories, that can be seen in Figure C1 (BMW Motorrad Modeloverzicht, 2024).

This project focusses on the Adventure subdivision of the BMW Motorrad line-up. This division is called BMW GS.

BMW GS product portfolio 2025

The BMW GS product portfolio in 2025 consists of six models that can be subdeviced into three main classses of ADV based on weight and engine capacity (Andy & Alissa, 2024). The subdevision, specification, and models in the GS portfolio can be seen in Figure C2.

Difference R 1300 GS and R 1300 GS Adventure

In an interview with Reiner Fings (product manager BMW GS, 2024) he explained that BMW is communicating to its customers and journalists that BMW has decided to spread the character of the two R 1300 GS models. The standard GS model will be positioned as a more universal, everyday motorcycle, while the GS Adventure will be marketed as a more robust, can-do-everything, multi-tool like multi-purpose motorcycle.

2024 Sales

In 2024, BMW Motorrad recorded the highest worldwide sales of new motorcycles in the company's 102-year history (210.408 motorcycles).

Europe was the largest sales market for BMW Motorrad (118.727 motorcycles). Of the sales figures in Europe, over 68.000 motorcycle riders bought an R 1300 GS, R 1300 GS Adventure or the outgoing R 1250 GS/GSA (BMW Motorrad Corporate Communications, 2025).

These sales figures underline the popularity of BMW Motorrad, especially in Europe, and the growing size of the motorcycle and ADV market.

BMW MOTORRAD PRODUCT PORTFOLIO

Adventure	Heritage	Roadster	Sport	M	Tour	Urban Mobility
Enduro and Tour-Enduro's to explore the world	Retro, Vintage, or Classic Motorcycles	Naked bikes	Fast, focussed, and powerful sport motorcycles	Racing focussed motorcycles	Long-distance ultimate-comfort motorcycles	Motor-scooters and electric urban mobility scooters

Figure C1 | 2025 BMW Motorrad simplified portfolio (BMW Motorrad Nederland, 2025)

BMW MOTORRAD GS PORTFOLIO

Lightweight Enduro

Single cylinder, engine capacity between 125 and 600 cc, and a weight lower than 190 kg

- BMW G 310 GS

Middleweight Enduro

Engine configuration of two cylinders or more, engine capacity between 600 and 900 cc, and a weight between 190 and 230 kg

- BMW F 800 GS
- BMW F 900 GS

Heavyweight/Maxi Enduro

Engine configuration of two cylinders or more, engine capacity higher than 900 cc, weight higher than 230 kg

- BMW F 900 GS Adventure
- BMW R 1300 GS
- BMW R 1300 GS Adventure

Figure C2 | BMW GS 2025 portfolio overview (BMW Motorrad Nederland, 2025)

Appendix D | Users

GS models are designed for versatility, offering the capability to handle a range of terrains and journeys, making them a popular choice in the market. BMW GS riders contribute to the diversity of the ADV segment, each creating their own adventure (ADV) (Scheffer, 2019).

Use-cases
There are different types of users/riders that use their BMW GS motorcycle for different use-cases (from short to long):

- Daily commute
- Weekend leisure rides
- Weekend trip
- Long-distance travel

Terrain
BMW GS models are designed to handle a variety of terrains and journeys, making them suitable for diverse riding scenarios, including on-road, cross-country, back-road, highway, off-road, and enduro. This versatility allows for a wide range of rider experiences, from those who primarily travel on paved roads to those who engage in more challenging off-road conditions (Scheffer, 2019).

Luggage
The storage requirements for these diverse types of journeys and surfaces vary significantly. A long weekend trip necessitates different storage solutions than a commute to work, and the quantity of luggage varies from minimal to substantial, depending on the activity.

Riding solo or in groups
BMW GS riders have a diverse preference of riding in groups or solo, and they like to ride in large groups, in small groups, with a friend, and/or riding alone (Scheffer, 2019).

Characteristics of an ADV rider
(incl BMW Motorrad)

ADV riders enjoy a number of characteristics that sets them apart from other groups of motorcycle riders (Ipillion, 2023).

1. Adventure spirit: The desire for exploration and freedom.
2. Love for off-road riding, or the idea of being able to do if they wish.
3. Embark on long trips through multiple countries or continents.
4. Independence, value self-sufficiency, and ride in small groups.
5. Safety and preparation are key priorities.
6. Problem solving mindset.
7. Connecting with fellow ADV enthusiasts at events or online.
8. Customisation is a large part of the community, creating the perfect ADV motorcycle for the needs of every user (Ipillion, 2023).

Appendix E | Functions of a LSS

Core functions

A motorcycle LSS performs several functions (Botan, 2022; Botan, 2024; Hughes, 2023). The core functions include:

Store items
Storage space for items that otherwise wouldn't fit on the motorcycle. Allows riders to carry everything from daily essentials to items needed for longer trips.

Security
LSSs often come with locks, offering protection against theft when parked. Some systems can also be locked to the luggage rack of the motorcycle, preventing unauthorized removal of the luggage storage system.

Protect
The LSS extends from the motorcycle, and is the first point of impact in a fall. The system can absorb a some, if not all, of the impact forces preventing damage to the rider, passenger, and/or motorcycle.

Weather resistance
LSS protects important items from the elements, and prevents damage to these items.

Organisation
Items stored in the LSS can be organised by the rider, making it easier to find the relevant item when it is needed.

Quick access
LSS provides the ability to quickly access stored items. For example, changing into rain gear when it starts to drizzle during a ride.

Versatility
The rider can decide which part of the LSS suits their needs in any situation. The rider also has the option to add or remove other items and storage solutions to or from the main luggage storage system, making it possible to customise the system to suit the rider's needs.

What mattes when buying

According to Scott (2020) there are a number of considerations buyers or possible buyers have before buying a luggage storage system.

Convenient access
The contents of the LSS should be easily accessible - nobody wants to spend five minutes opening a system in the pouring rain.

Durability and weather resistance
The LSS should be able to keep your belongings dry and dust-free for an extended period of time.

Safety and security
Prevents theft of the LSS and the products inside it.

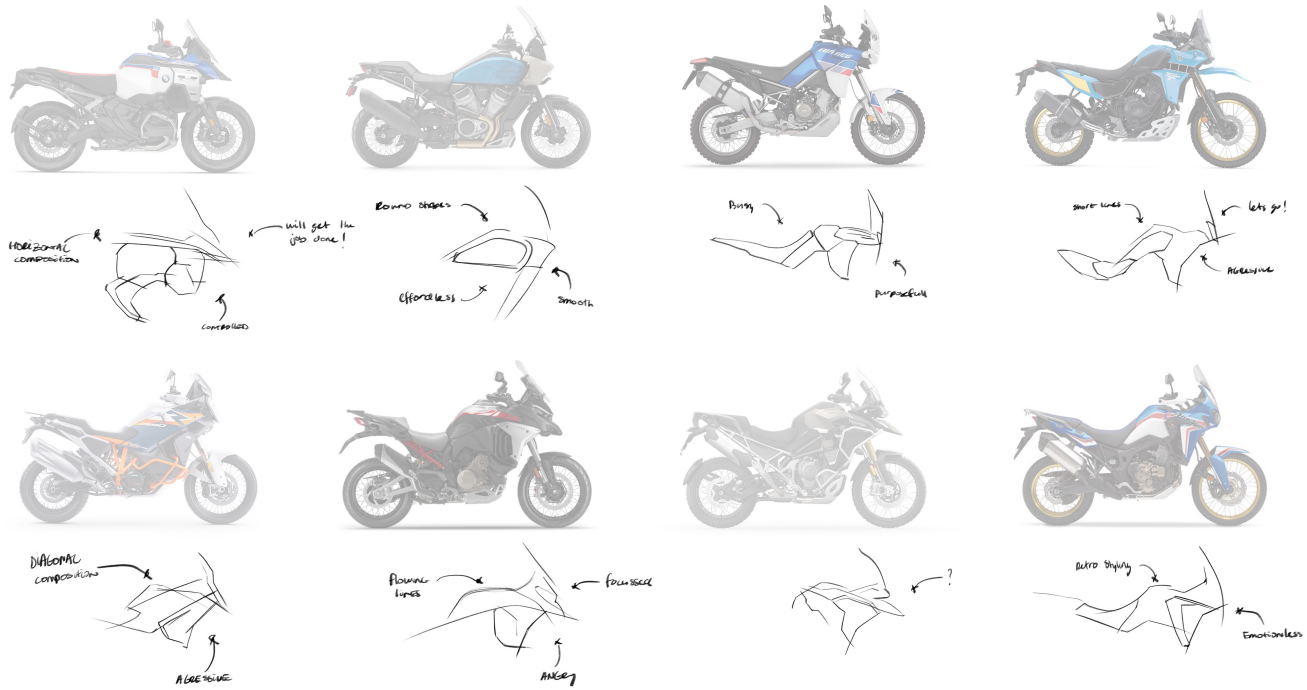
Ease of removal
It is important that the LSS is securely mounted to the motorcycle, but it should be easy to remove for use as a table or camping chair, or for storage in another location.

Robustness
The LSS should be able to withstand a certain amount of wear and tear, depending on the user's riding style.

Weight
How much weight is added to your bike with the chosen LSS and where that weight is placed are important considerations.

Size
The size of the LSS determines how much can be taken on a trip.

Appendix F | Key design feature analysis



Appendix G | Types of LSSs

The source of this information is the 8th edition of the Adventure Motorcycling Handbook (Scott, 2020, pp. 136-158).

Placement on the motorcycle

The centre of mass of a loaded bike should be around where the injectors usually are. Centralized mass creates a more nimble and stable motorcycle. Additionally, avoid putting heavy weights behind the spindle of the rear wheel (Scott, 2020).

Mounting options

Motorcycle luggage storage systems are attached to the motorcycle, which can be done in a multitude of ways. To make it easier to understand, these ways are divided into two categories: with a luggage rack and rack free.

A luggage rack is a metal structure, which is attached to the subframe of the motorcycle. The rack makes it possible to mount luggage storage solutions to the motorcycle. Most luggage storage solutions use some form of luggage rack.

Luggage can also be mounted onto a motorcycle without the use of a luggage rack, this is called rack free and has a number of advantages over luggage racks. Rack free luggage storage solutions are lighter, thus have less effect on the handling of the motorcycle when loaded. Furthermore, these rack free solutions are often less expensive but are more susceptible to theft or damage since they are not mounted securely to the motorcycle or luggage rack (Scott, 2020).

There are a number of considerations when choosing a luggage storage system. This include convenience of removal, easy of removal, robustness, durability and weatherproofing, and security.

Types of LSS

The luggage storage systems (LSSs) for motorcycles can be divided into three categories: soft fabric, firm plastic, and hard metal LSSs. An in-depth analysis of all three categories can be seen in Table G1.

