



DESIGNING BEYOND FIRST USE

A Circular Strategy for Ski Boots

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Master Thesis

Delft University of Technology
MSc. Integrated Product Design

Designing Beyond First Use: A Circular Strategy for Ski Boots

MSc. Graduation Thesis
April, 2026

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ABSTRACT

The winter sports industry depends on stable climatic conditions, yet its equipment, infrastructure, and travel systems contribute significantly to environmental degradation. Ski boots exemplify this contradiction: although engineered for durability, they typically pass through only a single ownership cycle, destroying substantial embodied value. This is reinforced by combining components with different lifespans into a single product, where the faster-degrading parts determine when the boot is replaced.

This thesis explores how a circular business model can enable economically viable value retention for ski boots, and which product adaptations are required to support such a system. The research combines literature review, product disassembly, life cycle assessment, expert interviews, and quantitative user surveys to identify the key barriers to circularity.

The findings reveal that 84% of a ski boot's environmental impact is generated during production, while its most carbon-intensive component, the shell (hard outer boot), remains structurally functional well beyond its typical use phase. Yet boots are frequently replaced prematurely due to liner (soft inner boot) degradation, comfort loss, and perceived obsolescence. Together, these dynamics reveal five systemic tensions: mismatched component lifespans, aesthetic value loss, lack of lifecycle control, limited return infrastructure, and ownership structures that discourage reuse. Rather than addressing these in isolation, they form the foundation for an integrated product–service system.

The thesis proposes a circular model in which the durable shell is retained and redistributed across multiple use cycles, while the liner remains a personal component. Once a shell no longer meets the demands of its initial use, it does not lose its value; instead, it is reassigned to a context where its performance still meets user needs. Value is captured through controlled refurbishment, performance-based grading, and structured return mechanisms. Deliberate product adaptations are introduced to make the system viable, including reversible connections that enable the replacement of high-wear components and design interventions addressing aesthetic degradation.

The thesis shows that value retention is not limited by technical feasibility, but by system design, ownership structures, and user perception. Circular value retention emerges not from isolated product improvements, but from the integration of product, business model, and system design. Design, therefore, plays a key role in reshaping how value is created, maintained, and recaptured over time.

PREFACE

Growing up in Austria, skiing has always been a big part of my life, and it still is today. I started skiing when I could barely walk, on a small slope my parents groomed in front of our house for my sister and me. Ever since, I look forward to the first snowflakes falling each year so I can finally bring out my skis again.

But in recent years, skiing has started to feel different. Green landscapes with a white stripe in between, temperatures that are far too warm, and seasons that feel shorter and less predictable. The environment is changing, and with it, the sport I care so deeply about is no longer guaranteed for tomorrow.

This thesis grew out of that realisation. It is an exploration of how design can contribute, even if only a little, to making sure that skiing can still exist for generations to come.



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List of Abbreviations

ACL – Anterior Cruciate Ligament

CO₂e – Carbon Dioxide Equivalent: a standard unit for measuring greenhouse gas (GHG) impacts, converting emissions of different gases (like methane, nitrous oxide) into the amount of carbon dioxide that would have the same warming effect, based on their Global Warming Potential (GWP) over a set time (usually 100 years).

CMF – Colour, Material, Finish

CSRD – Corporate Sustainability Reporting Directive

DPP – Digital Product Passport

EPR – Extended Producer Responsibility

ESPR – Ecodesign for Sustainable Products Regulation

GRF – Ground Reaction Force

ISO – International Organization for Standardization

LCA – Life Cycle Assessment

PP – Polypropylene

SBTi – Science Based Targets Initiative

SIA – Snowsports Industries America

TPU – Thermoplastic Polyurethane

Note to the reader:

CO₂ is written without subscript throughout this thesis for readability.

INTRODUCTION

chapter 1

"The future of skiing is at stake. And since the climate crisis poses such a clear and urgent threat to the winter sports industry, it makes sense that those within it should show clear commitment to reducing our impact."

- Atomic Impact Report 2024

1.1 CONTEXT AND BACKGROUND

Climate protection and adaptation to climate change rank among the greatest social, economic, and technological challenges worldwide. Sports tourism often depends on the natural environment, yet it frequently causes ecological harm (Malasevska et al., 2023). Among all forms of tourism, the winter sports industry holds a unique place in the climate crisis. Ski resorts visibly display the effects of global warming: glacial retreat, unpredictable weather, and rising temperatures highlight the impacts of climate change in action.

At the same time, ski tourism attracts 300 - 350 million skier visits annually, making it a multi-billion-dollar market (Steiger et al., 2019). A paradox emerges: while skiers rely on specific climatic conditions, their activities contribute to the very challenges that threaten the sport's future (Bischof et al., 2017). One of the contributions to this tension is illustrated by the equipment demand as climate change, resource depletion, and loss of biodiversity are accelerated by the linear consumption pattern of our take-make-waste economy (The Circular Economy in Detail, 2019). 16% of the carbon footprint of a skiing day is linked to gear (Utopies, 2025), and the global market for winter sports equipment is forecast to reach 1.7 billion U.S. dollars by 2028 (Statista, 2025).

Human pressure on the environment through resource extraction and waste is widely recognised. The circular economy offers a way forward by reducing waste and maximising resource efficiency (Velenturf & Purnell, 2021). In skiing, equipment producers play a decisive role, as frequent replacement driven by wear, fashion, or technological updates has a significant impact. Companies such as Atomic Austria GmbH could reduce this burden by rethinking business models and product life cycles. Since 80% of a product's environmental impact is determined at the design stage (Ellen MacArthur Foundation, 2022b), integrating value retention strategies from the outset is essential.



Figure 1: Winters without snow (Wermuth, 2023)

About Atomic

Atomic Austria GmbH is the world’s biggest ski producer. The main manufacturing site is in Altenmarkt, Austria. With two additional production facilities in Romania and Bulgaria, Atomic Austria distributes skis, boots, helmets, goggles, and apparel across 49 countries worldwide (Atomic Austria, 2025).

In 2022, Atomic set out to reduce its overall impact using the Science Based Targets Initiative (SBTi). Atomic’s long-term goal by 2050 is to drive skiing toward climate neutrality by cutting emissions to a small number of residual emissions that can be absorbed and durably stored by nature. By 2030, Atomics’ goal is to reduce CO2 emissions by 50% across all its products. Despite ongoing initiatives such as encouraging suppliers to switch to renewable energy, converting one production site to run fully on renewables, and redesigning two ski models, there is still a gap of around 28% to meet the targeted reduction in Scope 3 emissions. Scope 3 emissions refer to indirect greenhouse gas emissions generated across the value chain, both upstream (supplier) and downstream (customer), which are not directly controlled by the company.

The ski boot accounts for 41% of all Atomic’s sold goods (Figure 2) and therefore represents a critical leverage point for reducing Scope 3 emissions (Atomic Internal, 2025; Atomic Sustainability Impact Report 2024, 2024). Closing the remaining gap demands more than efficiency improvements; it requires a structural rethink of how ski boots are produced, used, and kept in circulation. This challenge defines the central focus of this thesis because “Time is running out.”

“There is no skiing without snow. Tomorrow, there can be no true performance without sustainability. Sustainable performance can and must inspire radical innovation.”
- Atomic Impact Report 2024

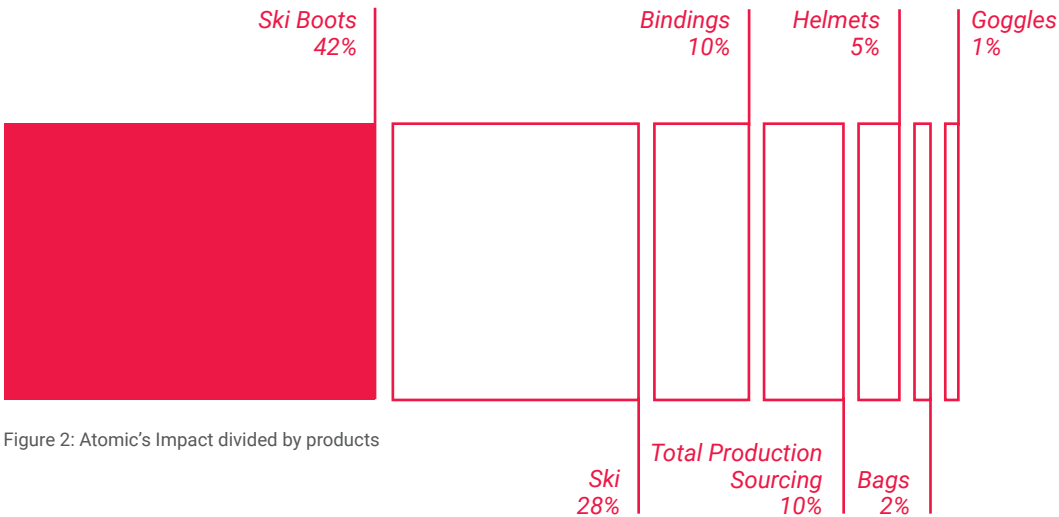


Figure 2: Atomic's Impact divided by products

1.2 RESEARCH AND DESIGN QUESTIONS

This report addresses the central design question:
How can a circular business model for ski boots enable economically viable value retention, and what product adaptations are necessary to support its implementation?

It establishes a strategic foundation for this business model and examines how product design, user behaviour, and system conditions must align to enable its practical implementation. To support this design objective, the thesis is guided by four research questions:

RQ1 – Boundary Conditions
What technical, safety, and regulatory requirements define the boundary conditions for redesign?

This question ensures that any proposed business model and product adaptation remains realistic. Ski boots must withstand high forces and comply with ISO standards. Understanding these boundary conditions prevents circular ambitions from compromising performance, safety, or compliance.

RQ2 – Loss of Value in the Current System
Where is embodied value currently lost across the ski boot lifecycle, and which product characteristics limit economically viable value retention?

This question identifies where value is currently lost in the linear system and why. By analysing lifecycle stages, durability, and product construction, it reveals which characteristics prevent repair, refurbishment, or cascade usage, and where interventions are most impactful.

RQ3 – User Feasibility
How do user behaviours and perceptions influence the feasibility of a circular ski boot business model?

This question explores whether a circular model would work in practice. User decisions about replacement, resale, hygiene, and participation in return systems directly affect value retention.

RQ4 – Economic and System Viability
What economic and system conditions must be met to make value retention economically viable at scale?

This question examines whether the proposed model can function beyond a conceptual idea. Refurbishment costs, logistics, ownership structures, and stakeholder incentives must align for value retention to be viable.

1.3 APPROACH AND METHODOLOGY

The ski boot industry operates in a technically demanding environment where product performance, user behaviour, and circular-economy ambitions overlap. To answer the research questions, a mixed-method approach was applied. The methodology combines theoretical analysis with empirical research to understand the problem from product, user, and system perspectives.

This section provides an overview of the applied methods. The detailed description of each method is presented within each chapter.

1. Literature Review

An exploratory literature review was conducted to build the theoretical and technical foundation of this thesis. Academic sources on ski boot biomechanics, safety standards, circular economy principles, and policy developments were analysed using the AI-based platform Consensus to identify and synthesise relevant scientific publications.

2. Qualitative Empirical Research

2.1 Internal: Multiple semi-structured interviews were conducted with experts at Atomic across product development, quality management, sustainability, materials, and advanced research. These interviews provided in-depth insights into internal processes, durability testing, material choices, lifecycle challenges, and strategic considerations. A significant share of the practical and technical insights presented in this thesis originates from these internal interviews, which are referenced throughout the main text.

- J. Roe: Business Unit Manager Boots (October 10, 2025)
- F. Lindebner: Quality Manager, R&D Boots (November 7, 2025)
- T. Howle: Design Manager Boots (November 12, 2025)
- A. Hochreiter: Sustainability Specialist (November 27, 2025)
- R. Schwarzenbrunner: Sustainability Manager (November 6, 2025)
- H. Holzer: Director Anticipation & Advanced Research (throughout)
- A. Magnetti: Material Scientist & Development of durability standard (throughout)
- F. Rieder: Manager R&D Liner (January 25, 2026)

2.2 External: Four expert interviews were conducted with retail and rental operators in the Pongau area. These conversations provided practical insights into customer behaviour, repair practices, rental fleet management, replacement patterns, and end-of-life handling. The names of the shops are not disclosed to protect their privacy.

- Rental and Retail 1 (October 27, 2025)
- Rental and Retail 2 (November 11, 2025)
- Rental and Retail 3 (December 2, 2025)
- Rental and Retail 4 (December 12, 2025)

3. Contextual industry Research

Industry field research was conducted through participation in two summits. At ISPO Munich (December 1, 2025), three sustainability talks in the outdoor sports industry were attended, offering insights into current challenges, material innovations, and strategic approaches. At the Climate Summit in Bolzano (January 14-15, 2026) discussions and

presentations on circular business models and best practices from other companies offered broader system-level perspectives.

4. Quantitative Empirical Research

Three quantitative online surveys were conducted. The first survey focused on ski boot ownership, replacement behaviour, repair practices, and end-of-life decisions. The second survey explored rental motivations, second-hand perceptions, and purchase barriers. The third survey aimed to understand how people perceive used and new ski boots.

5. Research-through-Design

Design is used as a research-through-design approach, where knowledge is generated through iterative exploration, prototyping, and testing of concepts. This enables exploration of user behaviour, technical feasibility, and system viability.



Figure 3: ISPO Munich 2025



Figure 4: Climate Summit Bolzano 2026



Figure 5: Talk at Climate Summit Bolzano 2026

1.4 SCOPE

This thesis has been developed in collaboration with Atomic Austria GmbH. Consequently, their ski boot designs serve as the foundation for this research. The study primarily focuses on recreational ski boots, with particular attention to the Atomic HAWX series for adults, including the Hawx Ultra, Hawx Prime, and Hawx Magna models (Figure 6). These three models share similar construction characteristics; the key distinction lies in the variation of their fit width.

This research takes a forward-looking perspective, exploring architectural and business model innovations that may extend beyond Atomic's current operating model. The research sets out to inspire.



Hawx Ultra

A forefoot width of less than **98 mm** is considered narrow.



Hawx Prime

Shells with a width of around **100 mm** are considered medium.



Hawx Magna

A forefoot width of **102 mm** and above is wide.

Figure 6: Atomic Hawx Range (How to Find the Right Ski Boot Size | Atomic International, 2023)

1.5 CIRCULAR VALUE RETENTION STRATEGIES

A core principle of the circular economy is to circulate products and materials at their highest value, keeping them in use for as long as possible rather than turning them into waste. In the technical cycle, this means prioritising maintenance, reuse, repair, and refurbishment before considering remanufacturing or recycling. Recycling remains important, but it is the last step, as much of the embedded value is lost once a product is broken down into raw materials.

Designing products for value retention requires designing them not only for one linear life, but for several lives. This means enabling durability, easy disassembly, repair, and component replacement, so that products can remain whole and functional within the system for as long as possible (Ellen MacArthur Foundation, 2022a).

DESIGN CONSTRAINTS FOR CIRCULAR TRANSFORMATION

chapter 2

This chapter defines the technical boundary conditions for circular transformation. It examines the construction of the ski boot, the forces acting on it during use, and the biomechanical requirements related to performance and injury prevention that must be considered in any redesign.

It also outlines the relevant industry standards and regulations that need to be met. Together, these factors establish the non-negotiable constraints within which redesign must operate.

The chapter, therefore, addresses the following research question:
RQ1: What technical, safety, and regulatory requirements define the boundary conditions for redesign?

To answer this question, a literature review was conducted using Google Scholar and Consensus. Search strings like these were used: (“ski boot” OR “ski boots”) AND (“contact forces” OR “axial load” OR torsion); “alpine ski boot” AND (bending OR torsional) AND (injury OR safety). Further literature was identified through the reference lists of papers found with the search strings.

Ski boots are important equipment in alpine skiing. They provide protection, performance, and comfort. They protect the foot and lower leg from environmental and mechanical stresses while transmitting forces efficiently to the ski via the binding system, which is essential for control and stability during skiing (Corazza & Cobelli, 2005; Honert et al., 2023; Petrone et al., 2013).

Alpine ski boots are generally classified into three main constructions: overlap, cabrio, and rear-entry designs. The overlap construction is the most widely used and is typically associated with controlled piste skiing, while cabrio designs are often used in freestyle disciplines. Rear-entry models are mainly found in children’s boots (Colonna et al., 2013). Since this thesis focuses on the Atomic “Hawx Range”, which features an overlap design, the report will primarily examine that design.

Each boot component is made from a specific material and joined using metallic or plastic fasteners, with material choices and design optimized to ensure precise load transfer, quick and safe binding engagement, shock absorption, injury prevention, and overall comfort through even pressure distribution and climate regulation within the boot (Colonna et al., 2013).

2.1 KEY INDICATORS OF SKI BOOT

*“A ski boot should feel like a firm handshake – not too tight, not too loose.”
- How Ski Boots Should Fit – Expert Tips on Fit, Comfort and Performance, n.d.*

Choosing the right ski boots is primarily based on four key indicators: size, last width, flex index, and intended skiing discipline (How to Find the Right Ski Boot Size | Atomic International, 2023).

Size
Size is based on foot length in centimetres. Two sizes usually share the same shell, with small adjustments made through insoles to adjust the volume accordingly.

Flex
Flex describes how stiff the boot is when leaning forward. A higher flex means more resistance, leading to more precise power transfer and control, but less comfort and forgiveness. Lower flex is softer and easier to handle, especially for less experienced skiers. Flex is influenced by material choice and thickness, overall shell construction, and additional components, such as the number of buckles and strap stiffness. The flex index is not a standardised value, and each manufacturer defines it differently (What Is Ski Boot Flex? | INTERSPORT Rent, 2021).