Table G1: Core information on three types of LSS, including brands, positve and negative notes on the type of system.

Type of LSS	Information	Brands	Positive notes	Negative notes
Soft fabric	Soft fabric LSS are made from weather resistant fabrics and come in different shapes and sizes.	Enduristan, Adventure Spec, Kriega, Giant Loop, and Mosko Moto.	+ Light + Easy to repair + Absorb impact	- Less secure from theft - Fragile luggage can be crushed or damaged
Firm plastic	Firm plastic LSS are made from PE , PC or ABS, and are often side loading. They weight just as much as a hard metal LSS and come in different shapes and sizes.	Hepco & Becker, Givi, Peli, and BMW Vario.	+ Robust + Lockable + Weatherproof + Do not dent or deform like alloy boxes	- Heavy - Hinges are the weak point on side loading cases - Require luggage rack - Locks can fail on impact
Hard metal	Hard metal LSSs are simple shaped, welded and riveted boxes that can take some damage. Up to the 1980's, riders would handmade their own aluminium LSSs until a number of companies in Germany started to mass-produce aluminium LSS.	The best well-known high-end manufacturers of aluminium motorcycle luggage systems are Touratech, Hepco & Becker, GIVI, SW-Motech, Metal Mule (UK), Jesse Luggage (US) (Nomad, 2024).	+ Robust + Look secure + Strong + Easy to paint and wrap + Weatherproof until the lid deforms + Versatile	- Heavy - Very expensive - Wide - Requires luggage rack - Hard to straighten when deformed - Boxes transfer stress to the subframe

Appendix H | Direct competitor analysis

Table H1: Competitor Analysis hard metal LSS, prices are for full LSS without luggage rack.

Drawing	Brand	Price	Size in L	Colour	Failure points
A	BMW Motorrad GS Adventure [R 1200/1250 GS Adventure]	€ 1,599.00 € 1,297.00	36/44 36/44	Black Silver	- Metal plate is most susceptible to damage - Closing of the lid after a fall is difficult - Use of a large number of non-reversible connections
B	Touratech Zega Evo	€ 1,529.70	31/31 38/38 45/45	Silver & Black	- Case will bend in the middle, just as the GS cases. - Edge is made from metal instead of plastic, will this deform more or less after a fall? - Matt finish will show scratches really fast
C	Hepco & Becker Xplorer	€ 1,278.00	30/30 40/40	Silver & Black	- Metal housing will bend, plastic will not, possible weak point - Chamfers are less aggressive, chance they will deflect rather than hit - Brushed aluminium
D	SW-Motech TRAX ADV	€ 1,200.00	37/37 45/45	Silver & Black	- Case will bend in the middle, just as the GS case - Bracket on this side top for lifting and attaching additional luggage -Lid edge susceptible to not closing after damage - Brushed aluminium not scratch resistant

BMW GS riders who do not opt for BMW LSS can choose from a wide range of universal aluminium LSS systems. These systems are designed to fit on custom luggage racks or on the standard BMW Motorrad OEM luggage racks. The BMW GS aluminium LSS is compared with three well-known motorcycle LSS manufacturers.

Construction

All these aluminium LSSs are constructed in a similar way, using welds and rivets to join the aluminium construction. This makes all systems not ideal for replacement of specific key components. The Hepco & Becker Explorer is the only aluminium LSS that uses a plastic bottom plate, the other manufacturers construct this part out of aluminium.

General conclusion

All LSS use a similar base structure, but differ in terms of design and the location of the plastic parts, the materials used, and the grips used to pick up the LSS. Furthermore, the large aluminium areas and brushed aluminium finish can result in highly visible scratches.

While the common failure points apply to almost all LSS, there are small differences between different LSS. In the event of damage, whether from a fall or other types of impact, it is reasonable to expect that the damage to LSS would be broadly similar.

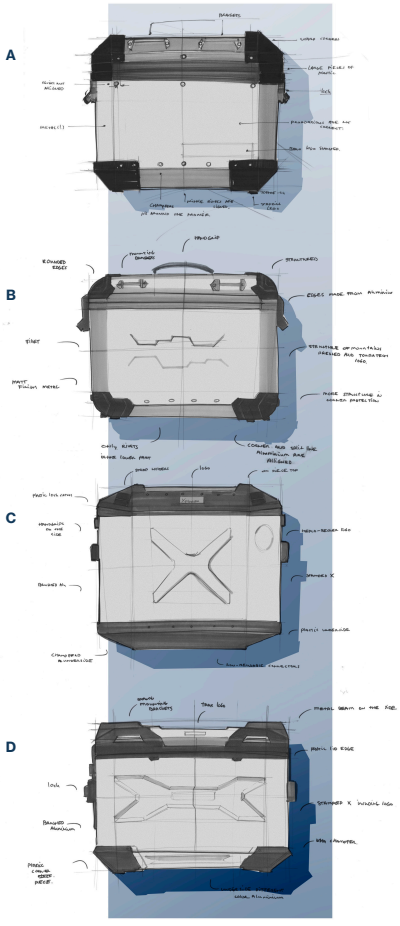


Figure H1: Analysed LSSs - (top to bottom) BMW Motorrad GS Adventure, Touratech Zega Evo , Hepco & Becker Xplorer, and SW-Motech TRAX ADV.

Appendix I | Circular economy

R-strategies help to convert the linear economy to a circular economy. There are three identifiable loops in the circular economy; short loops, medium loops, and long loops (Malooly & Daphne, 2023). The complete overview of the R-strategies can be seen in Figure I1.

Short loops

The short loop is the most desirable of the strategies because it eliminates waste early in the value chain (Malooly & Daphne, 2023).

Refuse (R0)
To refuse means to make a product redundant because consumers can do without it. (Malooly & Daphne, 2023). This can also be driven by innovation, as new technology renders the less sustainable products obsolete compared to the more sustainable and advanced competing product.

Rethink (R1)
Rethink refers to making a product more use-intensive by sharing products or launching multifunctional products (e.g. leasing clothes, battery swapping points or reusable coffee cups). (Malooly & Daphne, 2023).

Reduce (R2)
Reducing the use of natural resources aims to increase the efficiency of product manufacture and use. This results in using fewer natural resources, producing less waste and increasing the efficiency of a product's use (Malooly & Daphne, 2023).

Medium loops

The medium loops help to extend the life of a product and/or its components and therefore have the greatest impact on extending the life of products.

Reuse (R3)
Reuse is when another consumer uses a discarded product that is still in good condition and able to perform its original function. This ranges from the Second-Hand market to standardised products (Malooly & Daphne, 2023). Prolonging the use phase of the product by incorporating longevity and durability into the product design. This is achieved through high quality materials, construction and design for use and reuse (Cradle to Cradle Products Innovation Institute, 2023).

Repair (R4)
The repair strategy involves the repair and maintenance of a defective product so that it can function again (Malooly & Daphne, 2023).

At the design stage, it is helpful to think about user behaviour and provide appropriate repair services or repair kits to extend the life of the product. Modularity and upgradeability are design strategies in this category. A product should be designed with parts that are replaceable and the replacement of these parts can be used to maintain, upgrade or extend the product (Cradle to Cradle Products Innovation Institute, 2023).

Refurbish (R5)
Refurbish is the process of restoring, upgrading and modernising a product. In this approach, a product can be returned to its original condition by replacing or repairing major components that are failing or about to fail, and by making cosmetic changes that update its appearance (such as cleaning, painting or refreshing) (Cradle to Cradle Products Innovation Institute, 2023).

Remanufacture (R6)
Remanufacturing involves the integration of product components that are still functional into a new product with the same function (Malooly & Daphne, 2023). A product designed for a take-back programme can recover useful parts from discarded products. These products must be designed so that their components can be reused in other product applications (Cradle to Cradle Products Innovation Institute, 2023).

Repurpose (R7).
Repurposing is a strategy of incorporating discarded components into a completely different product (Malooly & Daphne, 2023).

Long loops

When waste reduction hasn't been achieved with the first eight strategies, the only options left are recovery of materials from solid waste destined for landfill, and energy/heat recovery from incineration, which are part of the long loops (Malooly & Daphne, 2023).

Recycle (R8)
Materials can be recovered from products that are no longer in use. This can be done by upcycling or downcycling (Malooly & Daphne, 2023).

Upcycling: The aim of the circular economy is to upcycle products of equal or greater value to the market through recycling (Cradle to Cradle Products Innovation Institute, 2023).

Downcycling: Recycling returns materials to the cycle at a lower value. This is less desirable than upcycling in the circular economy (Cradle to Cradle Products Innovation Institute, 2023).

Design strategies that help recycling include designing with mono-materials and designing for disassembly.

Recovery (R9)
Composting of organic waste can recover energy through anaerobic digestion in a biogas plant. Other wastes may be combusted for energy production (Malooly & Daphne, 2023).

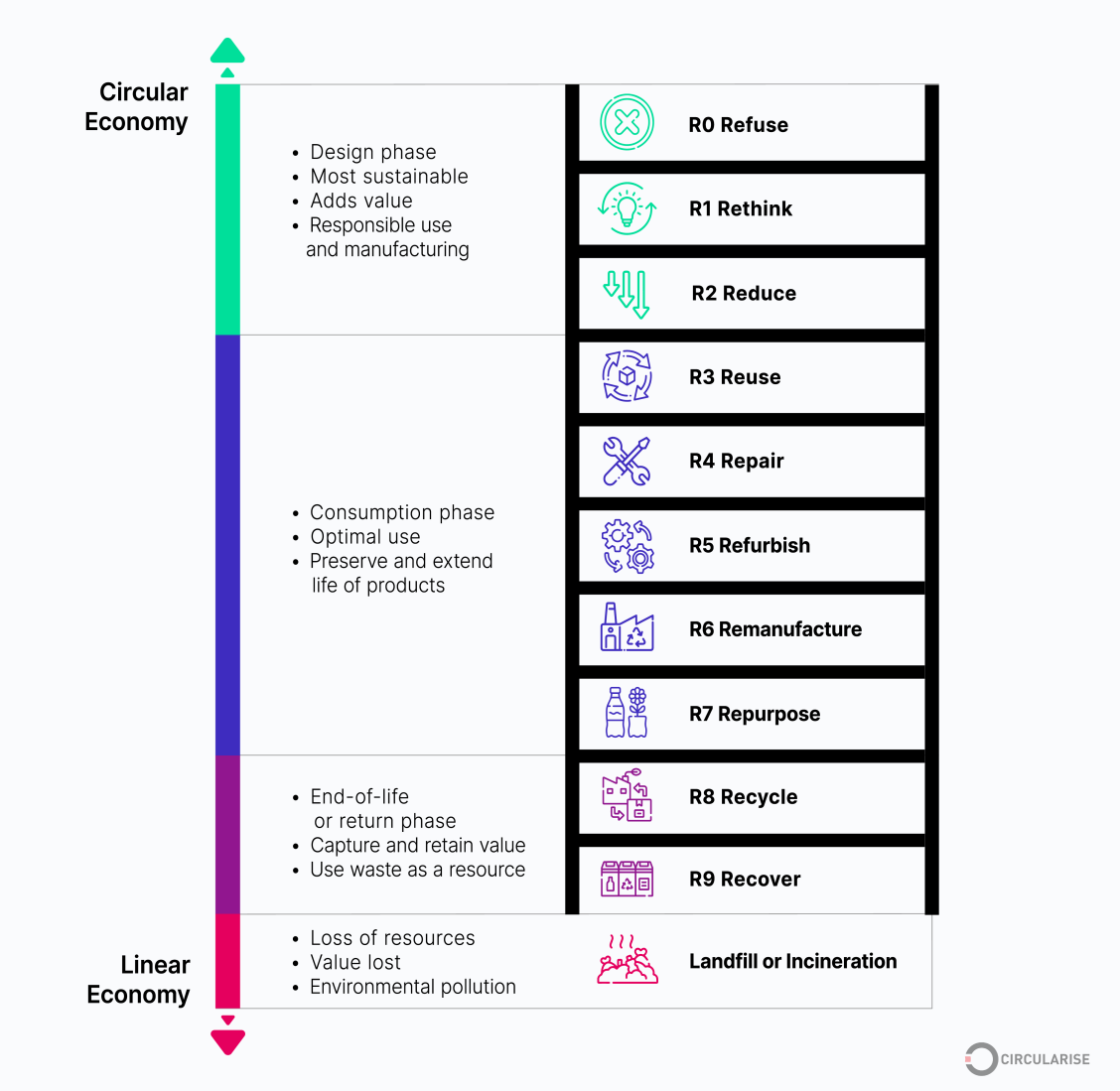


Figure I1: The different stages that R-Strategies can be implemented (Malooly & Daphne, 2023).

Types of obsolescence

Alzaydi (2024) identifies three types of obsolescence. Firstly, “functional obsolescence transpires when products can no longer perform their intended functions due to wear and tear, or when those functions are no longer required.” Second, technological obsolescence occurs when new technologies make the product obsolete. This is mainly related to electronics or changing platforms. Finally, changes in style and social norms lead to the most subjective form of obsolescence, which is aesthetic obsolescence.

Appendix J | Image of the R 1300 GS Adventure

BMW R 1300 GS

Reviews
The reviews describe the R 1300 GS as feeling smaller, more approachable, and a less intimidating machine (Oxley, 2024). Furthermore, the frame and subframe flow into the bodywork more fluently, and the integration of the headlight give the bike a more coherent and streamlined silhouette (Costa, 2024). Lastly, even thought the motorcycle has lost weight compared to the predecessor, the appearance is perceived even lighter than the weight it has lost (Conner, 2024).

According to Oxley (2024), the motorcycle feels relaxed and comfortable due to the features on the motorcycle. The GS is also described as ultimately comfortable for the highway and that it remains an excellent long-distance tourer.

Overall: Small, light and comfortable.

Comments online
Online comments mention the words compact, young, and sporty (papo4ever, 2023). It is further described with cleaner lines (Costa, 2024), mention the seemingly narrower and smaller look of it (Costa, 2024).

Overall: Compact and small

Co-creation session
The participants of the first co-creation session (n=2) described the R 1300 GS as light feeling, small and even feminine. They found the highway or Europenian cities as the most logical place where you would see this motorcycle.

The design language was compared to the Architectural style of Neo Futuristic. The design feels like it had help from software in the design phase.

Overall: Light feeling, feels small.

Combining these findings creates an image. The brand image of the BMW R 1300 GS is light feeling, compact and comfortable.

BMW R 1300 GS ADVENTURE

Reviews
The GS Adventure is characterised by journalists as intimidating (Child, 2024) and imposing, impending, and impressive (Sarasyn, 2024).

Furthermore, the GS Adventure is prized for it's comfort. According to Child (2024) you can cover hundreds of miles efficient and in a blanket of irritation-free comfort. Other journalists share this oppinion by saying that it is a comfortable long-distance travel motorcycle (Conner, 2024), that it makes you want to drive far and a lot (Sarasyn, 2024), and that the seating comfort have been top priority (Adventure Rider & Botan, 2024).

Overall: Intimidating, imposing (=heavy) and comfortable long distance.

Comments online
The comments reveal that they find the looks from the front looking like a hippopotamus (Maddjack & Adventure Rider, 2024), or describe it as a hippo (Conner, 2024). The hippo can be seen as an analogy for something that is heavy and big.

Additionally, the reactions describe it multiple times as a Lego set and like a transformer (Adventure Rider & Botan, 2024).

Lastly, the comments describe that this motorcycle is designed for a trip to the Starbucks Adventure Rider & Botan, 2024), and not the adventure that it is designed to communicate.

Overall: Lego transformer [Blocky], hippo thus heavy, and for urban adventures.

Co-creation session
The participants of the co-creation session (n=2) characterised the R 1300 GS Adventure as big, heavy, robust, a rugged beauty. It was compared with a transformer and the location where they would see this motorcycle would be on rural roads and on places like the Golden gate bridge.

An interesting comparison is with the industrial architectural style in which the Centre Pompidou is build.

Overall: Heavy, big, transformer.

Combing these insights creates an image. The brand image of the BMW R 1300 GS Adventure is highly comfortable and big, imposing, like a hippo; thus heavy.

Appendix K | Gentle dismantle

BMW R 1200 GS Adventure LSS

The right aluminium BMW R 1200 GS Adventure pannier has been disassembled using the gentle dismantle method. This is the first time this LSS has been dismantled, and it is dismantled until there are no parts left that can be removed with re-usable connections.

The setup of the gentle dismantle method is outlined in Figure K1. The dismantling process was completed within 14 minutes and 3 seconds.

Figure K1 | Setup of the gentle dismantle - Video camera to record the process, tools, and the LSS of the BMW R 1200 GSA.

Removable parts

The lid, three lock sub-assemblies, a metal cord holder and an internal rib reinforcement connected to a metal heat shield were removed during the gentle dismantle. An illustration of the parts removed by soft disassembly is shown in Figure K2.

The limited removal of parts in the gentle dismantle shows the poor state of disassembly and therefore repairability. However, the lock sub-assemblies are removable and can be almost completely disassembled, these three sub-assemblies are easily repairable and accessible for maintenance, unlike the rest of the LSS.

Non-removable parts

The majority of parts, such as the luggage rack mounts, plastic corner protectors, water-seal, and aluminium parts used in the main construction, could not be removed in the gentle disassembly process since they are connected use non-reusable fasteners.

These non-reusable fasteners include of use of a lot of rivets and in some connections adhesive. The use of these types of fasteners has a negative impact on the ability to replace parts and repair the LSS.

Challenging gentle dismantle

This preliminary analysis provides an overview of the challenge in dismantling the LSS, with only a limited number of components able to be disassembled without causing permanent damage.

The next step is to identify priority parts, economic indicators and environmental indicators to see which parts are most critical to the core function or have the biggest economic or environmental impact.

Figure K2: Knolled picture of the gentle dismantle.

Appendix L | Hotspot Mapping

Disassembly steps

The number of parts in the analysed right-hand pannier system is 143, of which 93 parts can be attributed to the three lock sub-assemblies and 50 parts in the product if the lock sub-assembly is left out of the count.

The number of steps to disassemble the analysed pannier is 124. Each step in the hot-spot mapping describes the name of the part, the sub-assembly to which the part belongs, the type of activity, the tool required, the frequency of the task and the total time to remove the part. It also assesses force, accessibility and positioning.

This number of steps to disassemble the pannier in the hotpot mapping gives a first impression that the product is more complex to disassemble than it appears at first glance.

This number, as derived from hotspot mapping, gives a first impression of the product architecture, but not the exact order in which parts are removed from the product. Insights into the product architecture and disassembly order/sequences are analysed in the Disassembly Map.

Disassembly time

The time taken to disassemble the right pannier for each step was recorded, with a total time of 12,591 seconds being recorded for this task. It should be noted that not all rivets have been removed for the Hotspot Mapping due to the large number of rivets (69) and the significant time required to remove each one. Each rivet removal is performed in two steps: drilling, followed by hammering and punching. The drilling time for a rivet connection is an average of 23 timed removals, and the hammering and punching time is an average of 13 timed removals. Additionally, it was not possible to separate two parts: the internal box plastic edge and the internal lid plastic edge.

Table L1 | Overview of the tools used in the Hotspot Mapping analysis.

Tools used in the Hotspot Mapping analysis	
Name of tool	**Propitiatory**
Hands	No
Wrench	No
Pliers	No
Lever/Prybar	No
Screwdriver TR20	No
Key	**Yes**
Drill	**Yes**
Hammer & Punch	**Yes**

Appendix M | Disassembly mapping priority parts

Priority parts

The priority parts were indicated in the Hotspot Mapping analysis and were based on observations from a case study about damaged aluminium motorcycle cases from BMW GS.

It is important for the repairability of a product that the priority parts are easily accessible and easily replaceable, since it is most likely that damage to these parts have the largest impact on the functioning of the product. The accessibility according to the disassembly map is elaborated for each of the seven priority parts.

Lid (#10)

The lid is an important part of the product, as indicated by the priority part, environmental indicator, and economic indicator. It is however very difficult to access due to the parts that are connected to the lid, which need to be removed before the part can be replaced.

Internal lid plastic edge (#9) & Internal box plastic edge (# 23)

The internal lid/box plastic edges are important parts of the product, as indicated by the priority parts, environmental indicators, and economic indicators. It is removable in two steps, these steps however involve a non-reusable connector and require a manipulation of the product which indicates that it is medium difficult to remove the internal lid plastic edge from the product.

External box steel top montage system (#18) & External box steel bottom montage system (#19)

The top and bottom montage system are priority parts and both have an environmental and economical indicator. These parts are difficult to reach in the disassembly due to the number of steps and actions that need to be taken in order to reach the part. Additionally these parts require the removal of non-reusable connectors and actions that require a large force. Lastly, the number of connections that need to be removed is also high, 9 rivets for both the montage systems.

Box underside (#24)

The box underside is an important part of the product, as indicated by the priority part, environmental indicator, and economic indicator. It is necessary to remove 22 heavy force and non-reusable connectors (rivets) and a friction fit connector before reaching the box underside. This part is therefore difficult to reach and replace.

Box side panel (#25)

The box side panel is an important part of the product, as indicated by the priority part, environmental indicator, and economic indicator. The box side panel requires even more non-reusable connectors to be unconnected before being able to extract the part from the product.