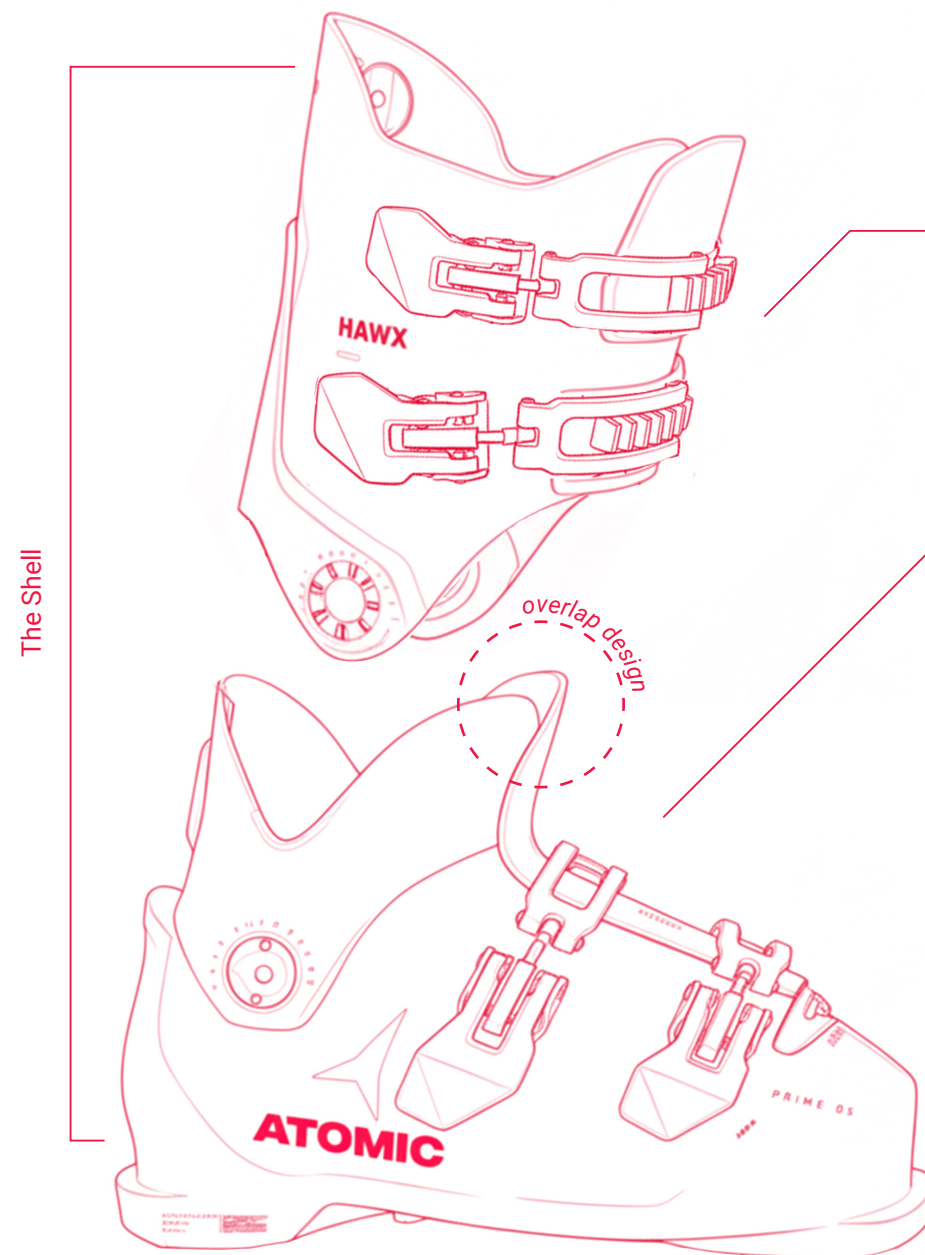
Last
Last refers to the internal width of the boot at the forefoot. It determines how tight or wide the boot feels and is key for fit, comfort, and control (How to Find the Right Ski Boot Size | Atomic International, 2023).

Discipline
Different skiing styles require different levels of stiffness, comfort, and features. The boot should match the skier’s ability, weight, and intended terrain (What Is Ski Boot Flex? | INTERSPORT Rent, 2021).

2.2 SKI BOOT COMPONENTS

In 1960, the first fully plastic ski boot was introduced. Early challenges related to low-temperature resistance were resolved in the following years, and by 1966, mass production of plastic ski boots using the overlap construction began (Colonna et al., 2013). Around the same period, levered buckle systems were invented, marking a significant development in closure mechanisms (Colonna et al., 2013). Although the materials, comfort, safety, and ergonomics of ski boots have continuously improved, the fundamental construction of the ski boot has remained unchanged over time and across manufacturers. Manufacturers differentiate themselves through boot fit and material combinations. In the following section, the main components of a ski boot are explained in detail (Figure 7, 8 and 9).

*“There is a lot of sameness in the market.”
- J. Roe, personal communication, October 10, 2025*



The Shell

The ski boot shell, also called the outer shell, serves as the rigid external structure that encloses the foot and lower leg. Its primary function is to transmit the skier's movements precisely to the ski, enhancing control and responsiveness. It also protects the foot and ankle from external impacts. (Colonna et al., 2013; Pulse Boot Lab & Ski Co., 2023). The shell is composed of two main parts: the lower shell, which surrounds the foot up to the ankle, and the upper cuff, which wraps around the lower leg.

Cuff

The Cuff is crucial for transferring forces from the leg to the ski. Its height and angle influence the skier's force and control. The stiffness of the boot (Flex) is largely determined by the hinge system connecting the cuff to the lower shell and directly affects the efficiency with which power and movement are transmitted from the skier to the ski (Colonna et al., 2013; Petrone et al., 2013).

Shell

The shell plays a key role in transmitting force from the foot to the ski. Its internal shape is vital for both comfort and performance. The shell can be adjusted through heat moulding or grinding to relieve pressure points. Its design should minimize pressure peaks to avoid pain or numbness, while maintaining a snug fit for optimal control (Colonna et al., 2013; Honert et al., 2023).

Material: The shell and cuff at Atomic are made from TPU and recycled TPU. Kids' boots and beginner boots are made from PP (Atomic Internal, 2025).

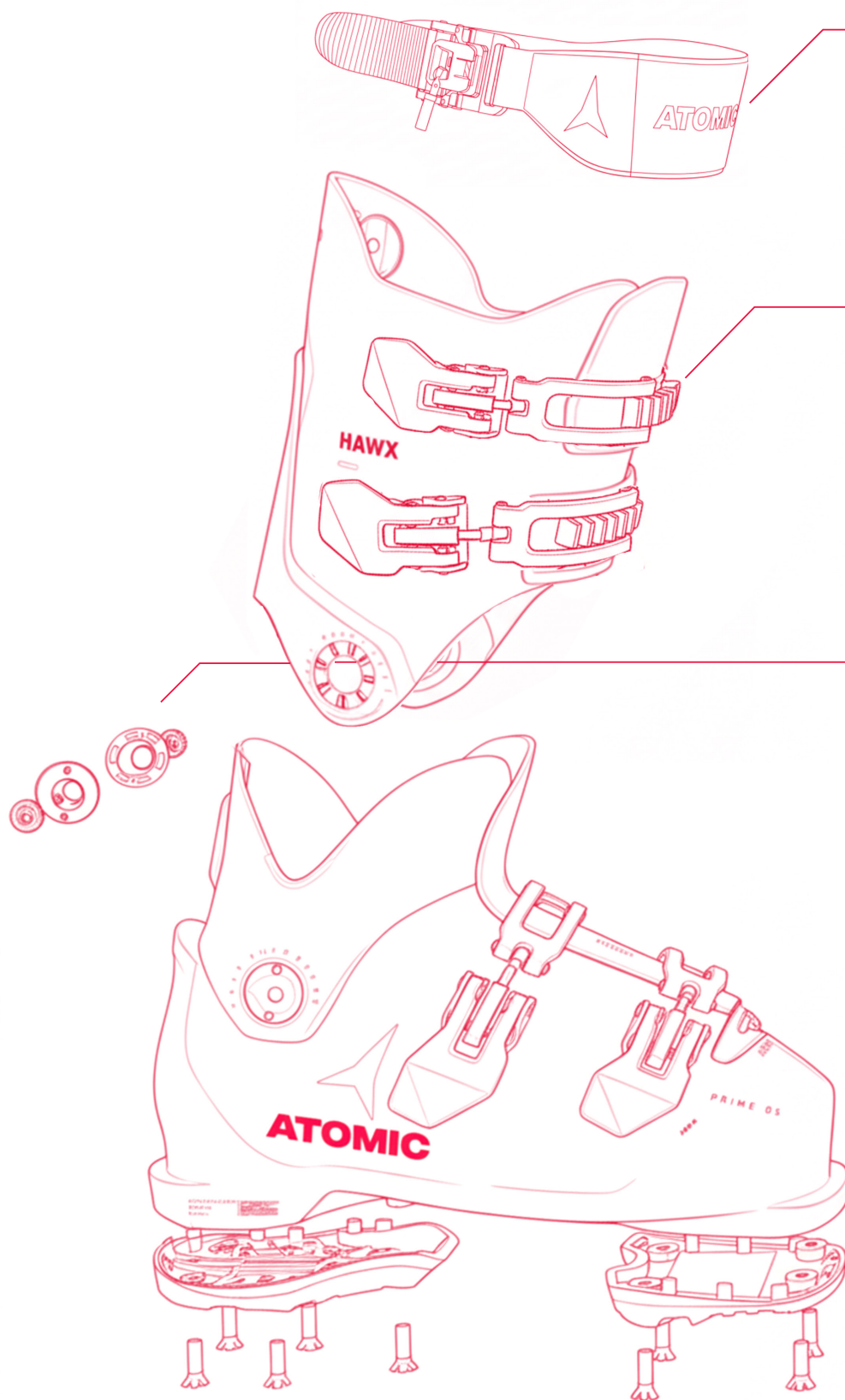


Figure 8: Outer shell components (own visualisation partly created with the use of AI)

Power strap

The Power strap is at the top of the boot and used to tighten the top of the boot to the leg. This helps transfer energy from the lower leg through the spine of the boot, where most of the boot's strength is (Pulse Boot Lab & Ski Co., 2023).

Material: Polyester, nylon and elastane for the fabric parts. Aluminum and steel for the metal parts (Atomic Internal, 2025).

Buckles with tooth plates

Buckles serve as the primary closure system for ski boots, securing the hard plastic shell tightly around the foot and lower leg. This snug fit is essential for precise force transfer and effective control (Honert et al., 2023).

Most boots feature four adjustable buckles, allowing fine-tuned customization to accommodate various foot shapes and preferences. Buckle tension influences pressure distribution; improper tightening can lead to discomfort, pain, or circulation issues (Honert et al., 2023).

Material: Aluminized steel (Atomic Internal, 2025)

Cuff alignment

The Cuff Alignment is also referred to as canting, which involves adjusting the angle of the ski boot's upper cuff in relation to the lower shell and the skier's lower leg. This adjustment compensates for anatomical differences, such as varus (bow-legged) or valgus (knock-kneed) leg alignments. Incorrect alignment may force the knees into unnatural positions, potentially increasing the likelihood of knee-related injuries (Böhm & Senner, 2008).

Material: Aluminium (A. Hochreiter, personal communication, November 27, 2025).

Grip pad/sole

Grip pads provide extra grip while walking on icy or hard surfaces. They also prevent excessive wear on the boot sole, which is important for maintaining proper binding compatibility (Atomic Internal, 2025).

Ski boot soles must comply with ISO standards to ensure safe interaction with bindings. In alpine skiing, soles are rigid and made from the same material as the shell. ISO 23223 and ISO 5355 define the geometry, hardness, and interface features for different types of ski soles, enabling consistent fit and reliable release across boot and binding manufacturers for normal ski soles. This standardization helps prevent lower leg injuries by ensuring proper retention and release during falls (Colonna et al., 2013; International Organization for Standardization, 2025; Österreichisches Normungsinstitut, 2006).

Material: TPU and fiberglass (Atomic Internal, 2025)

The Liner

Liners, also called inner boots, are made to provide thermal insulation, cushioning, and comfort to the leg. The tongue of the liner transfers the force of the skier to the shell and the ski, since this is the part that is in direct contact with the skier's leg. The liner is placed inside the hard outer shell and can be removed in seconds without a tool (Colonna et al., 2013). The liner consists of multiple glued or sewn components. The front opening allows entry, while a stiffer tongue transfers force to the shell and ski. The upper section is more rigid for support, and softer foam areas provide insulation and cushioning (Colonna et al., 2013).

Material: The Liner is often made from up to 30 different fabric raw materials, resulting in up to 200 material mixes (A. Hochreiter, personal communication, November 27, 2025)

The shell and liner are always sold together. The only exception is when upgrading to a higher-quality or custom-fitted liner, which can be bought separately (chapter 3.1.4). The shell is never sold on its own.

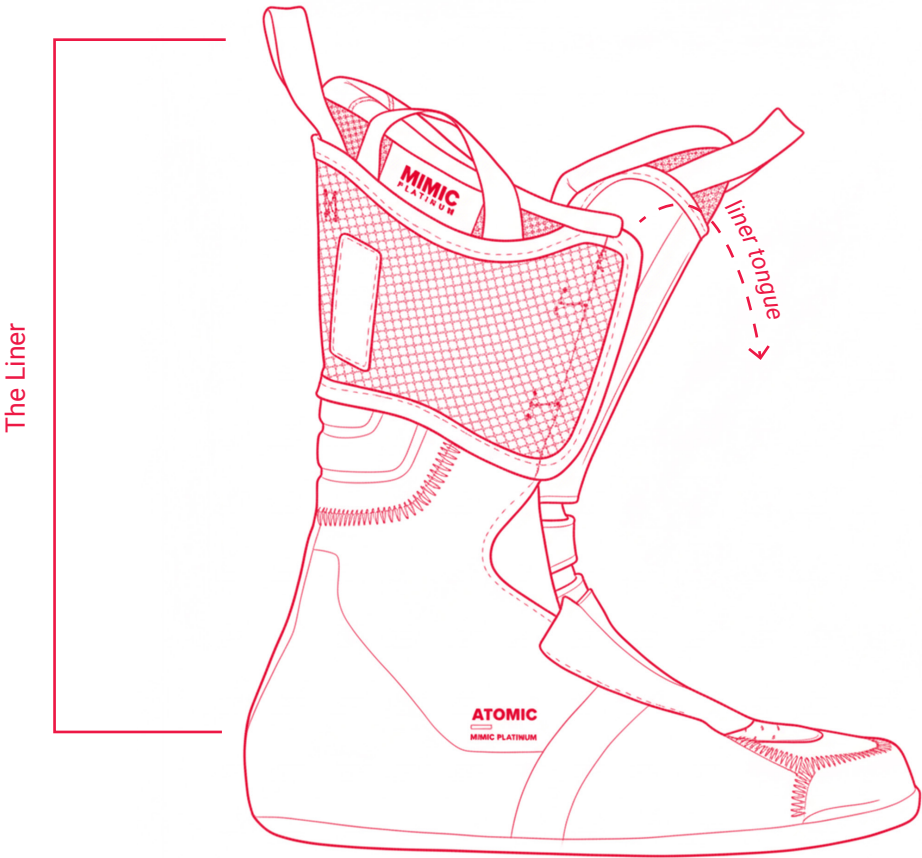


Figure 9: Liner (own visualisation partly created with the use of AI)

2.3 BIOMECHANICS AND FORCES

Ski boots are engineered to efficiently transfer forces between the skier and the ski, making them a critical interface for both safety and performance (Nimmervoll et al., 2021). In the context of ski boots, performance is primarily defined by how precisely and consistently forces can be transmitted, enabling control, responsiveness, and stability during skiing.

Performance is often simplified and communicated through the flex index, which indicates the boot's resistance to forward bending and serves as a representation for stiffness and responsiveness. However, this metric captures only one aspect of performance. Studies like Honert et al., (2023); Nimmervoll et al., (2021); Zullo, Cibir, Bortolan, et al., (2023) indicate that alpine ski boots are exposed to a variety of complex forces and are a dynamic blend of high-magnitude ground reaction forces driving performance, structural moments (bending and torsion) that define control, and localised internal pressures that govern fit and comfort, all while maintaining the capacity to resist acute impact and overload forces during a fall.

The tight and restrictive construction of the boot, particularly around the ankle, plays a crucial role in managing these loads. As the ankle joint cannot move freely, forces from the skier's leg are redirected through the upper structure of the boot and into the shell. During skiing, these interactions can reach several thousand Newtons, especially during dynamic manoeuvres such as aggressive turns (Nimmervoll et al., 2021).

As performance directly affects control, safety, and user confidence, it becomes a critical factor in how ski boots are judged and selected, making it central to any strategy aiming to retain value beyond first use.

2.4 SAFETY AND INJURY PREVENTION

Alpine skiing involves a considerable risk of injury, with the knee being the most affected joint and ACL injuries among the most common (Colonna et al., 2013; Davey et al., 2018; Spörri et al., 2017). The ski-binding-boot system plays a central role in this risk, as it governs how forces are transmitted between the skier and the ski.

While release bindings have improved safety by detaching the boot under excessive load, most knee injuries occur while the skier remains connected to the ski (Spörri et al., 2017). In these situations, injury mechanisms are closely linked to how forces are transferred through the boot. In particular, forward force transmission from the boot to the tibia can contribute to ACL injuries during landings or loss of control (Davey et al., 2018; Spörri et al., 2017).

This highlights a trade-off: increased stiffness and direct force transmission enhance control and performance, but can also elevate injury risk by increasing loads on the knee. Conversely, softer boots may reduce harmful forces but compromise performance. When discussing ski boot performance, it is inherently linked to safety, as the "right" boot must match the skier's skill level to reduce injury risk.

2.5 STANDARDS AND REGULATIONS

The only norms for ski boot design are ISO 5355 and ISO 23223, which regulate the boot–binding interface, as the geometry and rigidity of this contact area are critical to ensuring the binding can release the boot effectively during a fall. To maintain proper release function and skier safety, alpine ski boots must conform to strict dimensional and structural specifications at this interface (Colonna et al., 2013; International Organization for Standardization, 2025; Österreichisches Normungsinstitut, 2006).

2.6 CONCLUSION

Alpine ski boots operate under high, highly variable mechanical loads that directly affect safety, control, and comfort. Bending moments, torsional forces, axial loads, and ground reaction forces are concentrated in the shell due to restricted ankle mobility, making structural integrity and controlled stiffness essential. At the same time, the boot must ensure reliable force transmission and safe interaction with the binding system, in compliance with ISO 5355.

Across manufacturers, the fundamental overlap construction and force-transfer principles have remained largely unchanged for decades, reflecting their proven performance and safety requirements.

To answer RQ1: What technical, safety, and regulatory requirements define the boundary conditions for redesign?

The boundary conditions for redesign are defined by three non-negotiable factors: mechanical load resistance (chapter 2.3), the ability to control stiffness for injury prevention (chapter 2.4), and strict compliance with binding interface standards (chapter 2.5). Consequently, circular redesign does not require a fundamental reinvention of the core architecture, but rather identifies the specific product adaptations necessary to enable new value-retention strategies within these established structural constraints.

With these boundary conditions defined, the question shifts from how the boot functions to how value is currently lost within this established architecture.

DIAGNOSING VALUE RETENTION IN THE CURRENT SYSTEM

chapter 3

Sustainability is a complex topic, and truly sustainable solutions cannot be developed without a holistic perspective—one that considers the product, its users, and the wider system in which it exists (Designing Sustainable North Stars, 2024).

Enabling circular value retention requires understanding how and where value is currently created, preserved, and lost across the lifecycle of a ski boot. Rather than viewing sustainability as an isolated material issue, this analysis examines the product, the user, and the wider system as interconnected layers that shape the boot's time in circulation.