The priority parts that have been described above need to be taken out of the product before being able to replace the box side panel, making this part the most difficult part to remove from the pannier system.

Appendix O | Questionnaire - Setup

Setup
The questionnaire was created in Microsoft Forms and included multiple-choice questions, Likert scales questions to be able to access the importance of certain characteristics, and open questions for qualitative insights.

The questionnaire was created in English, and was shared in Adventure, Adventure-touring, and other ADV related groups on a social media platform. The data obtained from this questionnaire is processed using a spreadsheet tool.

Demographics
The total number of participants for this questionnaire is n=263. The majority identifies as male (93%), 3% identifies as female and 4% prefers not to say (Figure O1).

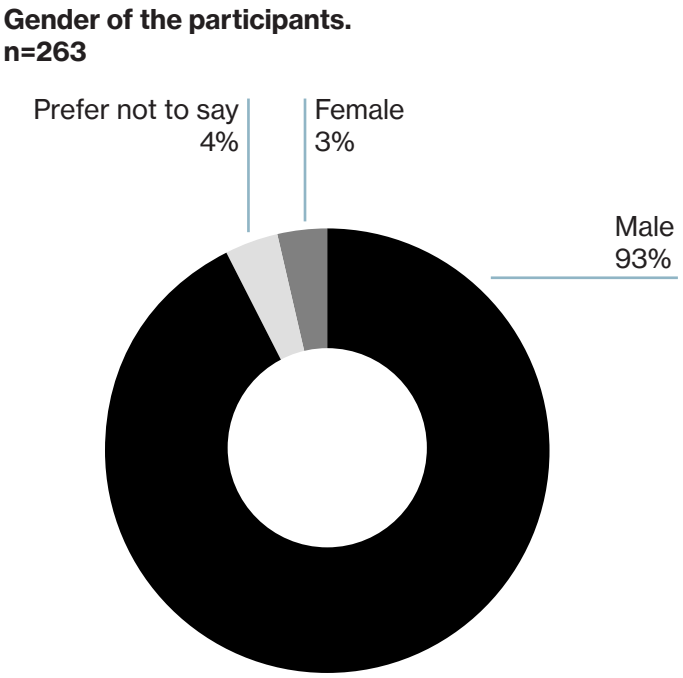


Figure O1 | Gender of the participants.

Experience
The largest group of the participants have been riding for more than 20 years (23%). Followed by 11-20 years (22%), 6-10 years (21%), and 3-5 years (18%) of riding motorcycles. The two smallest groups have the least experience in riding motorcycles with 11% having 1-2 years and 5 % having less than a year experience (Figure O2).

Brand
Lastly, the number of participants riding a BMW Motorrad motorcycle was highest with n=103, followed by Yamaha with n=43, Honda with n=31, and KTM/ Husqvarna with n=26 (Figure O3).

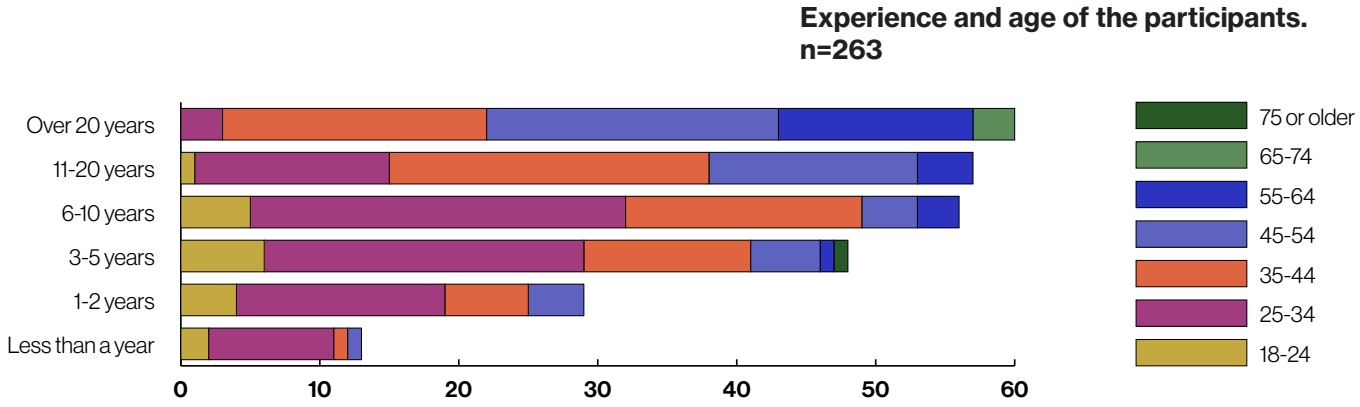


Figure O2: How many years have you been riding a motorcycle?

Over 20 years	23%
11-20 years	22%
6-10 years	21%
3-5 years	18%
1-2 years	11%
Less than a year	5%

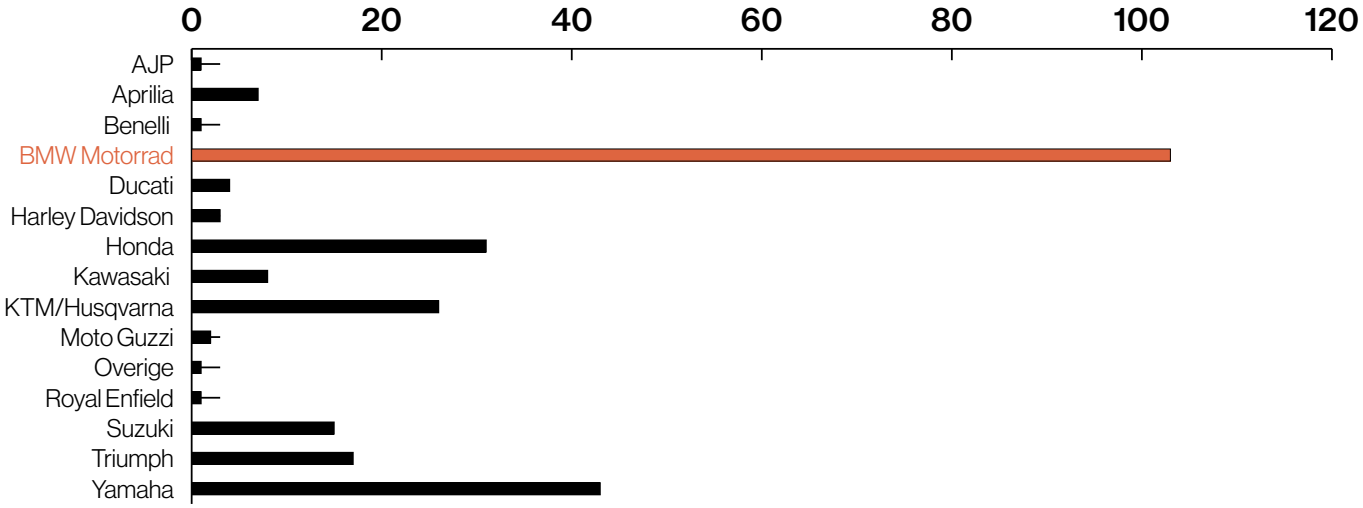


Figure O3: Motorcycle brands participants own.

Luggage Storage System Use

Luggage storage systems are a well used addition to the motorcycle. According to J. Kruis (2024) all 207 BMW R 1300 GS Adventure motorcycles ordered, before the end of November 2024, had the optional luggage rack fitted.

The participants were asked about the type of luggage storage system they use on their motorcycle. 97% of the participants used a luggage storage system, 3% did not use a luggage storage system. The reasons behind not using a luggage storage system were aesthetics, high cost, no use for it currently, and still deciding on a system.

The use of soft fabric bags was most popular under the participants with 45%, 38% of the participants used a hard metal/alloy luggage storage system, and 20% used a firm plastic storage system (Figure O4).

Type of luggage storage system | n=263

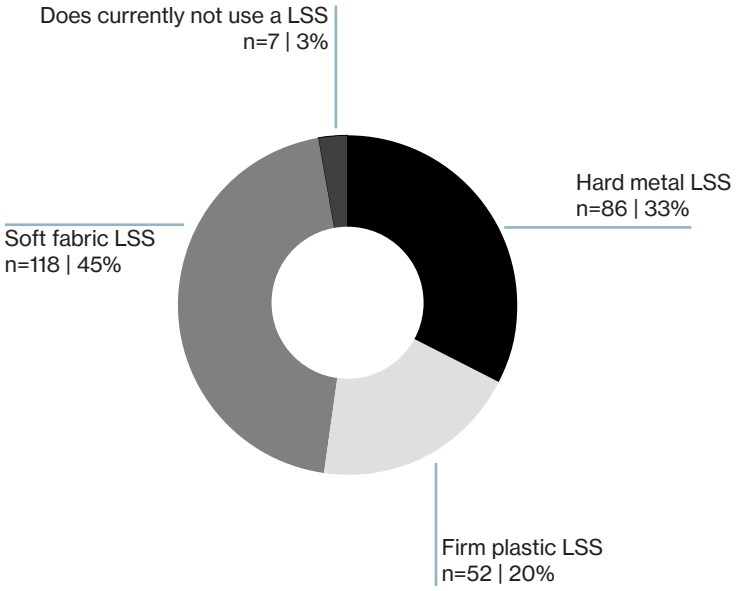


Figure)4 | Type of LSS used by participants.

Luggage Storage System for BMW Motorrad

Filtering the data from Figure O5 with the brand of motorcycle creates an insight in the preferences of BMW Motorrad owners concerning their preferred luggage storage system. The BMW owners use hard metal/alloy luggage storage systems most often with 49%. This is higher compared to the preferences off all participants (38%).

Additionally, 26% of the BMW Motorrad owners use firm plastic luggage storage systems on their motorcycle. Which is slightly higher than the use of this type of system for all brands (BMW 26% (Figure O6) vs all brands 20% (Figure O5).

The least used type of luggage storage system for BMW owners is soft fabric bags (23%). Soft luggage storage systems are used less by BMW Motorrad owners compared to Adventure motorcycle owners. Soft fabric bags are used by the largest part of the participants, while it is used the least for BMW Motorrad owners.

Lastly, 2% of the participants does not use a luggage storage system. These two participants who do currently not use a luggage storage system on their BMW motorcycle elaborated that this has to do with lack of funds and high expenses coupled to the luggage storage systems.

The participants were asked to further specify the configuration of their hard metal/alloy luggage storage system (n=86). The majority of the participants use a full system (66%), followed by a pannier system (23%), and a minority of 10% uses a top case (Figure O6).