The graphic outlines the current lifecycle of a ski boot across product, user, and system levels, providing a foundation for the analysis in this chapter.

Building on this overview, the chapter examines the product itself, user behaviour, and the wider system conditions in greater detail. By considering these interconnected levels, it reveals where embodied value is maintained, diminished, or irreversibly lost, and highlights opportunities to extend the boot’s time in circulation. The analysis begins at the product level, examining material composition, construction, and durability of the ski boot.

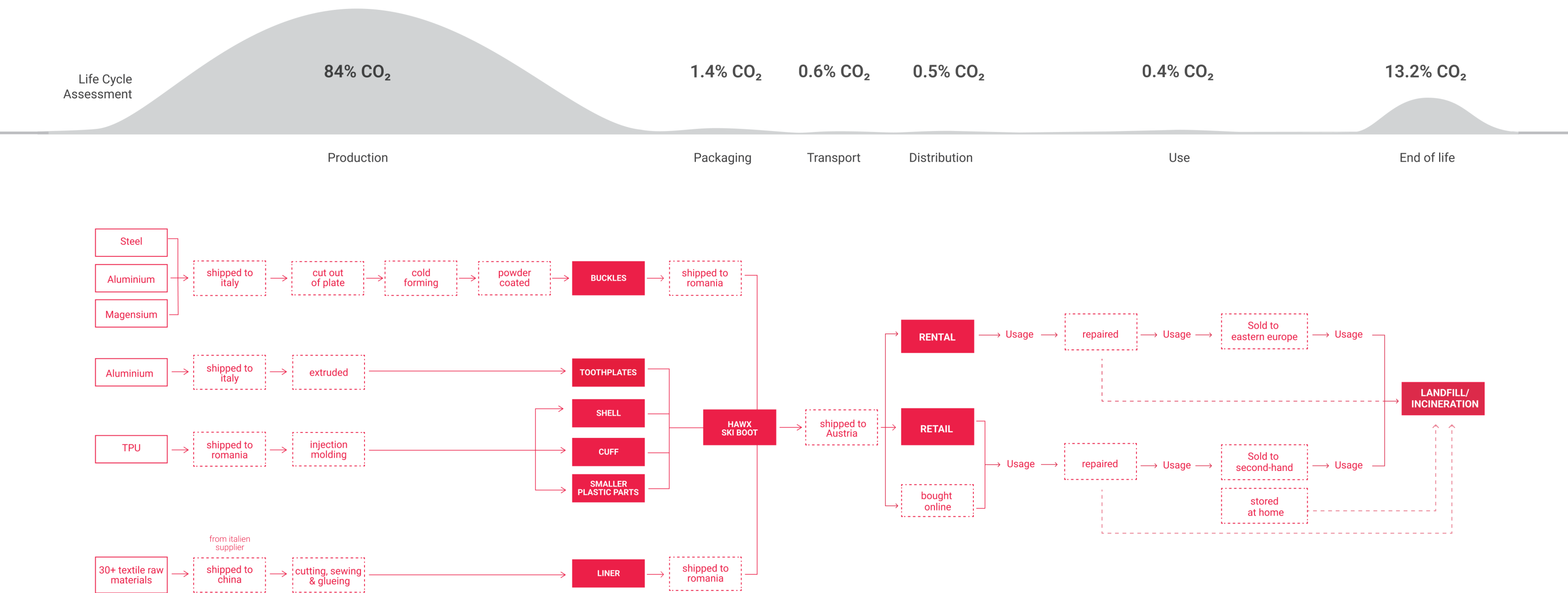


Figure 10: Linear Product Journey

3.1 PRODUCT-LEVEL OPPORTUNITIES FOR VALUE RETENTION

Each year, approximately 3.6 million pairs of ski boots are manufactured globally, and most are discarded as waste once they reach the end of their useful life. This results in an estimated nine million kilograms of plastic waste being sent to landfills or incinerated annually. Consequently, the materials embedded in these products are permanently removed from the raw material cycle (Sporting Goods Recycling, n.d.). To understand how this loss occurs at the product level, the following research question is addressed:

RQ2: Where is embodied value currently lost across the ski boot lifecycle, and which product characteristics limit economically viable value retention?

To answer this question, different research Methods were applied:

A product disassembly was conducted to understand product architecture and component connections. This was complemented by analysis of existing LCA data and testing protocols at Atomic, as well as internal expert interviews with the LCA expert, ski boot quality manager, and a durability specialist. Findings were supported by insights from industry discussions at ISPO Munich 2025.

3.1.1 ENVIRONMENTAL HOTSPOTS

To identify the environmental hotspots within an Atomic ski boot, a lifecycle assessment (LCA) of the Hawx Prime 130, a boot used by advanced skiers, was analysed and complemented with discussions with Atomics’ sustainability specialist (Atomic Internal, 2025; A. Hochreiter, personal communication, November 27, 2025).

The LCA indicates a total carbon footprint of 35.53 kg CO2 equivalent per boot under a conventional linear ownership scenario. In this scenario, one boot is produced, used by one skier for an average lifetime of approximately 100 ski days (reference value Product Environmental Footprint Category Rules - PEFCR), and then incinerated and metals landfilled.

The distribution of emissions across the lifecycle stages is highly concentrated in the production phase, which accounts for 84% of the total emissions (29.73 kg CO2e). The impact is primarily driven by raw material extraction and energy-intensive manufacturing processes (Figure 11).

The end-of-life stage represents the second-largest share at 13.2%, reflecting the impact of disposal methods such as incineration or landfilling, along with associated transportation to waste facilities. All other lifecycle stages contribute marginally.

This distribution highlights an important insight: the majority of emissions are embedded before the boot is ever used. Therefore, environmental impact is strongly determined by how long the product and its components remain in circulation.

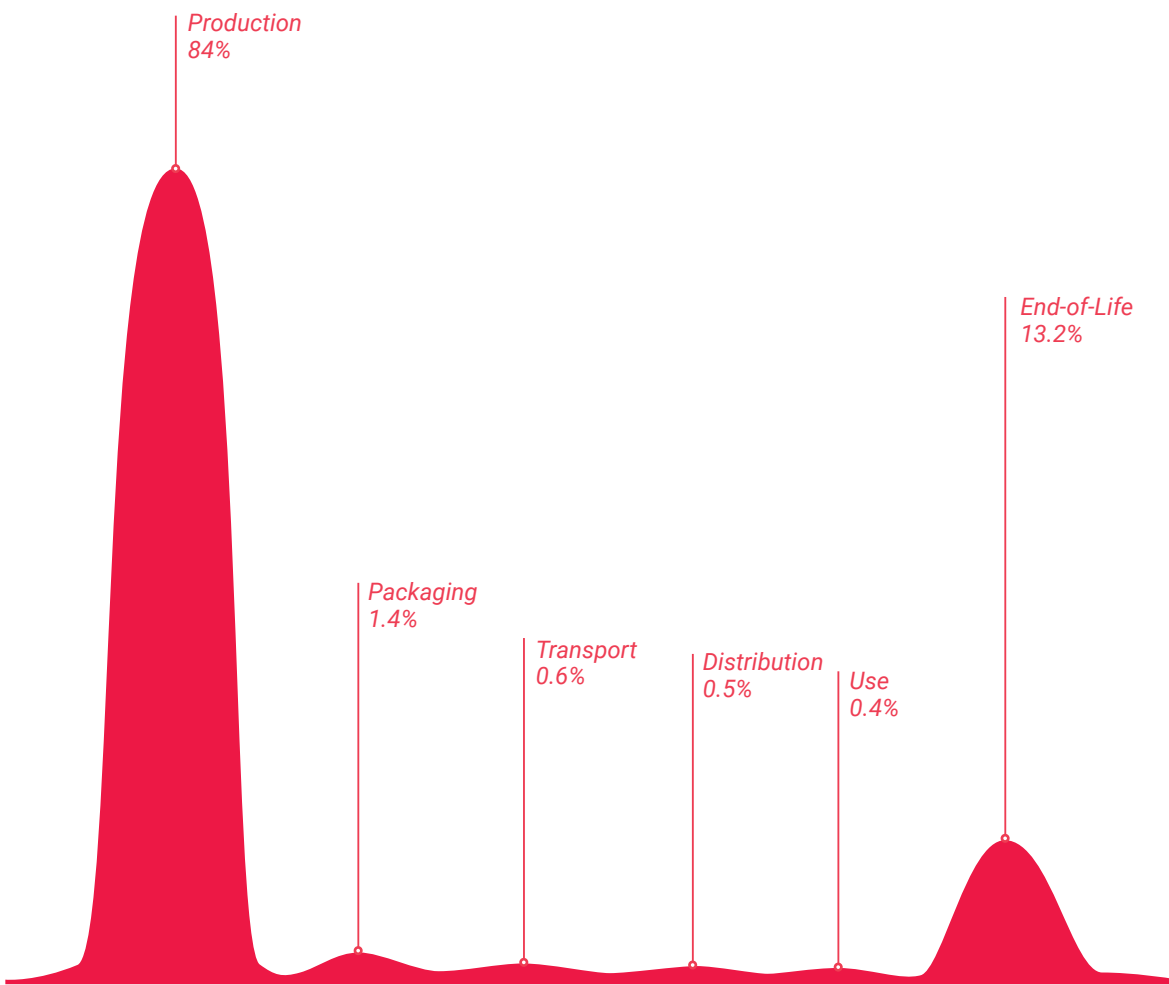


Figure 11: Life Cycle Assessment

Focusing on the production phase, which accounts for 29.73 kilograms of CO2 equivalent, the boot can be divided into two main components:

- the outer shell, which includes all hard components (Figure 12)
- the liner, which included mainly fabrics (Figure 14)

The shell accounts for the largest share, representing 84% of production emissions, equivalent to 24.73 kilograms of CO2, while the liner contributes 14%, or 4.01 kilograms of CO2. Although significant, the liner’s impact is much smaller than that of the shell. The remaining 2% of the CO2 impact is from waste treatment (Atomic Internal, 2025).

Environmental Hotspots in Shell Production

The total carbon footprint of the outer shell is 24.73 kilograms of CO2 equivalent is distributed across its individual components.

Within the shell, the buckles are the largest contributor, accounting for 35.7% of the shell's footprint, largely due to energy-intensive metals such as steel, aluminium, and magnesium. Atomic is currently unable to trace the origin of the raw materials. The U-shaped buckle design generates approximately one-third of production waste. Although this scrap is reportedly reused, it cannot be counted as recycled content in the LCA, as the external supplier cannot verify closed-loop reuse within Atomics' production.

Following the buckle, the shell (lower part of the outer shell) itself contributes 12% of the production emissions, and the cuff accounts for 10.6%. This is largely due to the outer shell being made from TPU, which is energy-intensive to produce, and the injection moulding process, which consumes substantial energy. It is the largest and heaviest component of the ski boot. The power shift contributes 7% of its impact, while smaller parts such as the toothplates, sole, and powerstrap screws account for 3.9%, 3%, and 2.1%. Auxiliary elements like nuts, hinges, and seals each contribute less than 1%, but together add complexity to the overall footprint.

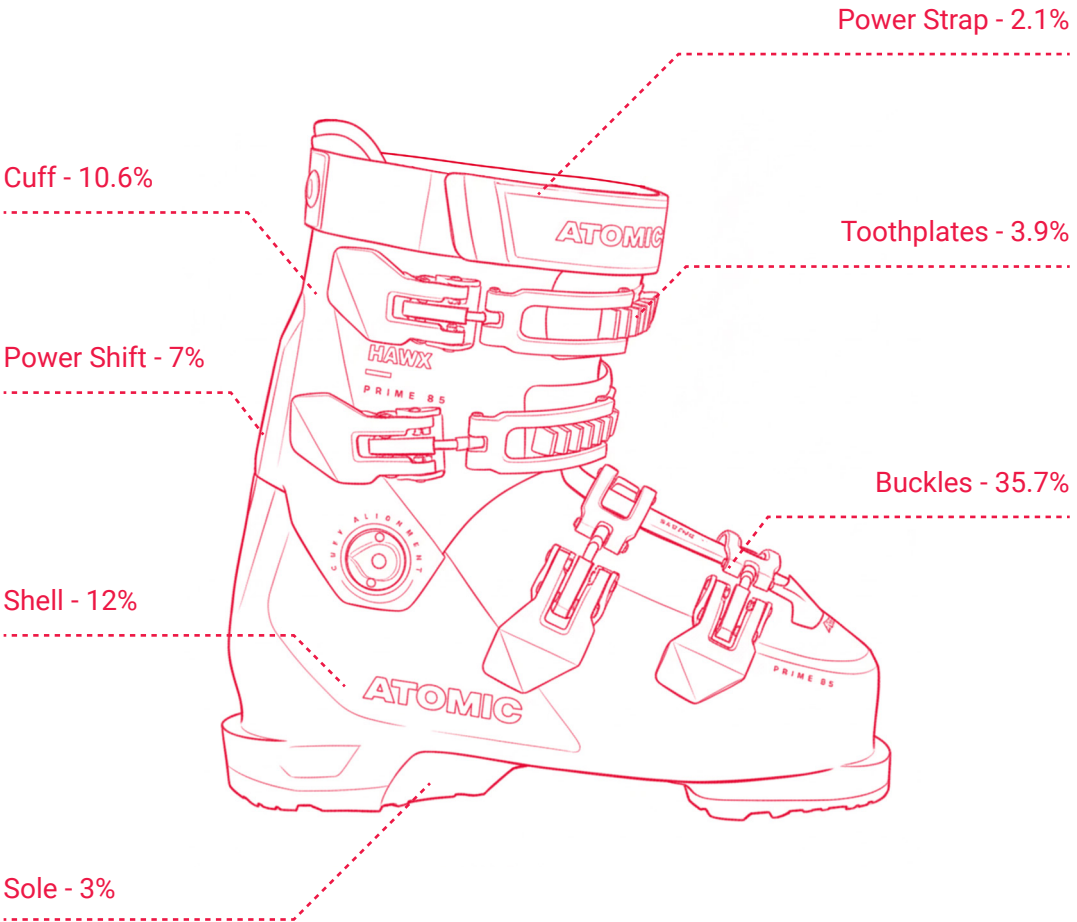


Figure 12: Carbon Footprint of the Shell Components

Environmental Hotspots in Liner Production

The liner is a highly complex component, consisting of more than 30 textile and foam raw materials, with up to 200 different material mixes in the final product. Although it is responsible for a smaller share of total emissions, it plays a decisive role in product replacement.

Within the liner, the “tongue injected part” and the “cuff liner” (see Figure 14), which are rigid plastic components that increase stiffness in these areas, are the largest contributors to the CO2 impact, accounting for 30.6%, equivalent to 1.23 kilograms of CO2. The fabric contributes 27.4%, the lining 19.4%, and the foam 11.4%. Smaller components, such as the sole and thread, contribute 3.7% and 2.2% respectively, and have minimal influence on the overall footprint.

Unlike the shell, the liner degrades relatively quickly due to foam compression and, therefore, loss of comfort and insulation.

Importantly, expert interviews, user surveys, and rental data indicate that the shell structurally outlives the liner in most cases. The liner degrades more quickly due to foam compression, resulting in reduced comfort and insulation. Shell failure is rare, and performance degradation occurs gradually rather than catastrophically.

This creates a mismatch: the shell, as the most carbon-intensive component, often retains functional capacity beyond the moment the product is discarded.

From a value-retention perspective, the shell represents stored embodied value that is currently underutilised, and the liner serves as a limiting component. It determines the perceived end-of-life of the entire boot, even though it represents a significantly smaller share of embodied carbon.

If the shell remains structurally intact while only the liner and high-wear parts are replaced, the embodied emissions of the shell can be distributed over a longer functional period. According to the Atomic Sustainability Impact Report, 2024 doubling the ski boot's life through liner or sole replacement reduces the overall environmental impact by 30.6%, despite additional transport and replacement parts.

3.1.2 PRODUCT ARCHITECTURE AND DISASSEMBLY CONSTRAINTS

Designing for circularity means keeping products in use for longer by repairing, refurbishing, remanufacturing, or reusing components. However, these strategies are only feasible if the product architecture allows them. In a circular business model, disassembly is not just a sustainability principle but a practical requirement. If components cannot be separated efficiently and without damage, value retention becomes economically unrealistic (Flipsen et al., 2020).

To understand whether ski boots can support such strategies, the current product architecture must be analysed. This was done using a disassembly map. This includes identifying which components and connections enable or limit non-destructive disassembly and future reuse.

As discussed in Chapter 2, the fundamental construction of ski boots has remained largely unchanged since the 1960s, with most competitors continuing to use the overlap construction. Given the limited variation in design approaches across the market, the decision was made to disassemble just one Atomic ski boot (Hawx Magna 80) to analyse and understand its product architecture. The goal of the disassembly was to disassemble the boot as far as possible to gain an understanding of how many parts the ski boot consists of, and which materials are used.

The ski boot consists of two main components: the soft fabric liner and the rigid outer shell. These can be separated in seconds, without any tools. Since it’s common to remove the liner to dry it after a day on the slopes, I will refer to the outer shell and liner as distinct components.

Disassembly Map

The Disassembly Map method visually captures a product’s components, their connections, and the order in which they can be taken apart. It helps evaluate how accessible a product is for repair, refurbishment, and material recovery, based on factors such as disassembly sequence, time, required tools, and fastener reusability (De Fazio et al., 2021).

The disassembly map on the next page (Figure 13) visualises how the ski boot shell is constructed, showing all components, their connections, and the sequence for taking the product apart. Due to the liner’s glued nature and the inability to separate all parts without destroying them, no disassembly map was created for the liner.

The map shows that the shell can be disassembled into individual parts relatively easily due to parallel sequences, allowing parts to be removed in any order. This simplifies repair, as there is no need to disassemble the entire product. However, the map also shows that the process depends on specific, high-force tools and is partly destructive, mainly due to riveted connections in the shell.

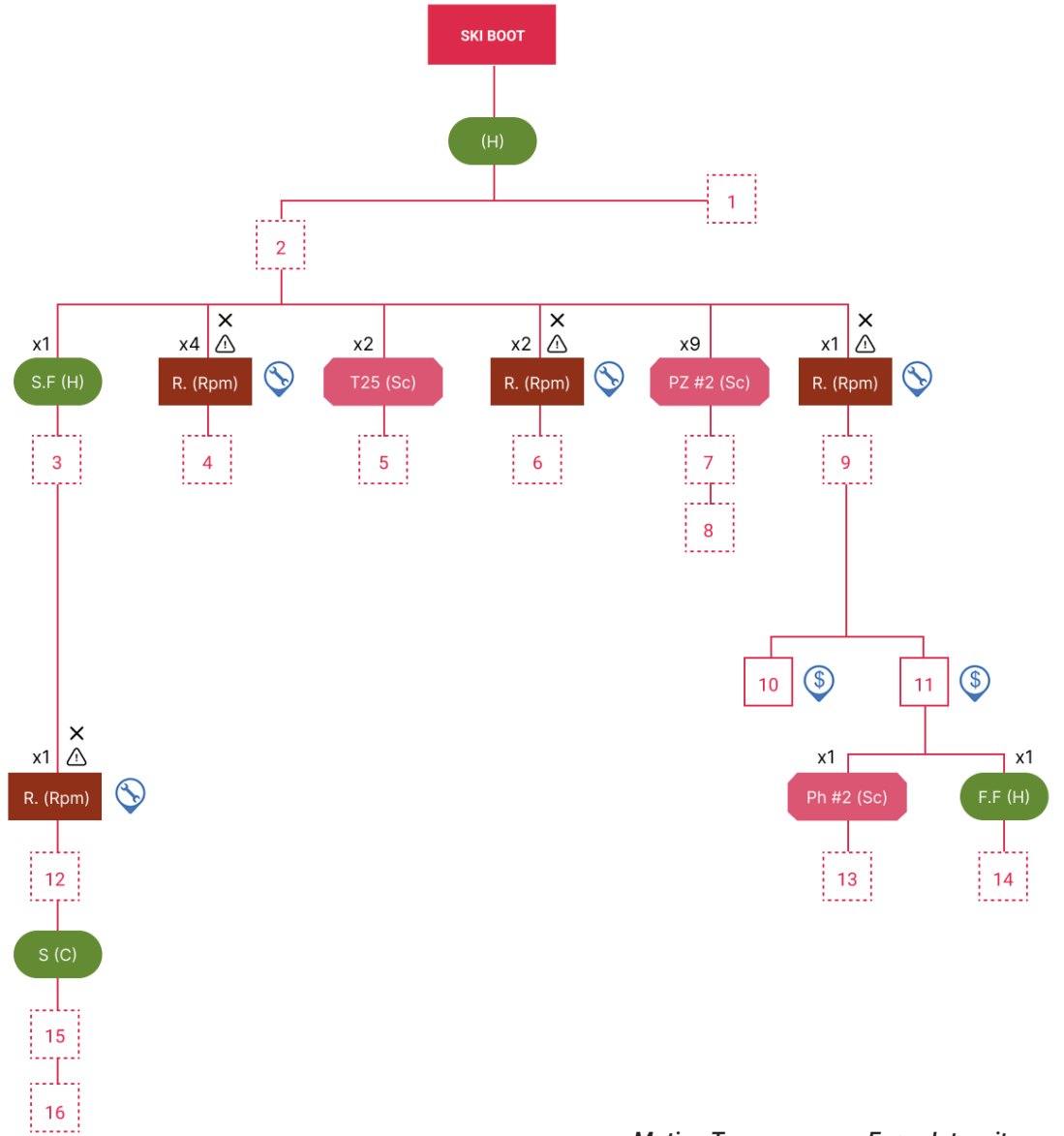


Figure 13: Disassembly Map

Product Parts

1. Liner

2. Outer Shell

3. Rear Spoiler

4. Buckles 4x

5. Toothplates Cuff

6. Toothplates Shell

7. Grip Walk Front

8. Grip Walk Back
9. Cuff Alignment

10. Cuff

11. Shell

12. Power strap

13. Insole

14. Tip Sealing

15. Metal Ring

16. Logo

1. Liner



Time spent	78 minutes for the whole boot
Tools needed	5 tools
Total parts	79 parts

2. Outer Shell



Figure 14: Hawx Magna 80 disassembled

The Shell

Most connections are straightforward to access and can be separated without difficulty. However, certain parts present challenges. Removing the cuff alignment system, which connects the cuff to the shell, along with all four buckles, the two shell-mounted buckle catches, and the power strap requires a rivet-punching tool. These components are riveted rather than screwed in most ski boots to reduce manufacturing costs. Additionally, a T25 screwdriver is required for the two buckle catches on the cuff, while a Phillips 2 screwdriver is needed to detach the grip walk elements at the front and rear, as well as the inner sole of the shell.

Challenges and limitations

The overall disassembly process is intuitive, with no hidden fasteners, adhesives, or unexpected obstacles. Nonetheless, the reliance on rivets as connectors introduces a significant limitation: rivets and the components attached to them cannot be reused once removed. Using a rivet-punching tool may also damage the shell or cuff, reducing the potential for part reuse or repair.

<i>Time spent</i>	16 minutes for first time attempt
<i>Tools needed</i>	3 tools: rivet punching tool, T25 and Philips 2 screwdriver
<i>Total parts</i>	48 parts with most connections being easy to access and separate



Figure 15: Shell Disassembly



The Liner

The disassembly of the liner is considerably more complex than that of the shell. There is no clear sequence of steps to follow, and the process is highly destructive. Glued areas often tear during separation, resulting in material damage and limiting the possibility of component reuse. As a result, many liner parts cannot be recovered for repair or even recycling in their current design as it is just too complicated and time intensive to separate the materials.

<i>Time spent</i>	62 minutes for first time attempt
<i>Tools needed</i>	2 tools: cutter knife, heat gun
<i>Total parts</i>	31 parts that are primarily stitched or glued together



Figure 16: Liner Disassembly



3.1.3 REPAIRABILITY AND REPLACEMENT PATHWAYS

The disassembly showed that the boot allows limited repair, although it was not explicitly designed for repairability. The external shell components can be repaired relatively easily if trained to do so, and if the liner begins to tear, it can be replaced, although repairing the liner itself is not possible.

For every Atomic ski boot model, spare parts remain available, even for discontinued products. The company offers a comprehensive selection of replacement components, including liners, buckles, power straps, grip pads, power shift mechanisms, cuff alignment elements, and soles (F. Lindebner, personal communication, November 7, 2025). However, Atomic does not currently put much emphasis on promoting these spare parts, and there is no clear system to help consumers identify which parts are compatible with their specific boots. Repairs must be carried out by authorised retailers, as Atomic is not permitted to sell parts that require tools directly to end users due to the absence of approved repair instructions. Currently, the liner is the only spare part that can be sold directly to consumers (H. Holzer, personal communication, October 2025; General Product Safety Regulation (2023) | EUR-Lex, 2024).

3.1.4 DURABILITY AND COMPONENT LIFESPAN

Most of a product’s environmental impact occurs before it even reaches the customer. 84% of the footprint of an Atomic ski boot arises during production. Extending the lifetime of existing boots and delaying replacement, therefore, has significant potential to reduce overall impact (Atomic Internal, 2025). But to extend the product lifetime, the product itself needs to be durable.

As sustainability shifts from aspiration to expectation, durability becomes central. It forms the foundation of circular economy strategies and creates a competitive advantage by building consumer trust (Gore-Tex, 2025). Durable products enable reuse, repair, and refurbishment, strategies that have a lower environmental impact than recycling alone. Durability depends on material properties, reliability, and repairability, which determine how long a product remains functional. (Mesa et al., 2022).

“Durability used to mean physical toughness. Today, it’s broader: it’s the ability of a product to stay functional, desirable, and repairable over time. It’s not just what it’s made of, but how it’s supported, and how it fits into someone’s life.”
- Thami Schweichler, founder of the United Repair Centre (Gore-Tex, 2025)

Component Lifetime

The average lifespan of a ski boot is approximately 100 days of skiing. Most skiers keep their boots for 6–7 years, but they can be used even longer. Ski boot wear is strongly influenced by the skier’s skill and intensity of use, as the user survey in the next chapter will reveal. The more advanced the skier, the higher the loads on their equipment, leading to faster degradation.

“Boots don’t get overused by the masses, and they are not done after 6-7 years. People just get tired of them.”
- J. Roe, personal communication, October 10, 2025

A key difference exists between the liner and the shell.

The standard liner, as it is sold with the ski boot, wears primarily from intensive use, so skiers who ski more than 50 days per year experience rapid degradation as the foam becomes thinner, starts to rip, and loses thermal insulation and damping, reducing comfort and warmth. Gradual wear is common, and for frequent skiers, the liner always wears out faster than the shell. Premium liners, often produced by specialised companies (Figure 18), are custom fitted using technologies such as heat moulding, foam injection (Figure 17), or adaptive materials. They offer significantly greater durability than standard liners, lasting up to three to five times longer, while typically costing as much as a full ski boot (Zipfit, n.d.).



Figure 17: Atomic Foam injected liner (HAWX XTD MIMIC PROFESSIONAL LINER, n.d.)



Figure 18: ZipFit Liner (ZipFit OMfit Cork Extra Tube | SP-11059-65, n.d.)

In comparison, the shell is much more durable because it is made from TPU. Its degradation is primarily caused by UV exposure, mechanical fatigue from repeated flexing, and freeze-thaw cycles (natural temperature fluctuations in which water freezes and thaws, causing expansion and contraction that damage materials). Ski boots rarely reach a true functional end of life, as performance degrades gradually rather than suddenly. Although properties such as flex decrease over time, shells largely maintain their structural integrity and do not compromise binding safety. (A. Magnetti, personal communication, November 10, 2025; F. Lindebner, personal communication, November 7, 2025; Retail and Rental 1, personal communication, October 27, 2025).

Failure parts

Complete failures are rare and typically occur only in localised areas. According to the Atomic Spare Part Database, GripWalk soles are the most frequently replaced component. This is expected, as they are designed to be replaceable in order to protect the shell and maintain binding compatibility. Components that are screwed on, such as the hinge alignment or buckles, are prone to loosening or loss over time (F. Lindebner, personal communication, November 7, 2025; Rental and Rental 1, personal communication, October 27, 2025). Therefore, having a boot that can be easily repaired is important for extending its lifespan.

Wear Patterns

Ski boot shells have structural durability that extends well beyond their current use phase. However, due to exposure to harsh conditions, they quickly show visible signs of wear, negatively impacting their perceived value, as further explained in the user analysis chapter. As illustrated in Figure 19 and 20, two rental boots used for 58 and 178 days show comparable levels of cosmetic degradation, primarily in the form of scratches on the shell and buckles, coating loss on the buckles, and a worn-out power strap. Despite this visual ageing, both boots successfully withstood a rear-impact test using a 27 kg pendulum, indicating that their functional integrity remains intact far beyond their perceived end-of-life.



This reveals a mismatch between perceived and actual condition: while aesthetic wear appears early and signals ageing to users, the shell's performance remains largely unaffected. Instead, it is the liner that degrades more rapidly and ultimately determines the product's functional lifetime.

An analysis of 20 used ski boots (see Appendix A) further shows that wear is not random but follows a pattern as the heatmap shows (Figure 21). High visual wear concentrates on the buckles, where coatings deteriorate quickly, as well as on the toe and heel due to walking and binding interaction. Additional scratches occur around the lower cuff through skiing contact, while the power strap gradually loses functionality over time.

Durability in ski boots is not only a structural question, but also an aesthetic one. While the shell remains functionally intact, visible wear limits its continued use. Extending the shell's lifetime, therefore, depends on addressing aesthetic degradation. As one expert states:

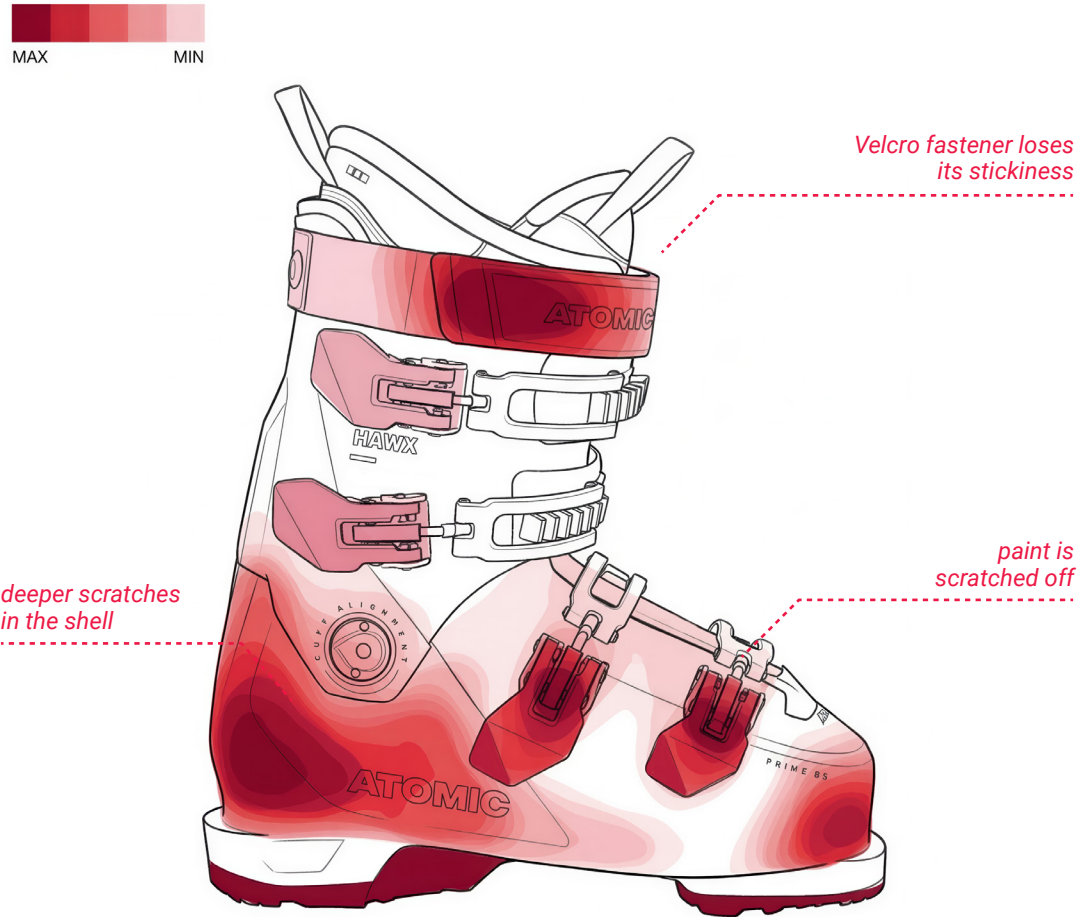


Figure 21: Wear Heatmap

"I don't think the customer is going to care about the flex if the boot looks beaten up, and we don't have a solution to make the outside of the boot look better again - that's the problem."
- J. Roe, personal communication, March 19, 2026

Durability Index

"Durability is often spoken about but rarely defined" (Gore-Tex, 2025). A major barrier to adopting durability in the outdoor industry is the lack of a standardised method to measure product lifespan. A durability standard would enable resale and rental businesses to compare products more meaningfully and help consumers make informed decisions beyond price, which does not necessarily reflect longevity (Gore-Tex, 2025).

At Atomic, durability is assessed through internal standards primarily aimed at minimising warranty claims, which are low at around 0.3%. Boots are routinely tested under impact conditions that exceed internal benchmarks, often by a factor of two, without failure. Currently, Atomic is exploring how to develop a durability index for ski boot shells, though this remains complex due to the many variables involved (Atomic Internal 2025).

3.1.5 CONCLUSION

The product analysis reveals that the ski boot itself is not short-lived. The shell, the most carbon-intensive component, remains structurally durable far beyond the point at which most boots are replaced. With 84% of emissions embedded in production, the majority of environmental impact is created before the boot is ever used.

To answer RQ2: *Where is embodied value currently lost across the ski boot lifecycle, and which product characteristics limit economically viable value retention?*

Embodied value is primarily lost due to a mismatch between component lifespans, product architecture, and replacement behaviour. The shell retains functional and environmental value longer than current use patterns allow. In practice, boots are rarely discarded because of shell failure. Instead, replacement is triggered by liner degradation, comfort loss, perceived performance decline, or psychological obsolescence. As a result, the shell, as the most carbon-intensive component, often outlives both the liner and the user’s willingness to retain the product (chapter 3.1.4).

Several product characteristics support this value loss. Riveted and partially destructive connections increase refurbishment effort and cost. At the same time, no solution currently exists to restore aesthetic wear on the shell, even though it is the main indicator for perceived remaining value. The liner’s multi-material construction prevents repair and material recovery. While component replacement is technically possible, it is not embedded in the current business model (chapter 3.1.2, 3.1.3, and 3.1.4).

The greatest circular opportunity, therefore, lies not in improving material efficiency alone, but in extending and restructuring how durability is retained.

3.2 USER-LEVEL OPPORTUNITIES FOR VALUE RETENTION

To design a circular business model for ski boots that enables economically viable value retention, it is essential to understand how users currently purchase, use, and replace ski equipment, and to design with existing user behaviour in mind, as “customer attitudes are vital to the achievement of a Circular Business Model”. Only then can a circular business model be functional (Mostaghel & Chirumalla, 2021).

Consumer insights from Snowsports Industries America (SIA), based on approximately 500 participants, reveal that replacement of worn equipment is the primary purchase trigger (63%). Although 54% considered sustainably produced gear somewhat or very important, only 9% intentionally selected sustainable options. Furthermore, 62% do not base their purchase decisions on sustainability, often because lower-priced alternatives are available. Notably, 59% of participants were unsure whether their products were sustainable at all.

Performance remains the dominant criterion for product success, with users most enthusiastic about improved responsiveness (83%), lightweight materials (49%), and extended product lifespan (44%). Cost emerged as the leading source of frustration when buying new gear (66%), whereas only 10% expressed dissatisfaction with the limited use of sustainable materials (Snowsports Industries America, 2024, 2025).

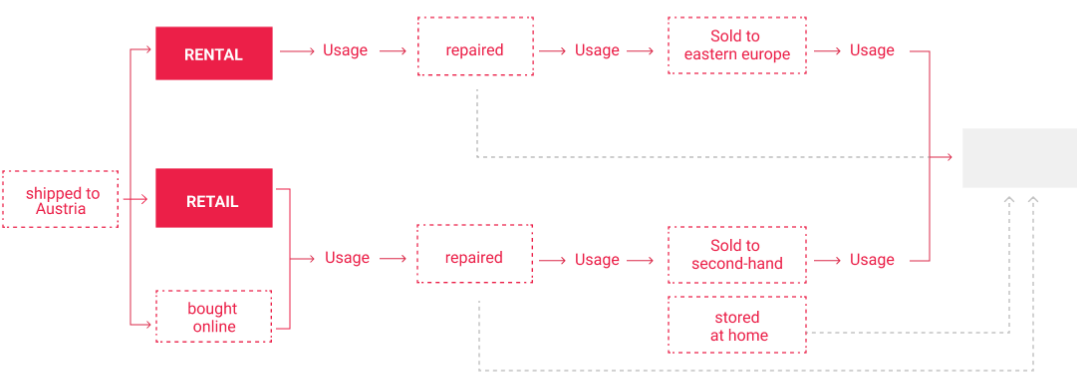


Figure 22: User level section of linear product journey

Approximately 25% - 30% of the Atomic Hawx range in Austria is distributed through rental, highlighting the coexistence of ownership and access-based models. Since usage patterns, wear, and end-of-life decisions differ between owned and rented boots, the following section distinguishes between the two user types. The following section will answer the question:

RQ3: How do user behaviours and perceptions influence the feasibility of a circular ski boot business model?