Type of LSS for BMW Motorrad owners | n=103

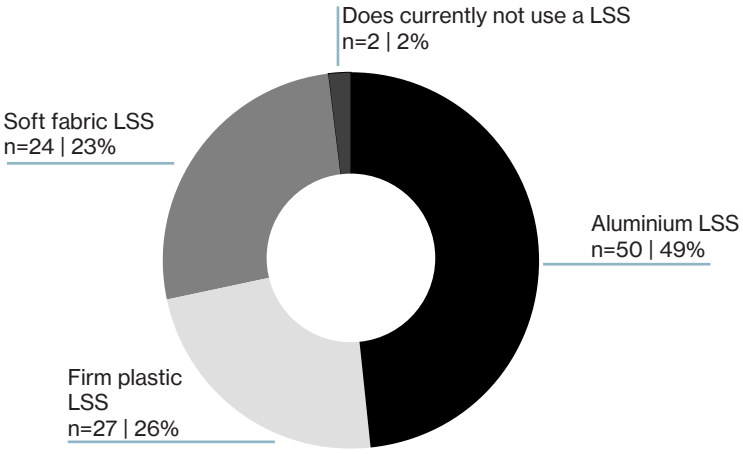


Figure O5 | Type of LSS used by BMW Motorrad owners.

Configuration of aluminium LSSs | n=86

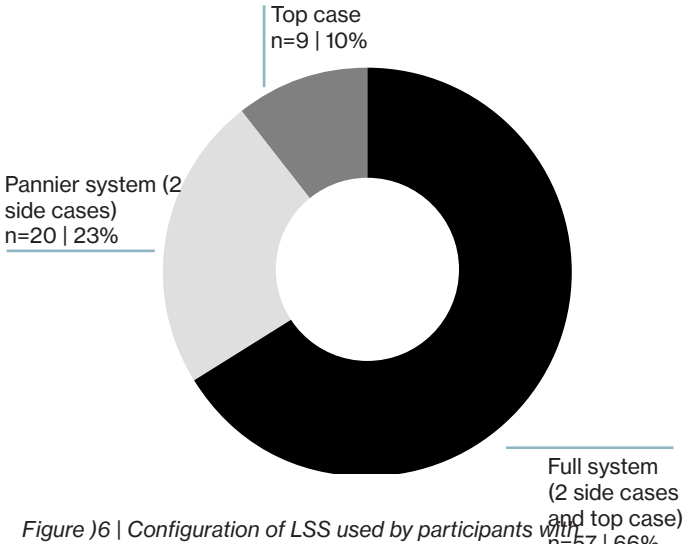


Figure)6 | Configuration of LSS used by participants with aluminium LSS.

Experiences with damage of aluminium LSSs.

The participants were asked if they have had damage to their luggage storage system. Of the participants using hard metal/alloy luggage, 45% had no experience with damage to their luggage storage system. 55% of the participants have had damage to their hard metal/alloy luggage storage system (47% minor damage, 8% major damage, Figure O7).

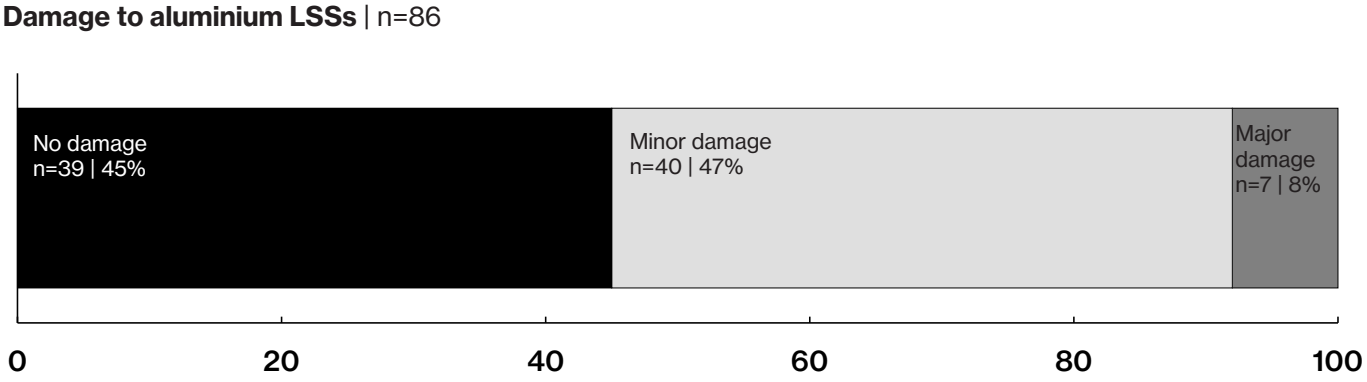


Figure O7: Experience of damage of aluminium LSSs.

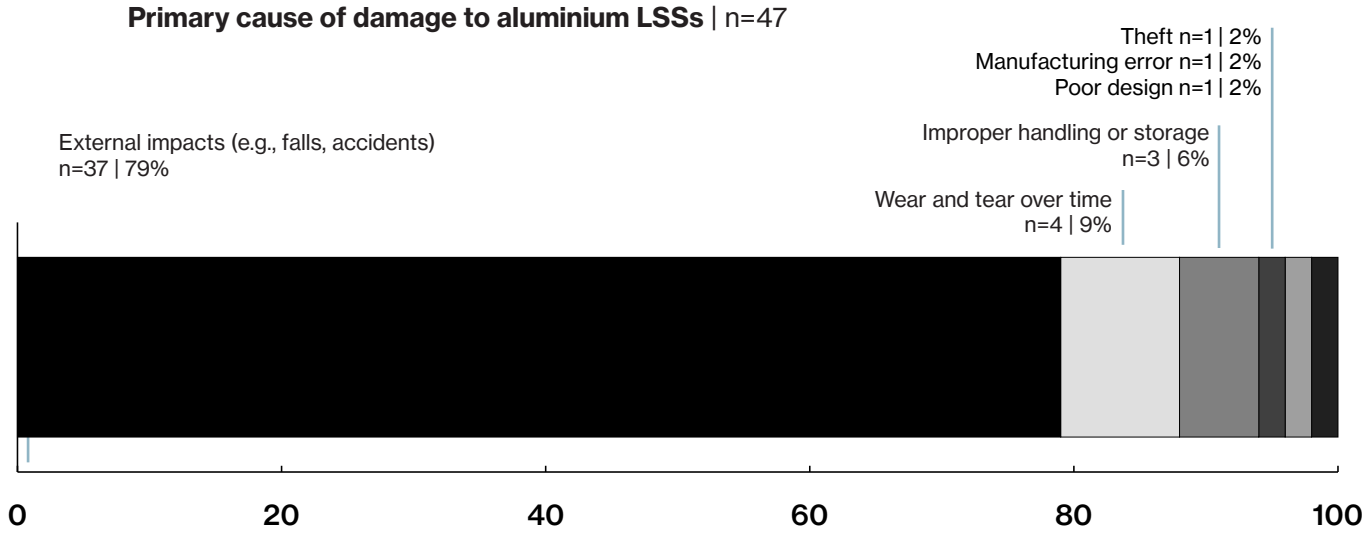


Figure O8: Primary cause of damage to aluminium LSSs.

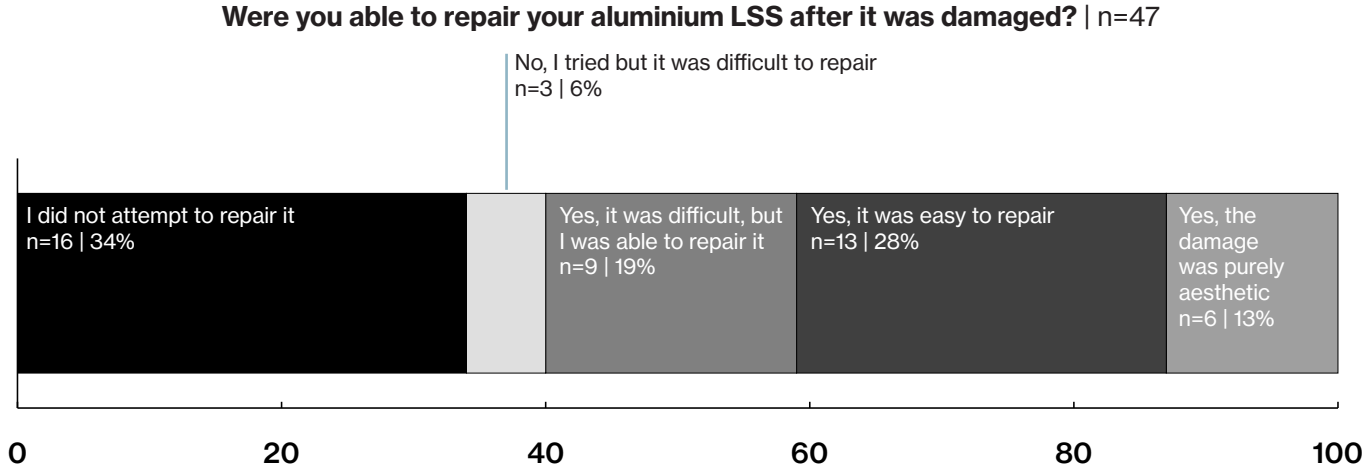


Figure)9: Was the damage to the aluminium LSSs repairable by the participant?.

Participants were asked to select (up to five) main reasons for their choice of motorcycle LSS, as shown in Figure O10. Of all the reasons, weather resistance (n=51) and durability (n=50) are the most common main reasons for choosing an aluminium LSS on their adventure motorcycle. Furthermore, security features (n=43), storage capacity (n=42), ease of installation/removal (n=42), and compatibility with my motorcycle (n=39) are important factors buyers take into consideration when selecting a hard metal/alloy luggage storage system. Finally, the factors design and aesthetics (n=33), ease of use (n=29), price (n=18), and brand reputation (n=13) are least important factors in the buying and selecting process.

One participant made an interesting comment that he thought rider safety was really important, that the legs should be protected in the event of a crash.