To answer this question, different research methods were applied:

1. **Literature review:** (skiing OR skiing industry OR winter sports) AND (consumer survey OR buying decisions OR market research)

2. **Three quantitative online surveys:**

2.1 The first survey aimed to examine user behaviour related to ski boot ownership, replacement, repair, and end-of-life practices. The survey consisted of 28 questions addressing usage patterns, purchasing decisions, repair experience, disposal behaviour, and attitudes towards circular models (see Appendix A). Data collection took place between November 21. to November 28 2025. The questionnaire was distributed through private networks and relevant Reddit forums. The final sample comprised 370 respondents. A pilot test was conducted prior to ensure clarity, logical flow, and alignment with the research objective. The data analysis was performed using Jamovi and Microsoft Excel.

2.2 The second survey was conducted to refine the findings of the first survey and to explore the underlying motivations behind renting and ownership, as well as to better understand the characteristics of each user group. The survey consisted of 11 questions for renters and 14 for owners. (see Appendix A). Data collection took place between February 6 to February 20 2026. The questionnaire was distributed through Wintersports.nl and relevant Reddit forums. The final sample comprised 134 respondents. The data analysis was performed using Jamovi and Microsoft Excel.

2.3 The third survey explored how visual appearance influences perceptions of new versus used ski boots and their perceived value. The survey consisted of 12 questions asking people to share their impressions between a used and a new ski boot just based on appearance (see Appendix A). Data collection took place between March 2 to March 13, 2026. The questionnaire was distributed through personal networks. The final sample comprised 10 respondents. The data analysis was performed using Microsoft Excel.

3. **Qualitative Interviews:** Four semi-structured in-person interviews in German were conducted in October and November 2025 with rental and retail shops in the Salzburg region. The selected shops represented different market segments, including high-end retailers and tourist-oriented rental providers. Interview durations ranged from 15 to 40 minutes. All interviews were recorded with participants' consent and transcribed for analysis.

3.2.1 USER SEGMENTATION

Skiing is a widely practised sport across Central Europe and North America, attracting participants with varying skill levels, usage intensity, and equipment expectations. Designing a circular system for ski boots requires understanding the different user segments to design for them.

Based on insights from the two quantitative user surveys and qualitative interviews, four primary user segments were identified (Figure 23). These differ in skiing frequency, equipment knowledge, performance expectations, and openness to rental models.



Figure 23: User Segments

1. High-Skilled Performance Skiers

This segment consists of highly skilled skiers who ski more than 20 days per season and possess strong equipment knowledge. It includes ski instructors, ski resort employees, and former racers.

They typically own their boots and are willing to spend money on the “perfect” boot. The boot gets replaced when they perceive a decline in performance rather than when structural failure occurs. Many ski multiple disciplines, such as touring and freeride, and therefore own multiple boots. Sustainability claims have low influence on purchasing decisions, while performance, precision fit, and reliability are critical. Refurbished equipment is often viewed with scepticism, particularly if performance consistency cannot be guaranteed.

“In my opinion, reworked ski boots only have an appeal if the shell didn’t stretch or soften, and the liner will be replaced.”
- Anonymous, Survey 1

“I like the idea of recycled materials; however, if I am being 100% honest with myself, I don’t think I would have bought upcycled boots knowing that I’ll keep them for years, and I want to put the money into good, long-lasting quality without any doubt.”
- Anonymous, Survey 1

Many in this segment use professionally boot-fitted systems, including aftermarket liners with foam injection or other custom-fit technologies tailored to the exact shape of their feet.

2. Skilled Recreational Skiers

This segment consists of skilled skiers with strong product awareness who ski approximately 10–20 days per season. Performance and comfort are the primary drivers in their purchasing decisions. They typically own their ski boots and are willing to invest in high-quality models that they expect to last for many years.

Replacement is rarely triggered by structural failure. Instead, boots are replaced once users feel they have “gotten their money’s worth” or believe it is time for a new pair. Durability is valued, but end-of-use is defined by subjective assessment rather than technical breakdown.

*“I did a personal boot fitting to find the right boots.
I have had my boots for 10 years”.*
- Anonymous, Survey 2

They show greater openness toward circular business models, as fit, consistency, and hygiene are guaranteed. They represent a potential transition segment between full ownership and controlled rental systems.

3. Holiday Skiers

This segment represents traditional “holiday skiers” who typically go on one or two ski trips per year for a couple of days. They are intermediate skiers and view equipment primarily as a means to be comfortable and capable on the slopes, rather than as a source of performance optimisation or technological advancement.

“It needs to fit and not break when I go down unprepared slopes.”
- Anonymous, Survey 2

Most do not live near ski areas and therefore often rent equipment. Cost and convenience dominate decision-making. Product knowledge is limited, and expectations focus on functionality rather than precision performance. This group shows low resistance to cosmetic wear and is already accustomed to rental models.

4. Beginners

This segment consists of beginners who have only recently started skiing. They show a strong preference for renting due to low commitment, limited equipment knowledge, and evolving skill levels. Ownership is rarely considered.

3.2.2 SKI BOOT OWNERSHIP

Beyond general insights on winter sports purchasing behaviour, there is limited reliable data on how long ski boots are used, why they are replaced, and what happens to them at the end of life. To address this gap, two quantitative surveys were conducted among skiers who own their ski boots, focusing on usage duration, replacement behaviour, disposal practices, and benefits and drawbacks. These findings were further supported by qualitative insights from four interviews with retailers and representatives from rental shops.

Demographics

Respondents to the first survey represented a wide range of ages and were geographically diverse. The largest share lived in Italy (35%), followed by the United States (26%) and Austria (14%). Smaller groups came from Switzerland, Canada, Germany, and other countries, each accounting for less than 8%. The largest group was aged 25 to 34, followed by 18 to 24, with smaller shares among older participants. Approximately 63% identified as male, 35% as female, and 2% as nonbinary. Most respondents described their skill level as expert, defined in the survey as confident on red slopes, capable on black slopes, and comfortable off-piste or in challenging terrain. A smaller portion identified as professional, such as ski racers or instructors, while fewer were intermediate or beginners. Skiing frequency also differed: most skied between 10 and 20 days per season (39%) or fewer than 10 days (26%), with some skiing 20 to 50 days and a few exceeding 50 days.

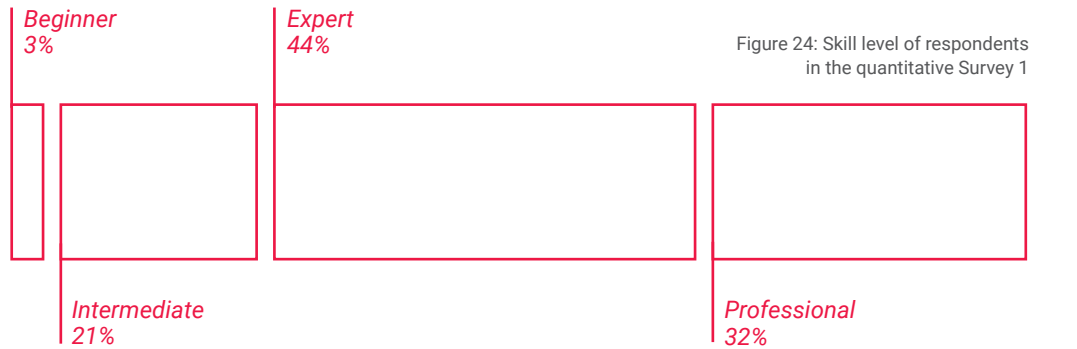


Figure 24: Skill level of respondents in the quantitative Survey 1

Respondents of the second group were predominantly based in the Netherlands (80%), with smaller shares from Germany (5%), Belgium (4%), and a few other European countries. The age distribution was concentrated in younger participants, with over half aged 18–24, followed by 25–34. 64% identified as male and 36% as female. Most respondents described themselves as expert (44%) or advanced (37%) skiers.

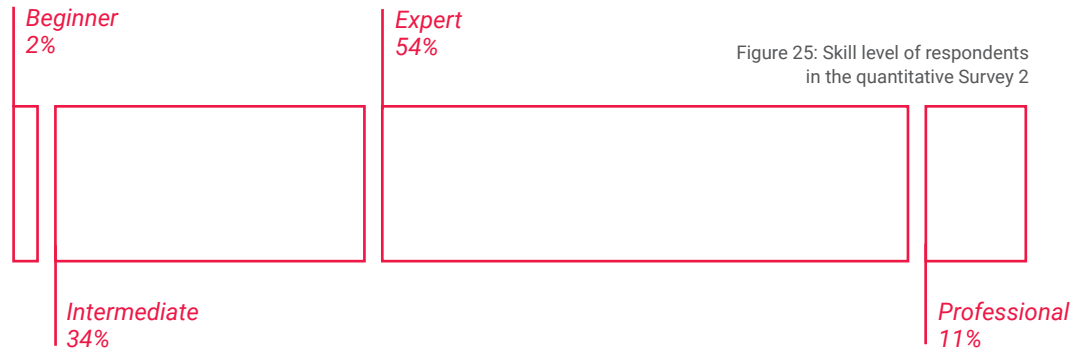


Figure 25: Skill level of respondents in the quantitative Survey 2

Ski Boot usage

Participants reported keeping their ski boots for an average of 5.08 years. Individual responses revealed two dominant patterns: many skiers replace their boots within five years, while others keep them for more than ten years. When asked about expected lifespan, respondents anticipated their boots lasting an average of 5.82 years, again showing a split between those expecting around 5 years and those expecting over 10 years.

Usage patterns varied by skier type. Occasional skiers, such as those who ski mainly during the Christmas holidays, often keep their boots for 6 years or more. In contrast, all-season skiers who spend over 50 days on snow typically replace their boots after about three years. Professional skiers, primarily instructors, replace their boots even more frequently, with 90% owning them for less than two years. Interestingly, one-third of intermediate skiers reported keeping their boots for more than ten years (Survey 1).



Figure 26: Ski Boots expected usage and actual usage

Drivers of Ski Boot Ownership

The decision to buy ski boots is primarily driven by fit and long-term value. “Better fit” was the main reason, selected by around 72%. Around 49% stated that owning is cheaper than renting in the long run. Performance-related motivations were also strong: 42% bought boots for better performance, and 38% for more consistency while skiing. More practical aspects played a secondary role, with 25% wanting to avoid time at the rental shop and 17% expressing hygiene concerns about previously worn boots. Overall, ownership is mainly justified through improved fit, performance, and perceived long-term cost efficiency (Survey 2).

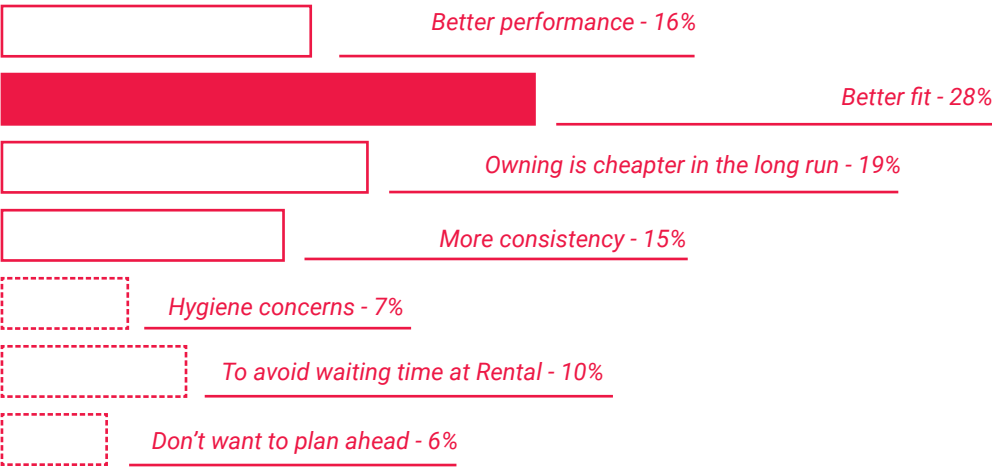


Figure 27: Reasons for ski boot ownership

Criteria for Ski Boot Selection and Replacement

When asked to rank factors influencing ski boot selection, respondents prioritized comfort above all, followed by weight and innovation. Brand and appearance were considered less important, while sustainability and the availability of spare parts for repairs ranked lowest (Survey 1). Despite comfort being the top selection criterion, 45% of respondents identified finding the right fit as the greatest difficulty during purchase. Secondary challenges included high upfront cost (14%), uncertainty about which boot matches one’s skiing style (11%), and the fact that boots feel different on the slope than in the shop (11%) (Survey 2).

In Survey 1, performance and comfort were described as the main reasons for purchasing a new boot. Performance issues were attributed to a loss of flex and rebound (reduced stiffness), while comfort decline was mainly due to the liner packing out, becoming thinner and colder, and creating pressure points. Survey 2 quantifies these drivers more clearly. The most frequently selected reason for replacement was “I had them for some years and felt it was time for new ones” (42%). Performance decline was cited by 23%, and comfort decline by 18%. Together, both surveys show that while performance and comfort matter, boots are often replaced based on when people feel it’s time, rather than actual technical need.

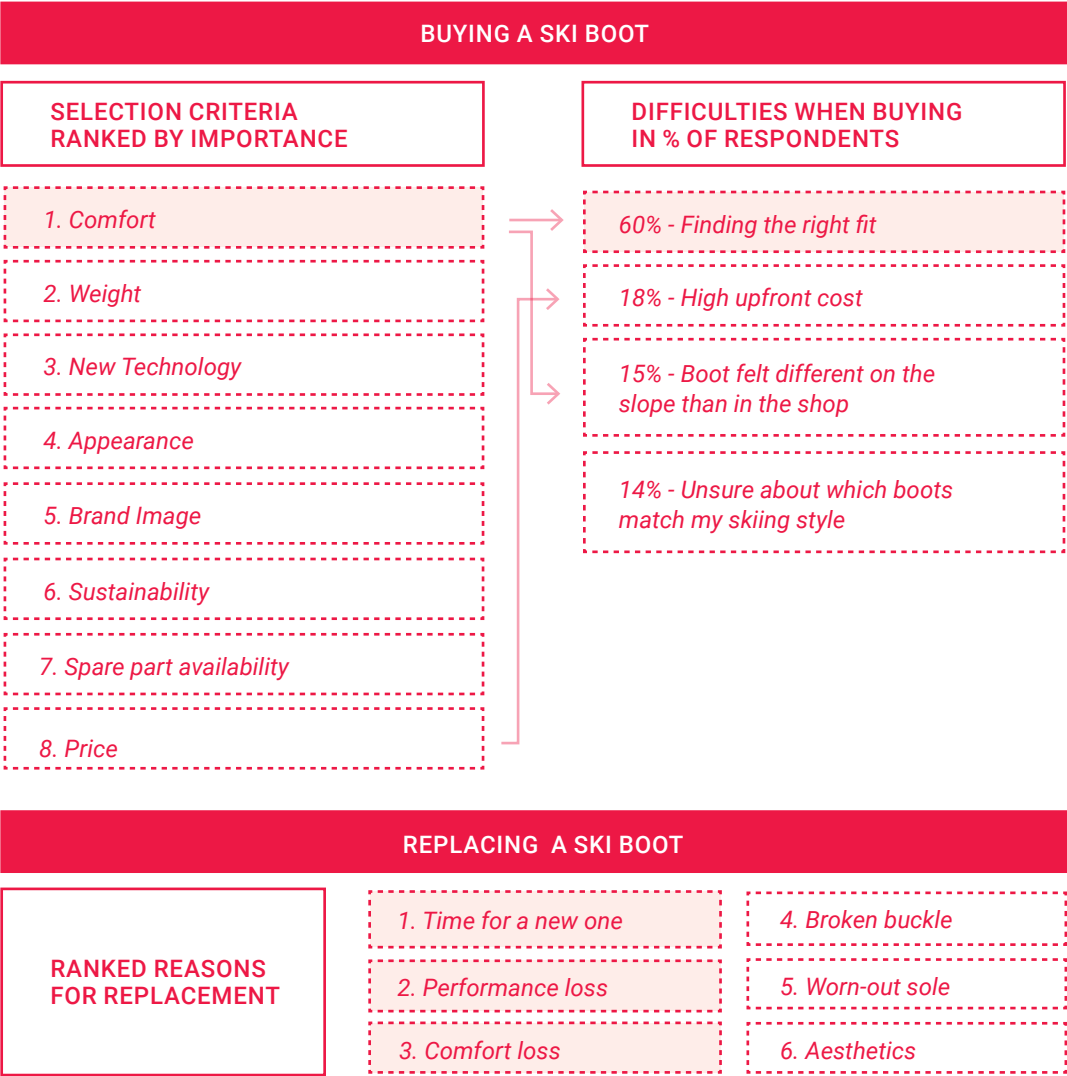


Figure 28: Ski Boot selection and replacement

Analysis of boot age at replacement reveals clear patterns. Boots discarded within five years were most often replaced due to performance issues, followed by comfort concerns. In contrast, boots kept for six to ten years or longer were typically replaced because owners perceived them as outdated and felt it was time for a new pair, although performance degradation also contributed to these decisions (Survey 1). These findings align with the retailer’s observations. One expert explained that “most of the time people buy a new ski boot even though their current boot is not yet at the end of its life” (Retail and Rental 1, personal communication, October 27, 2025). Another highlighted that older boots often become less stiff, and users are motivated by the desire to try something new (Retail and Rental 2, personal communication, November 11, 2025).