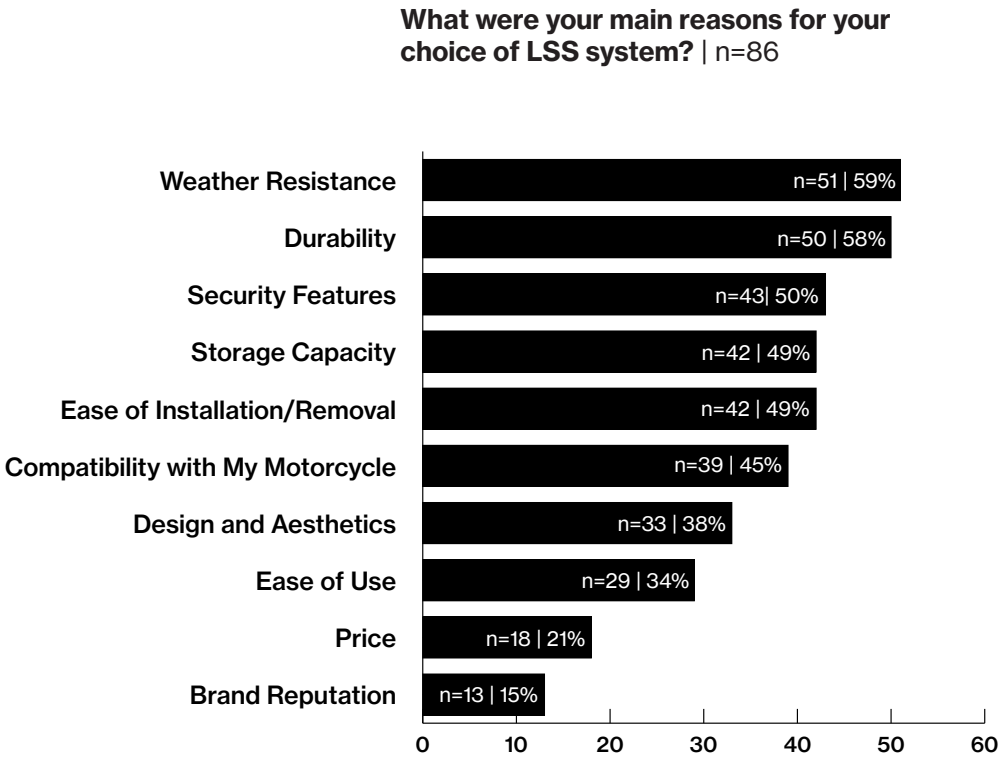


Figure O10 | Main reasons for the choice of aluminium LSS (up to five maximum). Percentage of the total n=86 selected that answer.

The following three questions were asked to all participants if they had experience with damage and/or repair of their LSS:

1. What part of the LSS did you repair? And how did you repair this part?
2. What part of the luggage storage system was not repairable and/or too severely damaged?
3. Can you describe where the damage occurred and what caused the damage to your luggage storage system? (Were you standing still, or were you moving?)

The answers for the most relevant cases are shown below.

#8 | A slow speed drop of the motorcycle with panniers resulted in hitting a rock, denting the panel enough to see daylight. The visible gaps have been hammered back into place, the dents are still there but give character.

#48 | Bike fell over due to putting it on its side stand at an improper angle of the road. I tried catching it by grabbing onto the open lid of the pannier, causing it to bend and not close correctly. Lid, bent back into place.

#74 | I had a low speed high side crash in a roundabout. It was rainy and cold and I lost traction. The bike impacted on the handlebar the right saddlebag and slid maybe 10 feet on it. Had to push out the walls of the pannier, and pinch the mounting frame back to being tight enough to support the bag.
I never bothered to fix the scrapes down the corner.

#77 | On my hard cases, the damage occurred when riding off road on single track. The luggage system only has visual damage.

#99 | Dropped the bike a few times. Took a mallet and hammered out it out. None of it was not repairable.

#102 | Fell while traversing Offroad trail. I hammered out large dents and deformations in the luggage and re-sealed a portion with silicon caulk. The rack that attaches to the motorcycle was bent and not repairable.

#109 | My center stand broke through the pavement, toppling my motorcycle. The result was a scratch and shallow dent in one of my cases.

#113 | Tipping over and bending the panniers, cracking the frame. The luggage frame had to be replaced because it was too severely damaged.

138 | Fell over, had to replace the lock system.

#139 | Fitment and re-alignment. The alignment needed adjustment.

#148 | Smashed into a tree after an off road incident at high rate of speed. Had to replace the top case.

#159 | Fell over on uphill. Dented one pannier.

160 | “Falls while climbing hill with loose rocks and pillion
Fall while fording river after hitting submerged rock”

#165 | The well known damage by closing with traffic poles.

#179 | Dent on lid causing seal issues. Hammer&dolly.

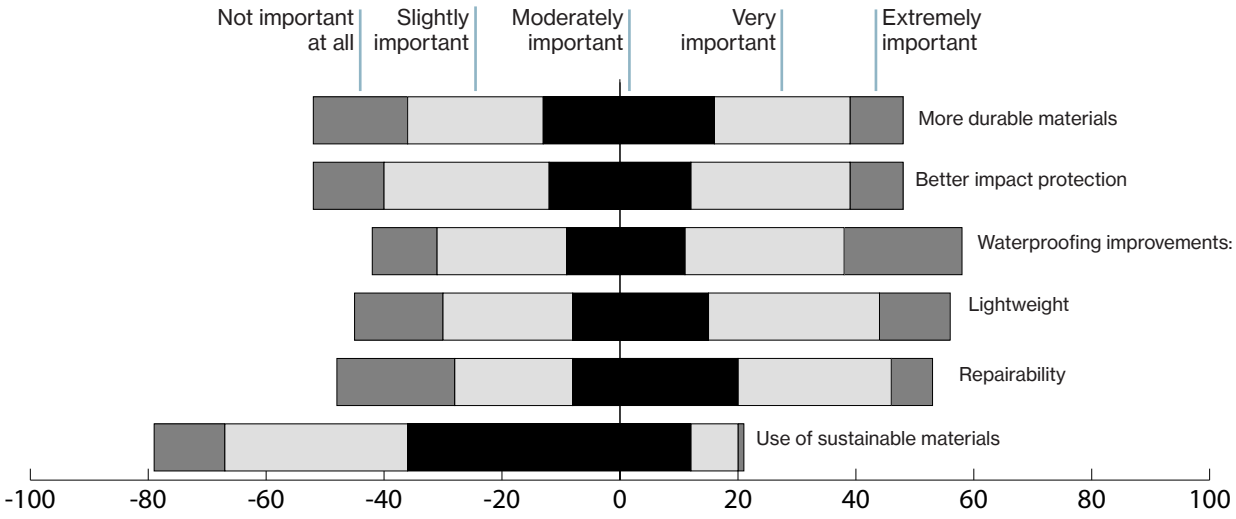
#191 | Moving slowly riding up a hill. The side cases got some scratches and minor dints.

Plastic cases are a write-off with any fall.
#212 | I dropped the bike twice on pavement at low speed. Each time the factory Honda case was damaged at the hinges. The first drop also cracked a piece out of the corner of the box itself (they are plastic). I replaced the box, but the second one was similarly damaged after another low speed drop so I switched to aluminum SW Motech. Those have gotten a little dinged up but no material damage in six years.

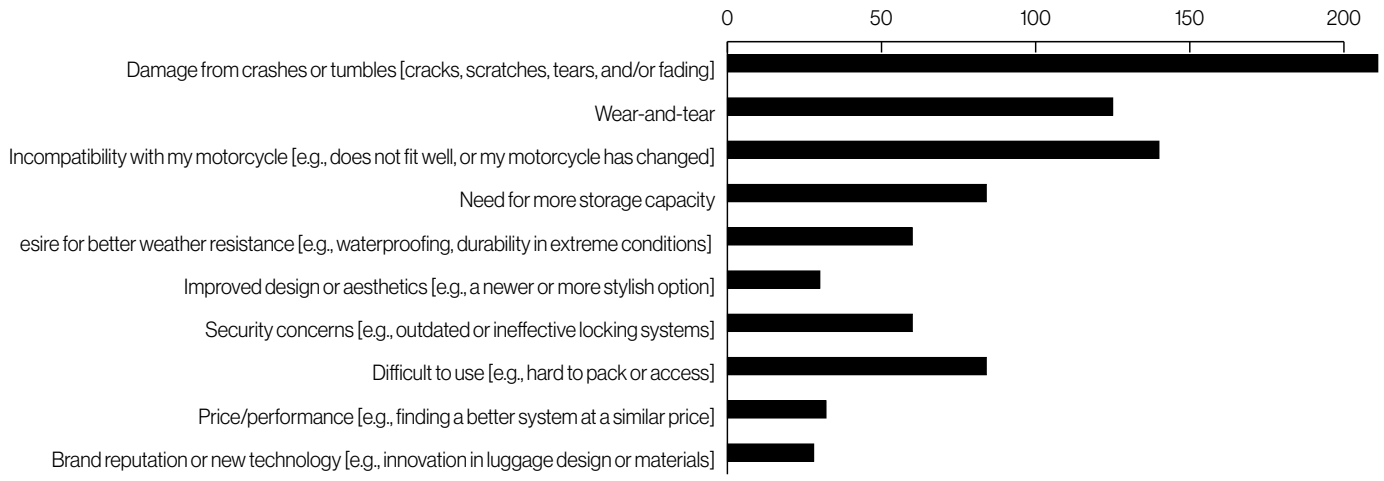
#230 | 30kph offroad riding on gravel. Came to river crossing and hit large rock. Bike fell over on side into side case. Repaired by hammering the metal side case. Side case corner skid plates could not be repaired.

234 | “Various levels of dents and scratches during grundsätzlich impact crashes (see above)
Most severe was front lippage on oily roundabout, dented and scratched the side of my luggage system, 1-2 inches deep dents and bracket bent” Repaired- Latches-swapped those out, mounting bracket-bent it back. Non repaireable - Cornes, paint.

How important are the following improvements for your next LSS.



Under what circumstances would you consider replacing your LSS? | n=263



Appendix P | Reference materials sacrificial strategies

Strategy 1: PROTECT

Crash Bar

Crash bar protects important parts of a motorcycle in a fall or other kind of impact.

Steel Engine Guard

Engine guard protects vital parts on the underside of the vehicle.

Air-bags

Air-bags deploy to protect the people in the vehicle from a large impact.

Metal Reinforced Hand Guards

Reinforced hand guards protect the hands and levers from impacts and major deformation.

Appendix P | Reference materials sacrificial strategies

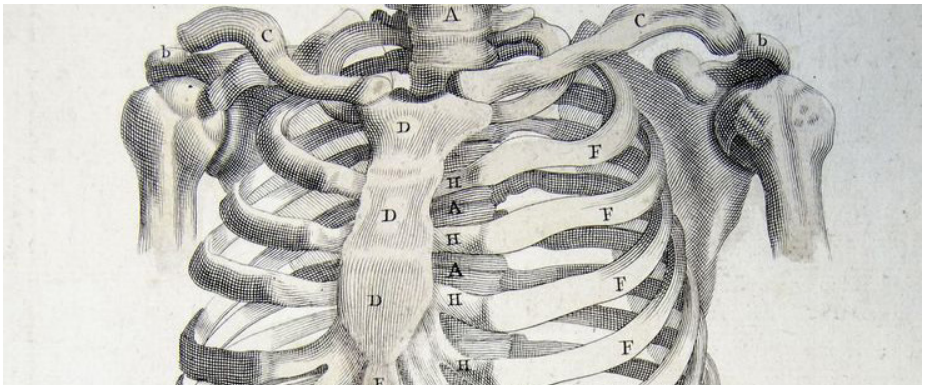
To use a structure or material to protect key components.