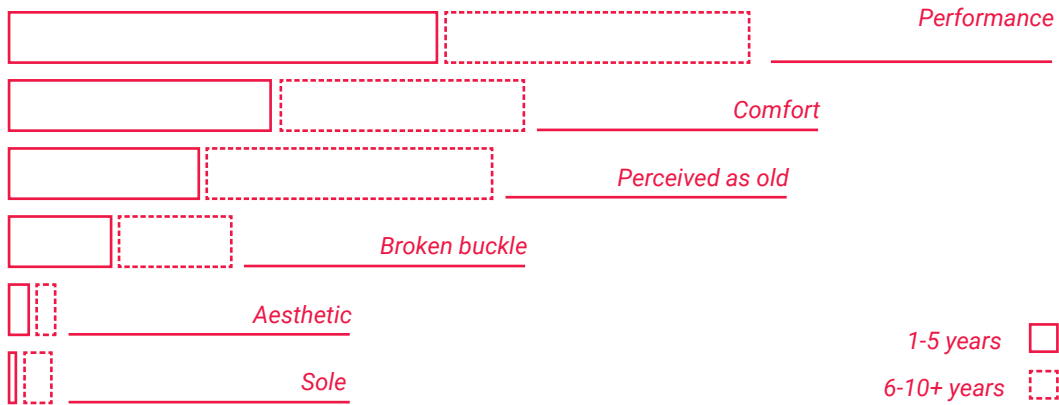


Figure 29: Reasons why people change their boots based on the age of their ski boot

After exploring why people purchase new boots, the survey examined what happens to the old ones. The findings show that most respondents either store their old boots at home or sell them, each accounting for 27% of responses. 19% reported discarding them, while 14% gave them away for free. Returning boots to a dealer was rare. About 10% selected “other” and mentioned reasons such as keeping boots for spare parts or using them as backups for guests. These responses largely align with the existing categories (Survey 1).

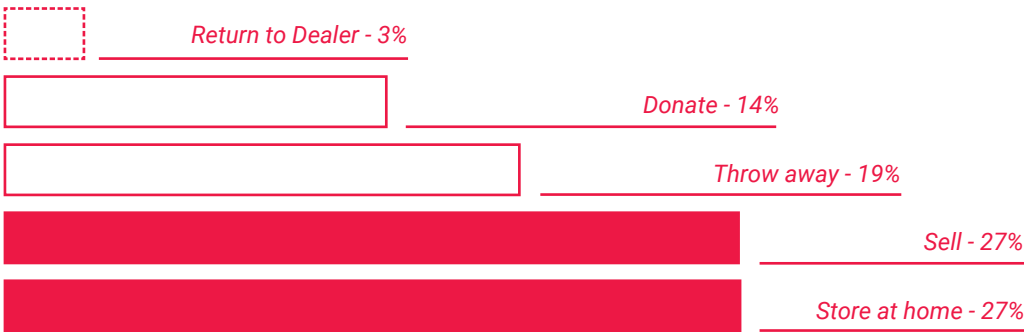


Figure 30: What do people do with their ski boots if they do not need them anymore

When examining the relationship between how long ski boots are used and what happens to them at the end of their life, a clear pattern emerges. After more than 10 years of use, skiers predominantly either dispose of their boots or store them at home. This indicates that the lifespan of the boots strongly influences the user’s end-of-life decision (Survey 1).

Repair
In response to the question of whether any of their ski boots had ever broken, 41% of participants reported that they had. A similar share, 39%, indicated that they had either repaired a ski boot themselves or had it repaired. Regarding specific components, half of the respondents reported replacing a buckle. Around 40% mentioned replacing the sole or the power strap, and 37% reported changing the liner (Survey 1). These findings align with retailers’ expert observations, which indicate that customers rarely express concerns about repairability or sustainability. One expert commented: “Nobody ever asks for a ski boot that is easy to repair. It is rare that people ask about sustainability” (Retail and Rental 1, personal communication, October 27, 2025).

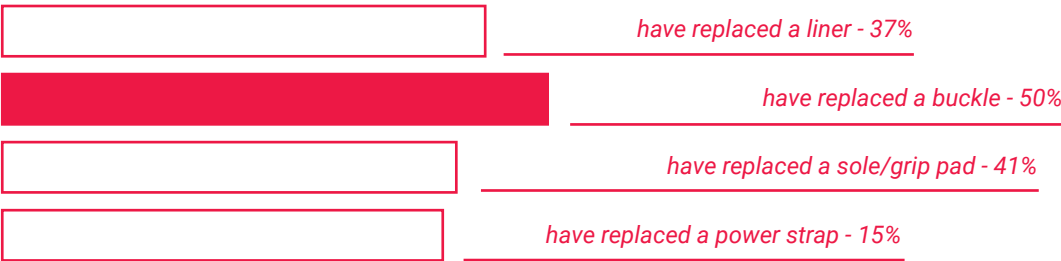


Figure 31: Parts that participants have replaced on ski boots

To enable repairs, it is also important to understand how confident users feel about repairing their own ski boots. The responses show that most participants do not feel confident at all in carrying out repairs themselves. Even when correlating these results with skiing ability, confidence levels remain consistently low across all skill groups (Survey 1).

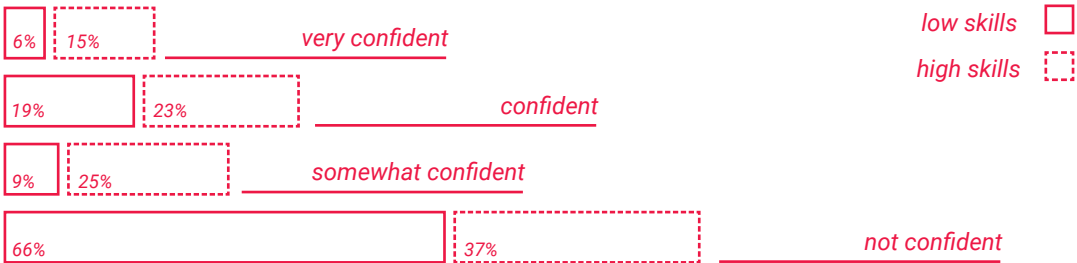


Figure 32: Confidence in repairing ski boots across different skiing skill levels

Refurbishment

In response to the question of how appealing a programme would be in which ski boots are collected, refurbished, and resold at a lower price, most participants (78%) expressed interest.



Figure 33: How appealing participants would find a programme in which ski boots are collected, refurbished, and resold at a lower price

Looking more closely at how such a concept might work, 74% indicated that they would be willing to return their used boots, and nearly half would be interested in receiving financial compensation in return. Only about one-third of respondents preferred to keep their boots, sell them privately, or dispose of them themselves. Although most participants viewed the concept positively, many still reported concerns – particularly regarding performance (46%) and hygiene (27%) of refurbished boots.

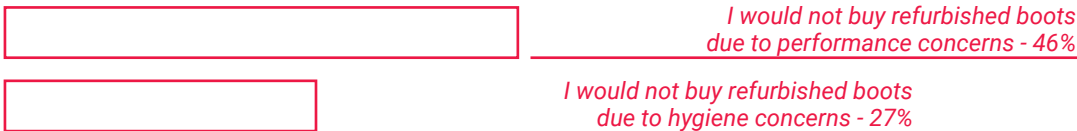


Figure 34: User concerns with refurbished ski boots

Recycled content

The survey also explored perceptions of recycled and regenerated materials in ski boots. When asked whether these materials could perform as well as virgin materials, 80% of respondents believed they could, while 20% disagreed. This question was intended as a quick indicator and may not fully reflect how users would evaluate material choices when purchasing new boots. Retailers similarly noted a limited awareness and influence of sustainability in purchase decisions. As one expert explained: “People do not know that ski boots contain recycled material, and they do not really care. They may find it interesting, but it will not influence their choice” (Retail and Rental 3, personal communication, December 2, 2025).

3.2.3 SKI BOOT RENTAL

To understand usage patterns, wear and tear, repairs, and end-of-life handling for rental ski boots, four expert interviews were conducted with retail and rental shops, along with the second survey. Renting a boot is a fundamentally different experience from owning one; these interviews, along with the survey, provided insights into rental-specific behaviour, replacement practices, and the fate of discarded boots.

Demographics

Ski boot rentals primarily serve tourists who typically stay for approximately one week. Most of these customers are beginners to early intermediate skiers. When selecting boots, renters focus primarily on fit, and most do not request specific models or technical performance features such as stiffness. Aesthetic considerations play a minor role, and visible signs of wear are generally accepted. Sustainability does not appear to be a topic that customers inquire about.

“Renters mainly don’t ask for stiffness; the most important thing is the fit.”
- Retail and Rental 3, personal communication, December 2, 2025

Drivers and Frustrations in Ski Boot Rental

Renting ski boots is primarily driven by low usage frequency and limited commitment. The most common reason, reported by 28%, is that they are skiing too infrequently to justify ownership. Followed by being a beginner or not committed enough to buy (18%), and avoiding transportation hassle (18%)

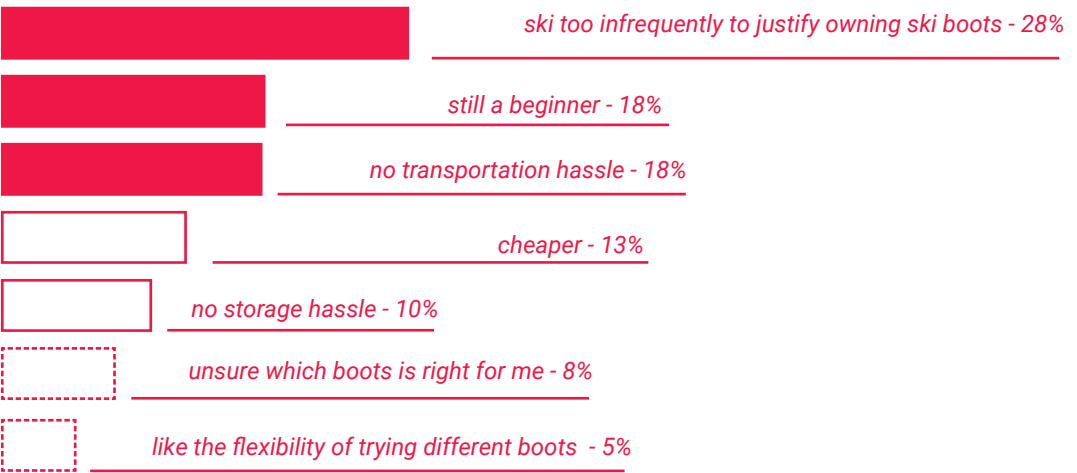


Figure 35: Reasons why people choose to rent a ski boot

The biggest source of frustration is poor fit or discomfort while skiing (35%), followed closely by long waiting times at the rental shop (29%) (Survey 2).

Usage

Rental ski boots are used regularly throughout the season. Across the interviewed shops, boots are rented on average between 25 and 40 days per season, with reported lower and upper limits of 15-50 days. The lifespan of a boot in the primary rental fleet ranges from 1 to 3 seasons, depending on overall condition and hygiene. In some cases, boots may continue in secondary use, for example, in school group rentals, for up to six years before they are fully discarded.

Hygiene is an important part of rental operations. Boots are cleaned and disinfected after each rental period, then thoroughly dried to avoid moisture and odour issues. Customers rarely express concerns about hygiene, as those who choose rental equipment generally expect a degree of shared use.

“It’s rare that people feel disgusted by rental boots because the people who rent a ski boot already know what to expect.”
- Retail and Rental 1, personal communication, October 27, 2025

Wear and Tear

Wear accumulates gradually and mainly affects the exterior of the boots. Shops reported that scratches, worn soles, and damaged buckles are the most common signs of ageing, while shell structural failures are rare. Liners gradually lose their shape through repeated use, which can reduce warmth and comfort. Repairs are limited, as replacing liners or shells is considered economically impractical. Routine maintenance typically involves replacing buckles or grip pads, which are often interchangeable across brands.

“People usually take care of the boots.”
- Retail and Rental 1, personal communication, October 27, 2025

End of life

At the end of each season, rental shops assess their fleet and remove boots that no longer meet performance or visual standards. Key factors in these decisions include the condition of the liner, the extent of scratches and other exterior wear, and the remaining thickness of the outsole. Removed boots are often sold at low prices to buyers who resell them in Eastern Europe. Once boots have exceeded all possible reuses, they are disposed of.

“There are no set criteria on how we decide which boot we will use for another season and which boot we will remove from our fleet. We go by how it looks and if the liner is packed out.”
- Retail and Rental 2, personal communication, November 11, 2025

3.2.4 PERCEPTION OF USED VS NEW SKI BOOTS

Comparing the same ski boot model in new and used condition, Survey 3 (see Appendix A) shows that visual condition strongly influences both perceived performance and for whom it is considered suitable. A new-looking boot is consistently rated around 4/5 for perceived performance, quality, and trust, and is associated with higher-skilled or performance-oriented skiers. In contrast, the same boot in a used-looking condition drops to around 2.5/5 across all dimensions. This indicates that users rely on visual appearance as an overall indicator of product value. As a result, the used-looking boot is perceived as less suitable for advanced skiers and more appropriate for beginners or low-performance use. Qualitative responses support this pattern, linking scratches and visible wear to assumptions of reduced performance and material weakness. This suggests that the perceived end-of-life of a ski boot is not only defined by actual performance, but by how it looks and for whom it is seen as suitable.

“If it’s [the ski boot] going to look beaten, it’s not going to be rented anymore. Nobody is going to want it. They [the skier] are coming with money, and they want it to look good.”
- J. Roe, personal communication, March 19, 2026

3.2.5 CONCLUSION

This section answers RQ3: *How do user behaviours and perceptions influence the feasibility of a circular ski boot business model?*

User behaviour ultimately defines when a ski boot reaches its functional end-of-life. Across all segments, replacement is rarely triggered by structural failure. Instead, it is driven by comfort loss, perceived performance decline, aesthetic wear, and a general sense that it is “time for something new.” As a result, structurally durable shells are removed from circulation while still fully functional, leading to a premature loss of embodied value (chapter 3.2.2 and 3.2.3).

At the same time, purchasing decisions are dominated by performance, fit, and cost, while sustainability plays a minor role. This means that a circular model cannot rely solely on environmental motivation, but must meet existing performance expectations and offer clear economic benefits (chapters 3.2.2 and 3.2.3).

Perception further reinforces this challenge. The analysis shows that visual condition strongly influences how performance and value are judged. Aesthetically worn boots are perceived as lower quality and less suitable for advanced users, even when functionally intact. This accelerates replacement and limits acceptance of reused products (chapter 3.2.4).

User behaviour also shapes product flows within the system. Current end-of-life pathways prevent systematic collection and make large-scale refurbishment difficult, as boots are stored, sold, or discarded individually. Without structured return mechanisms, circular value retention cannot be implemented effectively (chapter 3.2.2).

At the same time, the findings reveal a key opportunity. Users show openness towards circular models when core concerns are addressed. Acceptance increases when performance is guaranteed, hygiene is ensured, and financial incentives are provided. This indicates that user behaviour is not a fundamental barrier, but a condition that can be shaped through design (chapter 3.2.2).

In conclusion, user behaviours and perceptions influence feasibility by determining functional end-of-life, shaping return flows, and defining acceptance criteria. A circular ski boot model is only feasible if it addresses comfort degradation, performance expectations, aesthetic condition, hygiene assurance, and economic incentives.

3.3 SYSTEM-LEVEL OPPORTUNITIES FOR VALUE RETENTION

A sustainable business model should enable an organization to create value for all stakeholders, including customers, shareholders, suppliers, and the environment. Transitioning from a linear to a circular economy is essential to reduce environmental pressures and enhance the security of primary raw material supply. Under this new paradigm, guided by the principles of “reduce, reuse, and recycle,” the extraction of virgin resources is minimised by extending the useful life of existing materials (Comin et al., 2019; Neves & Marques, 2022). Achieving sustainability requires a long-term mindset. Instead of prioritising one-time sales, brands are encouraged to cultivate ongoing customer relationships through care, repair, and resale (Gore-Tex, 2025).

The following chapter examines system-level circularity in the ski boot industry, addressing the factors that enable or hinder circular practices:

RQ4: What economic and system conditions must be met to make value retention economically viable at scale?

To answer this research question, multiple methods were applied. Internal and external interviews were conducted to understand current end-of-life pathways. Insights on upcoming sustainability regulations were gathered through internal interviews and presentations at the Climate Summit Bolzano, supported by a literature review. In addition, a stakeholder analysis was carried out based on internal and external interviews.

3.3.1 CURRENT BUSINESS MODEL AND OWNERSHIP STRUCTURE

Atomic operates a linear, product-based business model. Ski boots are manufactured and primarily sold to dealers, who either retail them to end users or use them within rental fleets. Revenue is generated through unit sales, and economic value is realised at the point of sale. After this point, Atomic has no structural mechanism to regain control over the product. There is currently no systematic take-back scheme or refurbishment programme. End-of-life decisions are therefore left to the user, leading to storage, private resale, or disposal (Atomic Internal, 2025).

In the rental channel, ownership remains with the rental shop rather than the end user. However, once boots are removed from the rental fleet, they are typically sold to secondary markets or discarded. Atomic does not regain ownership or recover products from this stream (Rental & Retail Interviews, 2025).

As a result, the current business model is optimised for product throughput rather than recovering the embodied value that remains in the product at the end of its first use cycle. Control over the product lifecycle is largely lost after the first sale, limiting Atomics’ ability to implement refurbishment, cascade usage, or closed-loop material strategies. Any circular business model would therefore require structural changes to ownership, incentives, and product return mechanisms.

3.3.2 STAKEHOLDERS

To enable circular value retention, companies need to rethink how they create value, their stakeholder relationships, and ownership dynamics. The feasibility of a circular ski boot business model depends not only on product design but also on who controls ownership, margins, and product flows within the system (Tapaninaho & Heikkinen, 2022).

A total of five stakeholders were identified. Each stakeholder was assessed based on their level of power (vertical axis) and level of interest (horizontal axis). These rankings were then mapped onto Mendelow’s Matrix to analyse their influence and relevance within the current system (Figure 36). In the following, the stakeholders involved in the Atomic Ski boots case will be presented, and their relation explained.

1. Atomic

Atomic holds high power due to its control over product design, material selection, and production processes. However, under the current sales-based model, ownership transfers after the first sale, and Atomic loses control over the product lifecycle. This limits its ability to implement refurbishment, cascade usage, or systematic value recovery independently.

2. Regulators and Policy Makers

Compliance influences the overall rules through safety standards and emerging policies. Their power is high, as legislation can mandate take-back systems or eco-design requirements. While their direct involvement in the value chain is limited, their decisions can significantly shift economic motivations.

3. Retailers

Retailers control customer interaction and influence purchasing decisions. Their power is moderate to high, but their current revenue model is primarily based on new product sales. Interest in circular value retention depends on whether they provide economic benefits.

4. Rental Operators

Rental shops retain ownership within their fleets and already operate multi-user product circulation. This gives them operational control throughout the product’s lifetime. However, once boots leave the rental fleet, they are typically sold or discarded without systematic recovery. Their interest in circularity is primarily cost driven.

5. End Users

Private owners determine product lifespan and end-of-life decisions. Survey results show that replacement is often driven by comfort or perceived performance decline rather than structural failure. Users have influence over return behaviour but limited structural power and few incentives to participate in sustainability practices.

The mapping shows that no single stakeholder currently combines ownership control, economic incentive, and a high interest in circular value retention. The system is optimised for product throughput rather than value retention.