Beetle Exoskeleton

Hard outer shells protect delicate internal organs while maintaining mobility.

Phone Case

Shield against drops and bumps.



Bones

Rib structure protects vital organs.

Fenders

Fenders protect boats from damage while laying in the harbour.

Appendix P | Reference materials sacrificial strategies

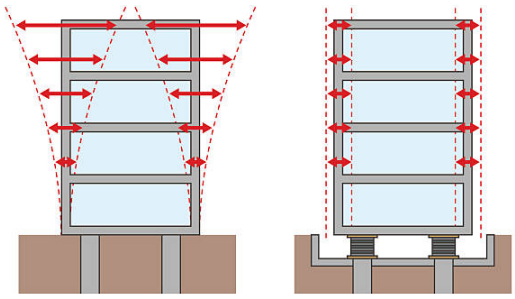
Strategy 2: MOVE

Mirror

Friction tightened, large forces can move the mirror.

Earthquake Resistant Buildings

Mechanisms in the basement can counteract on the forces from earthquakes.



Plastic Only Hand Guard

Can be moved in a crash.

Car Mirror

Small hit can flip the mirror inwards, preventing damage.

Movable Foot-peg

Foot-peg flips in case of an impact.

Appendix P | Reference materials sacrificial strategies

To move a product, or part off a product, out of the way to protect it.

Friction

Tight connections that use friction can move.

Suspension Bridge

There is movement designed into the structure of the bridge, the bridge can therefore move with the external impacts.

Flexible Tree Branches

Trees bend in high winds, shifting their branches to “move out of the way” of destructive forces.

Automatic Safety Gates

Gates are can rotate one way freely, the other is controlled.

Appendix P | Reference materials sacrificial strategies

Strategy 3: DEFORM & ABSORB

Spring and Damper System

The spring deforms, the damper absorbs forces.

Foam Helmet Structure

The hard plastic top deforms, the softer foam absorbs impacts from falling and loose flying rocks.

Crash Structure Vehicle

Structure of the vehicle can deform and absorb the forces from an impact.

Crash Cushion

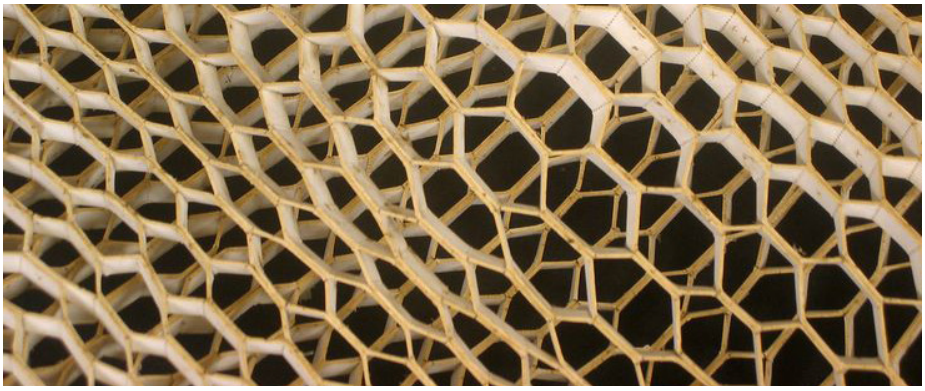
The crash cushion is designed to absorb the forces from an impact by deformation.

Guardrail

The guardrail absorbs the force by deformation.

Appendix P | Reference materials sacrificial strategies

Absorb forces by deformation in a desired location to prevent damage to more crucial components/locations.

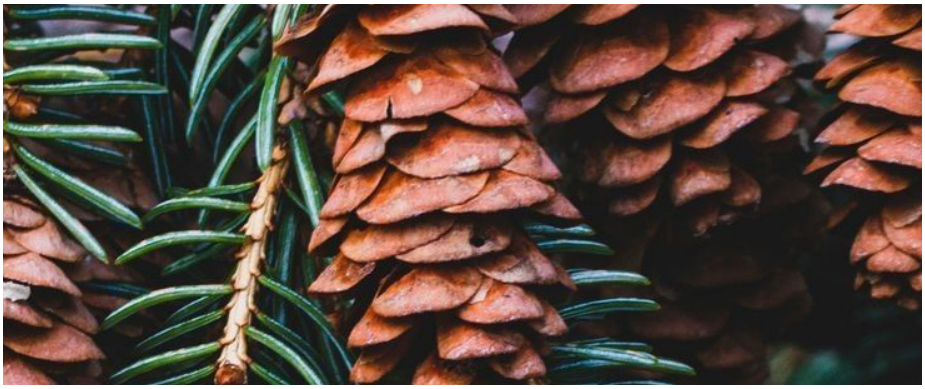


Honeycomb Packaging Materials

Structures deform on impact, protecting valuable items.

Metal Foam

Deforms under pressure, distributing impact forces evenly while returning to its original shape.



Pine cones

Deform to absorb water in predictable ways.

Tree Bark

The layered bark tears off from external influences. The bark deforms and absorbs external factors, protecting the core of the tree.

Appendix P | Reference materials sacrificial strategies

Strategy 4: BREAK [FRANGIBLE]

Frangible Break Lever

The most outward part can snap-off in a fall, making sure the rider can still continue after this impact.

Arai Tour X5 Helmet

Helmet has an egg shape, all other components are added on the outside and are designed to snap-off in an accident.

Frangible Ammo

Ammo that disintegrates on impact, reducing the chance of recoil when shooting at metal targets.

Appendix P| Reference materials sacrificial strategies

To break in a desired location.

Deer Antlers

Breakable and re-growable antlers and are designed to sacrifice parts while protecting the core body.

Perforations In Packaging

Tear lines allow breaking at specific points without damaging the contents.

Fuses

Fuses break circuits when excess current flows.

Icebergs Calving

Ice shelves break in specific zones to balance the stress and prevent larger uncontrolled breaks.

Appendix P | Reference materials sacrificial strategies

Strategy 5: GUIDE

Motorcycle Neck Brace

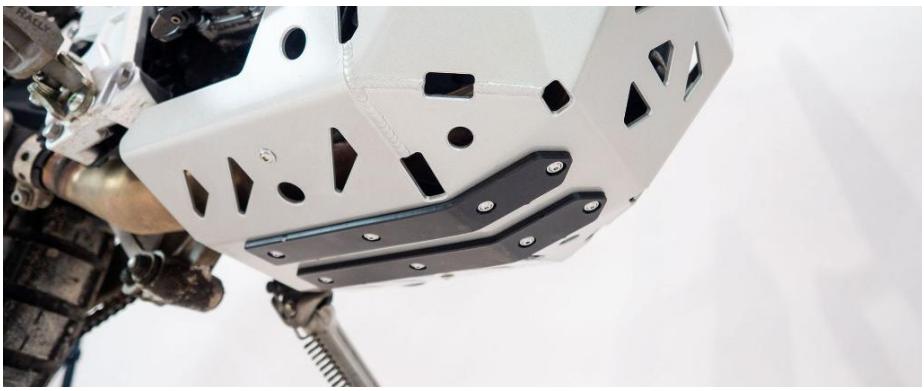
Guides and limits the forces on the neck in case of an accident.

Plastic Hand Guards

Guide the wind and branches during rides.

Skid

Skids make it easier to slide over large objects such as rocks and trees.



Rubber Mud Flap

Mud flaps guide the loose flying rocks and sand back to the ground.

Appendix P | Reference materials sacrificial strategies

Guiding the forces to a desirable location.

Tree Trunk And Roots

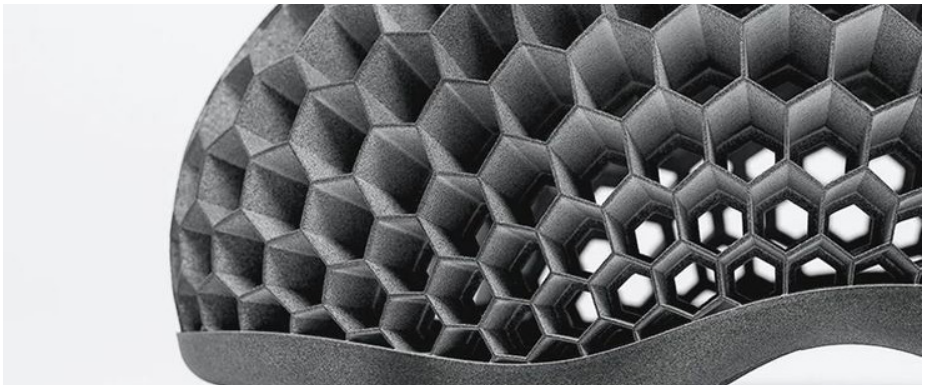
Guides and distributes forces.

Meandering River

The water is guided from high to low via the most convenient, and ever changing, way.

Arch

In architecture, arches are used to guide forces towards the ground.



Hexagonal Honeycomb Structure

Guiding forces from impact to a larger area of the helmet.

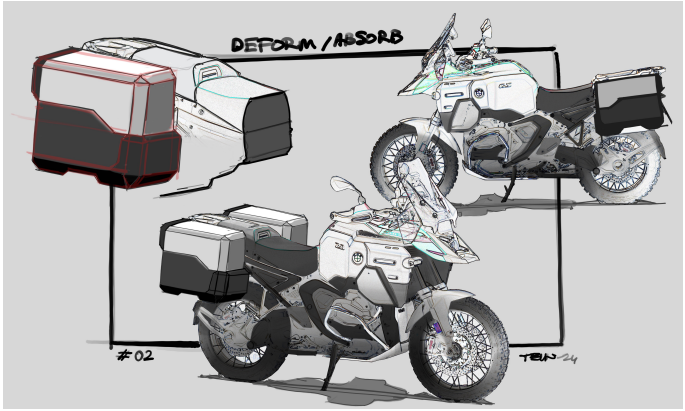
Appendix Q | Concept selection weighted objectives method

Three concepts have been selected using the weighted objectives method (Van Boeijen et al., 2020).

The 26 concepts have been screened for their feasibility, the concepts that were not feasible have been removed from the selection process. The weighted criteria from the three chosen concpets can be seen in Tables Q1, Q2, and Q3.