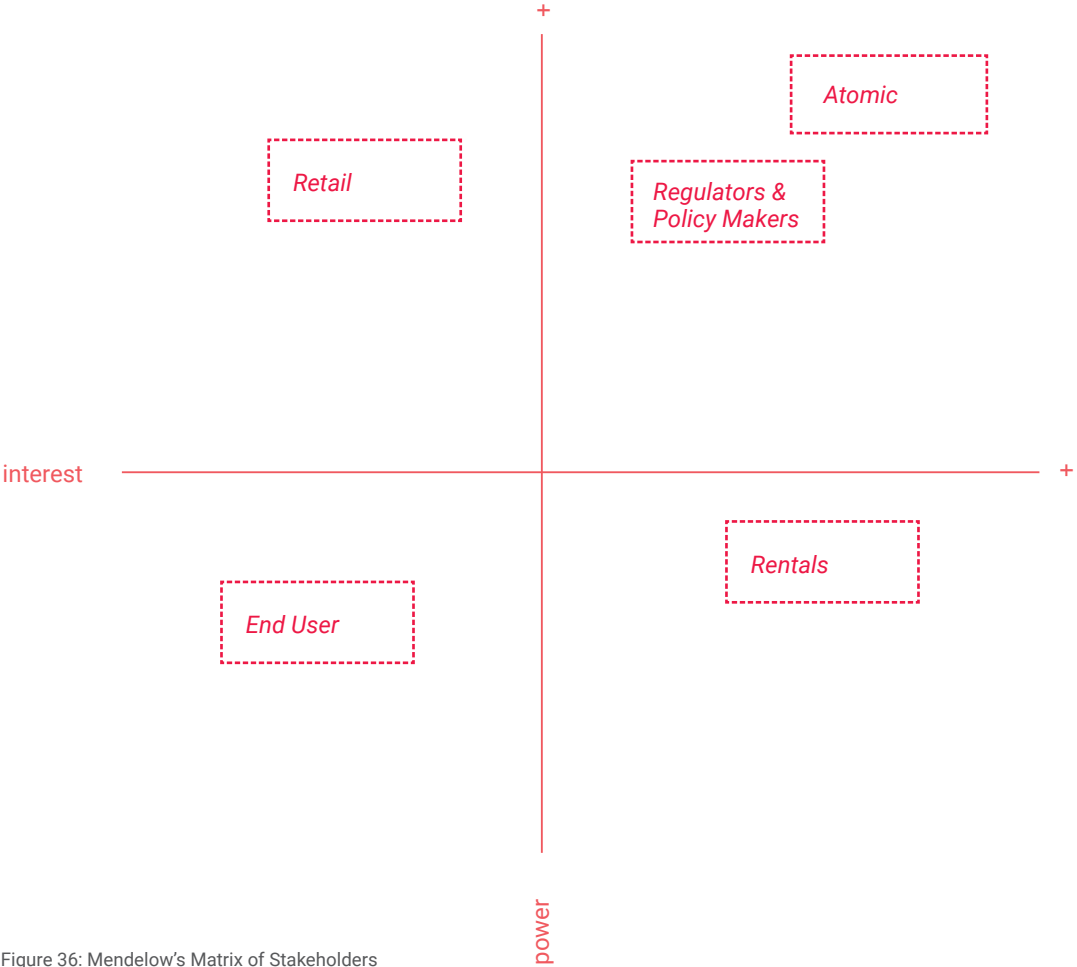


Figure 36: Mendelow's Matrix of Stakeholders

3.3.3 END-OF-LIFE PATHWAYS AND VALUE LOSS

Every year, around 3.6 million pairs of ski boots are produced worldwide. Their average lifespan is three years in rental use and six in private ownership (Sporting Goods Recycling, 2024; Customer Survey). After this period, most boots are incinerated or landfilled (Technica Group, 2025).

For an Atomic ski boot, end-of-life accounts for 13.2% of total lifecycle emissions (4.7 kg CO2e), making it the second largest impact stage after production (Atomic Internal, 2025). Despite this, current end-of-life pathways do not enable systematic value recovery.

*“Most ski boots just get burned at the end of life.
In Europe, everything that is plastic is burned right now.”
- R. Schwarzenbrunner, personal communication, November 6, 2025*

Atomic has previously initiated pilot projects to collect used ski boots from dealers for recycling, with the aim of reusing shell material in new products. In 2023 and 2024, approximately 7,500 pairs were collected, amounting to 30 tons of material. The liners were

removed, and the shells were shredded and processed through magnetic and aluminium separation. The recovered material then required compounding before it could be reused in injection moulding (Atomic Internal, 2025).

However, the process remains economically unattractive. Recycled material currently costs roughly twice as much as virgin material and has lower performance properties, limiting its use to a maximum of 30% and to black colour variants (R. Schwarzenbrunner, personal communication, November 6, 2025; J. Roe, personal communication, October 10, 2025).

Recycling should also be a last resort rather than a primary solution. As long as products are not systematically returned and processed on a large scale, recycled material will remain more expensive than virgin material.

“The recyclability of the hard parts is there; we are just missing the scale to do it, and we are missing the cost factor to do it. With current technology, it takes too many rounds of filtering to get the material to a usable standard. When you can buy virgin for way cheaper than recycled, why would you buy it? The business does not make sense.”
-J. Roe, personal communication, October 10, 2025

The liners were incinerated because their construction, which involves adhesives, stitching, and a combination of various materials, currently prevents them from being recycled (R. Schwarzenbrunner, personal communication, November 6, 2025).

3.3.4 UPCOMING CIRCULAR LEGISLATIONS

“Sustainability from a regulatory viewpoint is not going away, but it’s looked at differently.”
- Pero, 2026

The Ecodesign for Sustainable Products Regulation (ESPR) is an EU framework that sets binding requirements for products to become more durable, repairable, recyclable, and transparent across their lifecycle. Although ski boots are not yet explicitly targeted, the regulation is designed to expand across product categories over time. For ski boots, this means future design decisions may need to prioritise durability, repairability, traceability through a Digital Product Passport, and potentially minimum recycled content, even though the category is not yet explicitly regulated (Ecodesign for Sustainable Products Regulation - European Commission, n.d.; Pero, 2026). Atomic ski boots already have a QR-Code that enables the DPP.

Extended Producer Responsibility (EPR) is a policy approach that holds manufacturers financially and operationally responsible for the collection and end-of-life treatment of their products. For Atomic, this would directly challenge the current sales-based model, where lifecycle control ends after the first sale. They would require structured take-back and recovery systems (Pero, 2026; Revised Waste Framework Directive Enters into Force - Environment, n.d.).

3.3.5 CONCLUSION

This chapter addressed RQ4: ***What economic and system conditions must be met to make value retention economically viable at scale?***

The analysis shows that value retention is currently not economically viable because the system is linear. Atomic generates revenue at the point of sale and loses lifecycle control. Retailers are incentivised to sell new products, rental operators focus on efficient turnover, and end users independently decide when a boot reaches its end of life. As a result, durable, high-impact components, such as the shell, are removed from circulation while still functional.

For value retention to become economically viable at scale, three conditions must be met. First, lifecycle control must be regained. Without a structured take-back system or a shift in ownership, products cannot be recovered in sufficient quantities. Reverse logistics must become part of the business model rather than an afterthought (chapter 3.3.1).

Second, economic incentives must align across stakeholders. As long as virgin material remains cheaper than recycled material and new product sales generate higher margins than refurbishment, linear production will dominate. Circular strategies must therefore create either cost advantages or new revenue streams (chapter 3.3.2).

Third, the product must be designed for multi-cycle use. Efficient disassembly, replaceable high-wear components such as the liner, and clear traceability are necessary to reduce refurbishment costs. Without design adaptation, circular processes remain too complex and costly (chapter 3.3.3).

Upcoming regulations such as ESPR and EPR are likely to shift these system conditions by introducing durability, repairability, and producer responsibility requirements. This may make lifecycle control and take-back systems structurally necessary rather than optional (chapter 3.3.4).

SYNTHESIS

chapter 4

This thesis set out to answer the following design question:

How can a circular business model for ski boots enable economically viable value retention, and what product adaptations are necessary to support its implementation?

The previous chapters examined this question from three perspectives: product architecture, user behaviour, and system conditions. While each analysis revealed constraints and opportunities, economically viable value retention can only be achieved if these perspectives align.

This chapter synthesises the findings across levels to identify structural tensions and leverage points.



Figure 37: Notes and Ideation

Method

Statement Card Analysis, a Method developed by Stappers et al., (2023) at the Delft University of Technology, was used as a qualitative sensemaking method to synthesise insights across interviews, product analysis, literature review, and survey data. After each data source was reviewed, key insights were translated into individual statement cards.

Each card contains a short statement capturing the core insight, the original source, and my interpretation. For the purpose of this project, where relevant, the statement was additionally linked to a circular R-strategy. By externalising insights into comparable units, the method enabled not only the identification of patterns and similarities, but, more importantly, the identification of frictions and contradictions between product, user, and system perspectives. The cards were first clustered according to their associated R-strategy. In a second step, insights were compared across clusters to identify recurring conflicts and misalignments. This iterative process yielded 34 findings that form the basis for the synthesis (Figure 38).

Not all findings contributed equally to answering the design question. Some insights are more structurally relevant, while others provide context. The findings can therefore be understood as hierarchical, with certain insights carrying more strategic weight. The challenge does not lie in individual product flaws, but in misalignments between durability, user perception, ownership, and economics. These misalignments are described below.

Rather than presenting all findings individually, they were abstracted into a smaller set of systemic tensions that capture the core misalignments within the current system. These tensions directly inform the subsequent design direction. A detailed overview of all statement cards and findings is available in Appendix B.

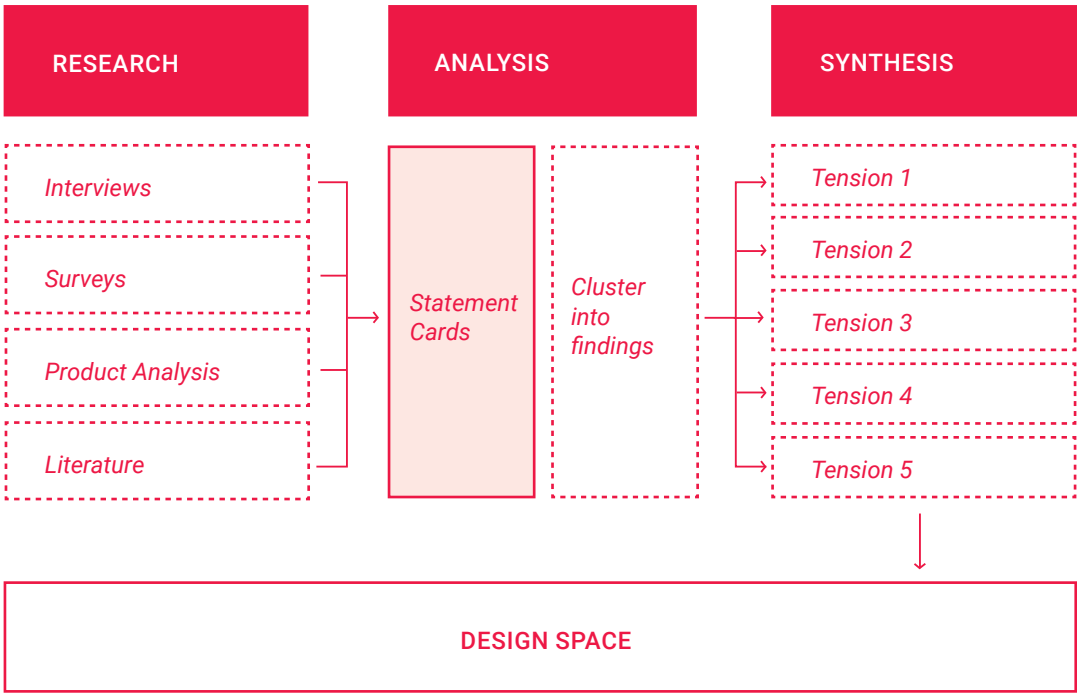


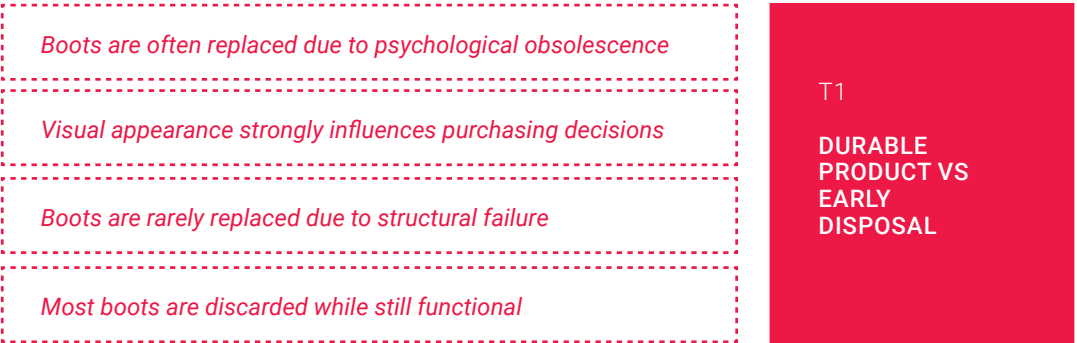
Figure 38: Synthesis Method

4.1 SYSTEMIC TENSIONS

The synthesis does not reveal isolated problems, but systemic tensions that prevent economically viable value retention. A systemic tension in this context is defined as a conflict between aspects across the three perspectives: product, user, and system level. These five tensions define the design space for intervention.

1. Durable Product vs Early Disposal

The majority of environmental impact is embedded in production upfront. Yet products are discarded while still functional due to users’ perception rather than failure. As a result, embodied value is prematurely destroyed. The system removes durable components from circulation before their technical lifespan has expired. (RQ2)



2. Long-Lasting Shell vs Short-Lived Liner

The shell represents the largest share of embodied carbon and demonstrates strong structural durability. In contrast, the liner degrades more quickly due to material compression, resulting in reduced comfort and warmth. Although these components have different functional lifespans, they are sold and perceived as a single product. Because the liner wears out first, users perceive the entire boot as worn out, even though the shell still has significant functional life left. (RQ2)



3. Technically Possible vs Economically Sensible

Within the current architecture, the shell and liner differ significantly in their circular potential. Repair and closed-loop recycling are technically possible within the current ski boot shell. Components can be replaced, shells can be dismantled, and materials can be recovered. However, riveted connections, disassembly labour costs, and low return volumes increase refurbishment and closed-loop recycling costs. Closed-loop recycling also requires material separation and compounding, which makes recycled materials more expensive than virgin alternatives. Closed-loop recycling is therefore technically feasible but economically uncompetitive. In contrast, the liner offers limited repair potential. Due to its glued, multi-material construction, it cannot be repaired or easily separated into material streams. Its only realistic end-of-life pathway is incineration. Circular solutions are possible, but they are currently too costly and operate at too small scale to be economically attractive. (RQ2 + RQ4)

Boot shell is technically easy to repair	T3 TECHNICALLY POSSIBLE VS ECONOMICALLY SENSIBLE
Repair is rare for ski boots	
No standardised evaluation system exists for returned boots	
Lack of backwards compatibility creates logistical barriers	
Recycled TPU has technical and colour limitations	
Closed-loop-recycling is currently more expensive than using virgin material	

4. Ownership Mindset vs Circular Use

User behaviour is currently shaped by a linear ownership model. Replacement is considered a normal consumption pattern, and end-of-life pathways are determined by individual users. Sustainability plays a minor role in purchasing decisions, and users rarely demand it. However, results from Survey 1 indicate openness to refurbishment and return models, particularly when performance standards and financial incentives are ensured. Acceptance to participate in circular practices depends less on environmental motivation and more on perceived performance and economic benefit. User behaviour, therefore, does not automatically enable circularity, but it does not automatically prevent it. Participation is dependent on how the system is designed and communicated. Circular models must meet existing performance expectations rather than rely on users choosing them purely for environmental reasons. (RQ3 + RQ4)

Performance and comfort are the primary purchasing criteria	T4 OWNERSHIP MINDSET VS CIRCULAR USE
Sustainability is only accepted if price and performance are maintained	
Frequent skiers prefer ownership to ensure consistent performance and fit	

5. Designed for Sale vs Designed for Lifecycle

Atomic holds full control over product design, material selection, and manufacturing decisions, enabling them to influence durability, reparability, and disassembly. However, under the current sales-based business model, ownership transfers after the initial purchase. As a result, the company loses visibility over the product, making it difficult to facilitate returns or ensure controlled end-of-life pathways, even for boots distributed through rental shops. As a result, circular ambition conflicts with a linear ownership structure. Without regaining lifecycle control at scale, economically viable value retention cannot be implemented. (RQ4)

Current product architecture does not support circular use	T5 DESIGNED FOR SALE VS DESIGNED FOR LIFECYCLE
Ownership transfer after sale prevents lifecycle control	
Current business model does not support lifecycle control	
No structured end-of-life system exists for ski boots	
No systems exist to ensure product return after use	

4.2 PROBLEM STATEMENT

The identified tensions reveal multiple structural misalignments across product, user behaviour, and ownership. While each tension highlights a specific friction, together they point to a central problem:

The ski boot integrates components with unequal lifespans into a single product and ownership model. A fast-degrading liner determines the perceived end-of-use of a slow-degrading, carbon-intensive shell that holds most of the environmental and economic value. As a result, high-impact components are discarded prematurely. This loss of embodied value is embedded in the current sales-based business model that does not retain lifecycle control or enable economically viable multi-cycle use.

4.3 VISION STATEMENT

Enable a circular ski boot ecosystem where structurally durable shells remain in long-term circulation, while performance, comfort, and desirability are continuously renewed across multiple use cycles.



Figure 39: Brainstorming

DESIGN SPACE EXPLORATION

chapter 5

The identified tensions reveal that there is no single solution path. Multiple strategic directions could address parts of the problem, each targeting different aspects of value loss. Exploring these alternatives was a central part of this thesis.

The following section outlines the broader design space that emerged from the tensions.

5.1 CREATIVE COLLABORATION

Rather than generating solutions in isolation, the findings were used to facilitate a brainwriting workshop at Atomic in Altenmarkt on November 26, 2025. The workshop aimed to explore ideas at both the product and business model levels rather than converge on a final concept.

Method

The workshop was conducted with nine participants from Atomic, representing design, engineering, sustainability, marketing, and management functions (Head of Design, Quality Manager Boots, Product Marketing Manager Boots, Boot Designer, Sustainability Manager, Sustainability Specialist LCA, Sustainability Specialist Protection & Gear, Intern Product Management, Intern Material Scientist).

Participants were divided into three teams of three and rotated in a structured format: one person remained at each table to ensure continuity, while the other two rotated in opposite directions. This enabled cross-functional exchange while allowing ideas to build over multiple rounds.