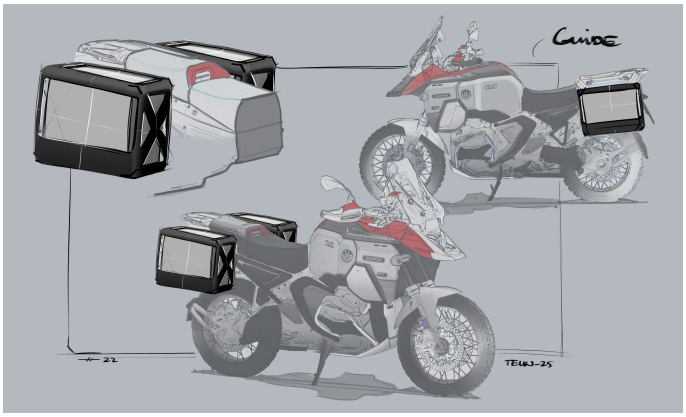
Concept 1 | Protection sleeve

The Protection Sleeve features a dual material finish for durability and functionality. The locking mechanism is positioned on the back, reducing the risk of damage in low-speed off-road crashes. A rubber bumper on the underside helps absorb impact through deformation, increasing overall protection. This rubber bumper is attached to the luggage rack, not the pannier itself.



Concept 2 | Open X

The Open X features a rubber exoskeleton that creates a buffer zone around the case for increased durability and impact resistance. Strategic openings in the case allow additional bags and accessories to be attached for increased versatility. These openings also act as handles, making it easier to lift and manoeuvre the luggage system. In addition, the deformable rubber exoskeleton provides an extra layer of safety for the rider by providing a softer impact surface for the legs in the event of a fall.



Concept 3 | Soft crash bag with protective padding

The Soft Crash Bag with protective padding features a front soft bag that absorbs impact by storing less critical items. Protective padding between the soft and hard storage increases shock absorption while protecting the rigid structure. This design increases the storage capacity for soft items while maintaining the integrity of the hard LSS. A see-through feature gives the case a lighter look.

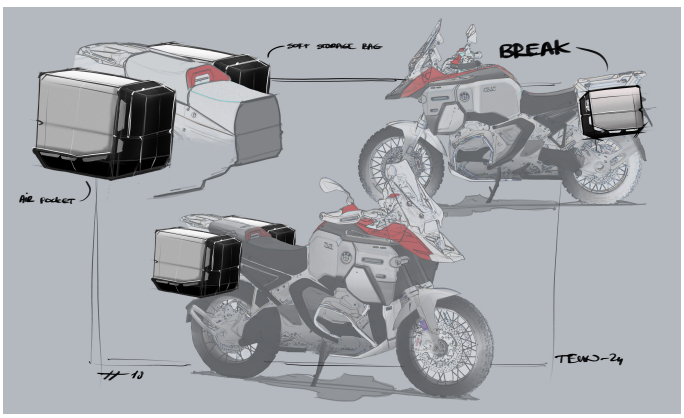


Table Q1: Criteria for weighted criteria for concept 1

Selection criteria	Weight of criteria	Score [1/10]	Weight x Score
Message/Story	10	8	80
Durability	10	8	80
Aesthetics	10	7	70
Prolong liftime (CE)	10	7	70
Safety	5	10	50
Ease of use	5	8	40
Max score	50	-	**390**

Table Q2: Criteria for weighted criteria for concept 2

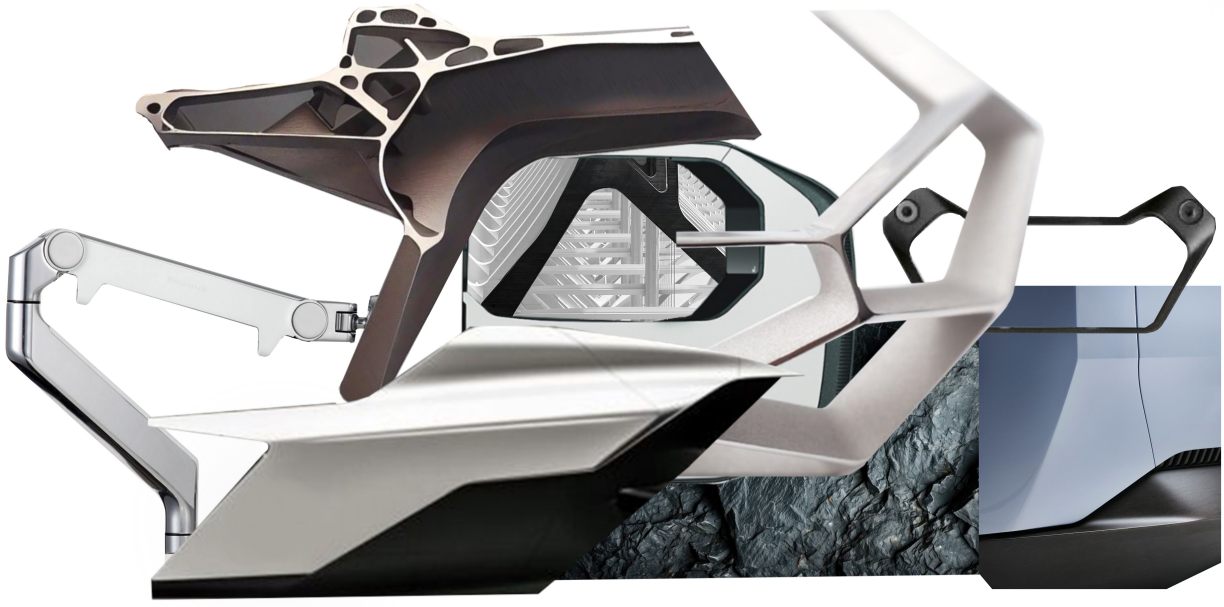
Selection criteria	Weight of criteria	Score [1/10]	Weight x Score
Message/Story	10	10	100
Durability	10	7	70
Aesthetics	10	7	70
Prolong liftime (CE)	10	7	70
Safety	5	10	50
Ease of use	5	6	30
Max score	50	-	**390**

Table Q3: Criteria for weighted criteria for concept 3

Selection criteria	Weight of criteria	Score [1/10]	Weight x Score
Message/Story	10	9	90
Durability	10	9	90
Aesthetics	10	8	80
Prolong liftime (CE)	10	8	80
Safety	5	10	50
Ease of use	5	8	40
Max score	50	-	**430**

DESIRED CHARACTER

Form collage **durable**



Appendix S| Full programme of requirements

Category	ID	Requirement
General Requirements	GR1	The maximum weight of a single pannier is 5.5 kg.
	GR2	The maximum target production cost is 200 Euros per single pannier.
	GR3	The maximum dimensions of the LSS are 500mm x 330mm x 450mm.
	GR4	The consumer price of the LSS without luggage rack is lower than 1200 Euros.
	GR5	It is essential that a USB charger and light are integrated into the LSS.
Storage Capacity	SC1	The LSS must have a luggage storage capacity of 30 Litres.
	SC2	A pannier in the LSS must be able to store 10 kg of luggage.
	SC3	External attachments must be connectible to the exterior of the LSS to increase storage capacity.
Weather Resistance	WR1	The LSS must be weatherproof up to IP65 standard. (6 stands for Dust tight. 5 stands for Protected against water jets from any angle.)
	WR2	The LSS must remain weatherproof after event of a stationary and/or low speed incident.
Durability	D1	The LSS must be able to withstand vibrations from the engine in normal riding situations.
	D2	The LSS must be able to absorb impacts without major deformations when subjected to falls from standstill up to speeds of 30 km/h.
	D3	The sacrificial parts must be able to absorb and protect the core functions of the LSS in when subjected to falls from standstill up to speeds of 30 km/h.
	D4	The LSS must be able to withstand at least 5 of the D3 types of impact.
	D5	The rider must be able to temporarily repair any damage sustained damage while on the road and be able continue their journey.
	D6	The sacrificial parts of the LSS must be able to withstand damage from the side, underside, and front.
Security	S1	It is essential that the LSS is lockable in order to prevent theft and to ensure the safe storage of items.
Prolong Lifetime	PL1	The types of connections used must be re-usable.
	PL2	Priority parts must be completely removable and replaceable.
	PL3	The absorbent and protective parts must be replaceable with the use of basic tools. (EN45554 Norm)
	PL4	It is essential that maintenance manuals are easily accessible
	PL5	Spare parts must be available via official BMW channels.
	PL6	BMW Motorrad must provide a repair service for the LSS.
Modularity	M1	It is essential that the LSS functions effectively with and without the soft bag.
	M2	The LSS must be suitable for use as a camp chair, table or workbench.
Ease of Installation and Removal	IR1	It is vital that the LSS includes a secure and tool-free mounting mechanism that allows for rapid attachment and detachment from the motorcycle.
Compatibility	C1	The LSS must be designed to securely fit on the luggage rack of the BMW R 1300 GS Adventure.
	C2	The LSS must be designed to fit on the adaptor plate, making it possible to mount the LSS to the luggage rack of the BMW R 1300 GS.
Design and Aesthetics	DA1	The LSS must fit in with the aesthetics of the BMW R 1300 GS Adventure's styling.
Ease of Use	EoU1	The user must be able to open the LSS while wearing gloves.
	EoU2	The base of the luggage system must be flat.
	EoU3	The opening of the pannier must have a minimum dimension of 250mm x 300mm.
	EoU4	It is critical that the location of the USB charger remains easily accessible at all times, from when the LSS is empty to when it is fully loaded.
Rider Safety	RS1	It is vital that contact between the rider, and possibly the passenger, and the LSS is made with soft, deformable materials in order to reduce the risk of injury in the event of a fall or crash.
Ergonomics	E1	The LSS must be used comfortably by a single rider in a seated and standing position.
	E2	The LSS must be used comfortably with a duo riding setup without the LSS intervening with the seating comfort of the rider and/or passenger.

Appendix T | Materials

Al 6061 - Core structure

	Aluminium, 6061, T4, wrough	(Granta Edupack, 2023)
Material family	Metal	Non-ferrous
Price	2.74 - 2.77	EUR/kg
Young's modulus	66.6 - 70	GPa
Yield strength	110 - 145	Mpa
Tensile strength	206 -240	MPa
Elongation	16 - 23	% Strain
Fracture toughness	30 -36	MPa.m^0.5
Toughness (G)	13.3 - 18.9	KJ/m^2
Metal cold and hot forming	Excellent	
Metal press forming and metal deep drawing	Acceptable	
Weldability	Good	
Durability	Water (fresh), Weak acids, Strong acids, UV radiation (sunlight)	Excellent
Recycle	YES	

TPU - Protective parts

	TPU (Ether, aromatic, Shore D55)	(Granta Edupack, 2023)
Material family	Elastomer	thermoplastic, TPE
Price	3.11 - 4.36	EUR/kg
Young's modulus	0.148 - 1.152	GPa
Yield strength	14.6 - 15.4	Mpa
Tensile strength	47.3 - 53	MPa
Elongation	421 - 464	% Strain
Fracture toughness	2.05 - 2.07	MPa.m^0.5
Toughness (G)	27.9 - 28.7	KJ/m^2
Polymer injection molding	Acceptable	
Polymer extrusion	Excellent	
Durability	Water (fresh), Water (salt),	Excellent
	Oils and fuels	Acceptable
	UV radiation (sunlight)	Fair
Recycle	YES	