Each table addressed a different guiding question derived from the identified tensions:

- How would a new ski boot function within the existing system?
- How would the current boot operate within a new system?
- How would a new boot look within an integrated Atomic ecosystem?

At the beginning of the workshop, previously developed concept sketches were briefly presented as inspiration (Appendix C). Participants were then asked to generate ideas individually and collaboratively, documenting them through sketches and written notes on Post-its. Ideas were clustered on prepared posters structured around product, customer, and business dimensions. All emerging ideas are in Appendix C. The workshop ended with a 1-hour discussion round to evaluate the concepts.



Figure 40: Brainwriting Workshop at Atomic



5.2 EVALUATION OF STRATEGIC PATHWAYS

The most promising directions that emerged from the brainstorming sessions and my own explorations are described below. They are clustered into product-, user-, and system-level interventions. Each of these seven directions has been explored to an initial extent and is briefly introduced here.

All of these pathways present potential starting points for future projects. To compare the explored directions, they were mapped along two dimensions: structural change required (product to system) and value retention potential (Figure 41). The matrix shows that most product-level strategies improve recyclability or durability but have a limited impact in regard to value retention. System-level approaches, particularly ownership restructuring, demonstrate higher potential to retain embodied value.

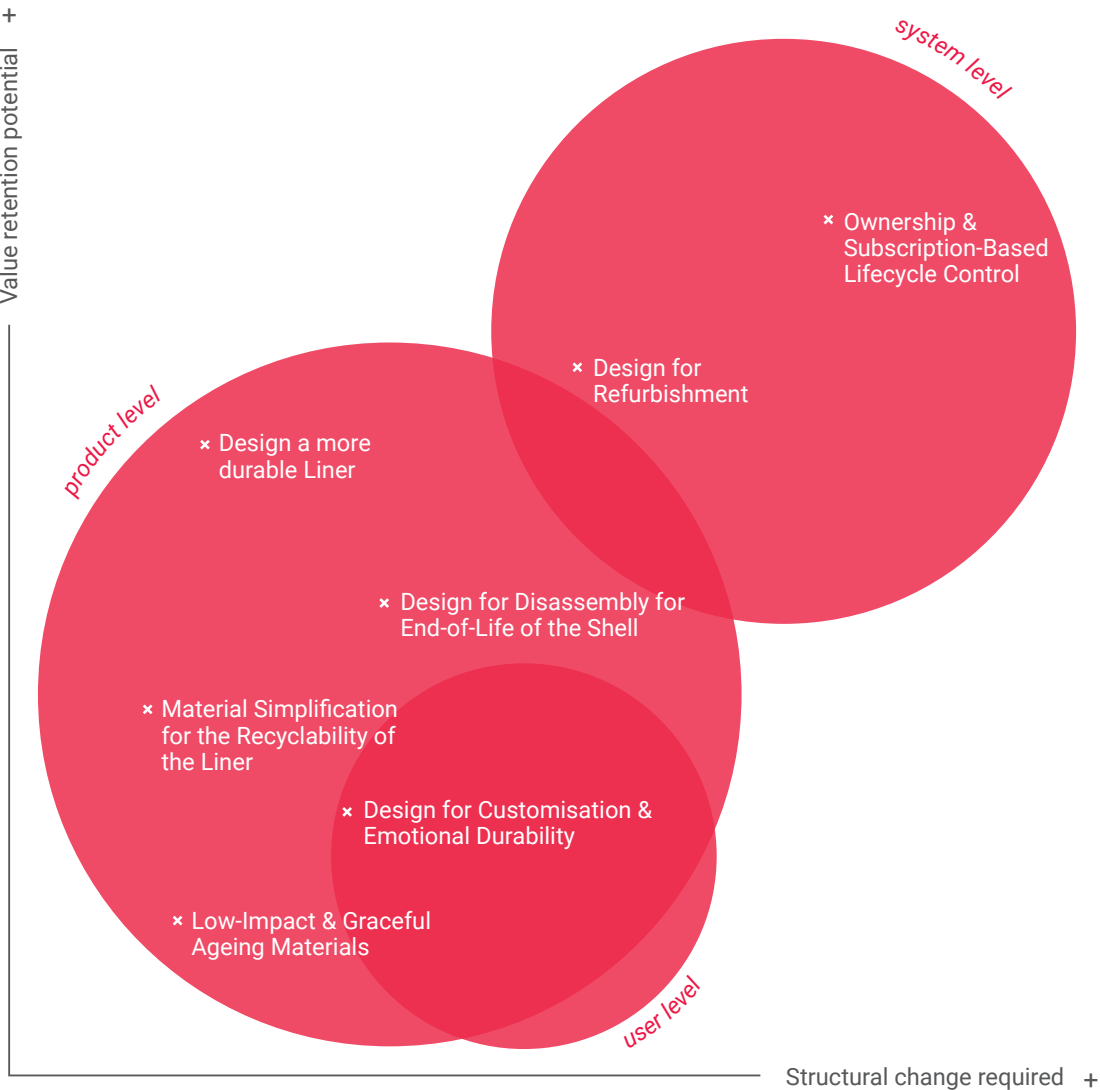


Figure 41: Overview of explored directions

PRODUCT LEVEL

1. Material Simplification for the Recyclability of the Liner

This direction explored reducing material complexity through monomaterial concepts for the liner. The main thought was to enable easier material separation and improve recycling efficiency at the end of life.

This approach improves the potential for material recovery but fails to extend product use cycles or prevent premature replacement of structurally durable components. Recycling is the last value retention strategy.

2. Design a more durable Liner

Given that the liner's packing out often determines the end of life for the entire boot, several ideas were generated to extend the liner's lifespan. These included replaceable foams, separation of fit and comfort layers, and the use of materials like cork that do not pack out over time. Premium liners are typically positioned as aftermarket products. For intermediate and recreational skiers, current liners are sufficient for several years. Improving liner longevity alone does not address premature boot replacements driven by psychological obsolescence, nor does it address the lack of a product return system.

3. Low-Impact & Graceful Ageing Materials

This pathway investigated the use of materials with a lower CO2 Footprint and CMF strategies that age visibly but are acceptable. The intention was to reduce the environmental footprint and mitigate aesthetic-driven replacement. However, material substitution alone is not enough to change people's behaviour.

4. Design for Disassembly for End-of-Life of the Shell

The idea behind these concepts is to enable faster disassembly at end-of-life and economically viable recycling by reducing labour costs. Ideas included central release systems for buckles, connections that would loosen when placed in a vacuum chamber, or a single screw that would cause the boot to fall apart. While this improves end-of-life processing efficiency, recycling occurs after value has already been lost.

USER LEVEL

5. Design for Customisation & Emotional Durability

This direction explored reducing psychologically driven replacement by tackling the feeling that it is "time for something new" through increased opportunities for personalisation and aesthetic renewal. Ideas included changeable side panels, protective buckle covers, stickers (especially for children), and add-on elements similar to phone cases that both protect the product and allow visible individualisation.

However, while customisation may delay psychologically motivated replacement, it does not address structural lifecycle control or guarantee product return.

SYSTEM LEVEL

6. Design for Refurbishment

Traditional refurbishment models were explored, including surface renewal techniques (such as sandblasting, heat moulding, ...), integrating "wear zones" into the design that can

be refurbished, and connections that can be disassembled more quickly. While this extends product life, it relies on voluntary return, limiting scalability and economic viability.

7. Ownership & Subscription-Based Lifecycle Control

This direction explored moving away from a pure sales model towards a service or subscription logic in which Atomic retains ownership of the boot. By keeping control over the component, product return, refurbishment, and multi-cycle use become possible. However, such a shift cannot stand alone. It requires a deeper analysis of stakeholder roles, incentive structures, and user pain points. Rental partners, retailers, and end users would need to see clear value in participating.

The exploration revealed that no single pathway resolves the structural tensions identified earlier. Material simplification improves recyclability but does not enable multiple-use cycles and value retention. Liner innovations address component mismatches but do not address psychological obsolescence, value loss, or product returns. Refurbishment extends the lifetime but struggles without guaranteed return flows.

Viewed in isolation, each strategy improves a fragment of the system. However, looking at these concepts with the design question in mind: How can a circular business model for ski boots be designed, and what product changes are required to enable economically viable value retention? requires combining strategies across Product, User, and System Level. The proposed concept, therefore, emerges from the combination of high-impact elements across concepts, as shown in Figure 42.

“Circularity begins with a shift in mindset from linear to systems thinking.”
(Spijker & Grison, 2025)

It combines the decoupling of fast- and slow-degrading components, a refurbishable-focused design, the concept of a more durable liner, and a shift in ownership logic. By aligning product adaptations with a revised business model, the concept enables extended circulation of high-impact components while addressing user-level concerns. The following concept was developed through multiple iterations and validation sessions with experts from Atomic.

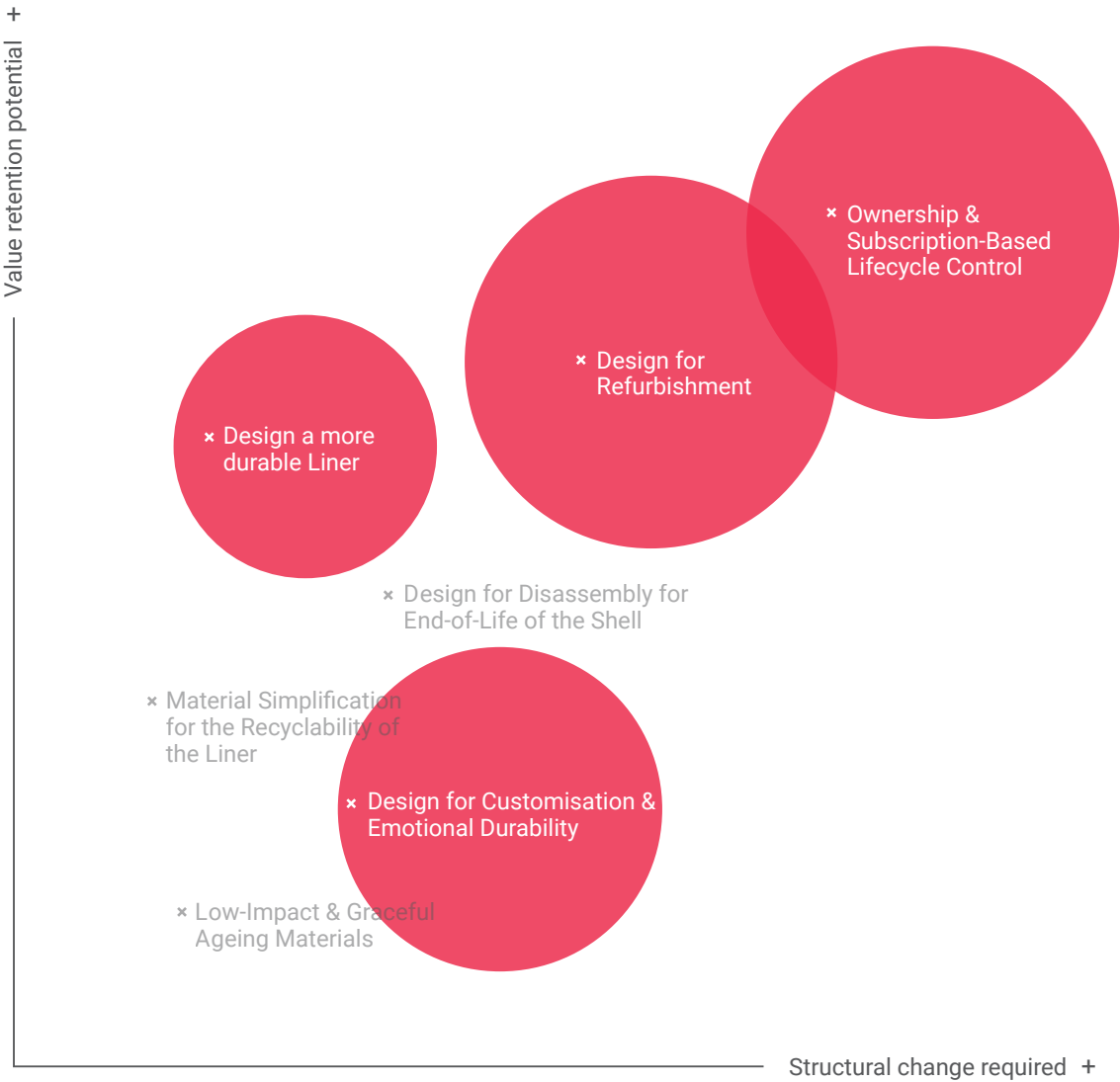


Figure 42: Overview of combined directions

FROM LINEAR PRODUCT TO CIRCULAR SYSTEM

chapter 6

As a result of the analysis, we can see that the current linear product system is not aligned with the circular economy. The linear product system is based on a single-use product that is discarded after use. This system is not sustainable because it leads to a large amount of waste and a high carbon footprint. The circular system, on the other hand, is based on a multi-use product that is designed to last and be repaired. This system is more sustainable because it reduces waste and lowers the carbon footprint. The circular system is also more aligned with the values of the circular economy, which are to reduce, reuse, and recycle. The circular system is a more sustainable and aligned way of producing and consuming products.

The analysis chapters showed that ski boots are rarely discarded because they fail structurally. Instead, high-impact components are prematurely replaced, and the current sales-based system does not enable product returns or circulation. As a result, embodied value is lost despite the shell's durability.

Buying a ski boot is a commitment. Skiers invest in a product that is expected to fit perfectly, perform consistently, and last for years. Yet, this expectation is rarely met. Boots often feel right in the store but perform differently on the slope. Over time, comfort decreases, performance changes, and the boot is replaced, not because it is broken, but because it no longer feels right.

6.1 THE CORE IDEA

Not all parts of a ski boot age at the same pace or serve the same purpose. The liner is personal. It adapts to a specific foot, carries hygiene, and determines comfort. The shell is structural. It provides performance, but it does not need to belong to one person. The liner is purchased and owned by the skier. The shell is retained by Atomic and accessed through a service – the Atomic Performance Guarantee.

In practice, this means a skier travels to a resort carrying only their liner. At the rental shop, they pick up a shell matched to the day’s terrain and conditions – piste, freeride, or touring – step in, and ski. At the end of the day, the shell is returned. The liner comes home with the skier. The result is a boot that always fits, because the fit lives with the skier. And performance that always matches the moment, because the shell can change. The concept targets high-performance and recreational-skilled skiers (identified in chapter 3.2.1), users who currently avoid rental precisely because they value fit and performance.

This shifts the ski boot shell from a product that is sold once to a product that is used over time. Once a shell no longer meets the demands of high-performance skiers, it does not stop being useful; it is reassigned to intermediate users whose needs it still meets. The cascade is not a downgrade. It is a realignment of the shell’s performance with the skier’s capability.

To understand the proposed business model and how it functions in practice, the system is explained across three interconnected layers. First, user interaction within the system is outlined. Second, the value created for different stakeholders is described. Third, the product architecture that enables the model is presented.

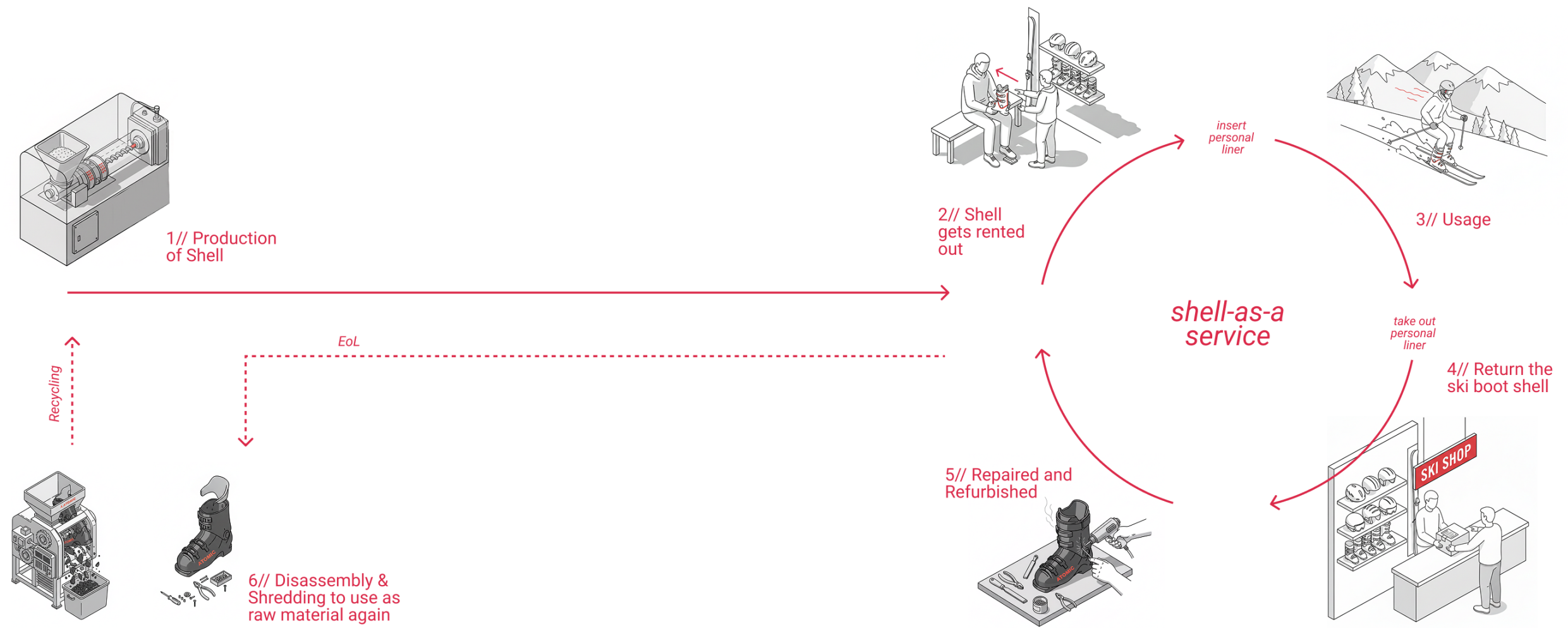


Figure 43: Simplified visualisation of the Shell-as-a-Service Model

6.2 USER JOURNEY

The user journey shapes the business model. It defines how users become aware of the concept, understand and adopt it, and experience it over time. Each interaction, from first contact to return of the shell, influences trust, perceived value, and long-term acceptance (Customer Journey Stages, 2022). To illustrate how the Atomic Performance Guarantee could operate from the user perspective, the following section maps the concept along the three stages of pre-sale, sale, and post-sale.

PRE-SALE

Most skiers first encounter the Atomic Performance Guarantee through word of mouth, social media, or online research. Users can locate nearby retail shops and understand what entering the system looks like before committing.

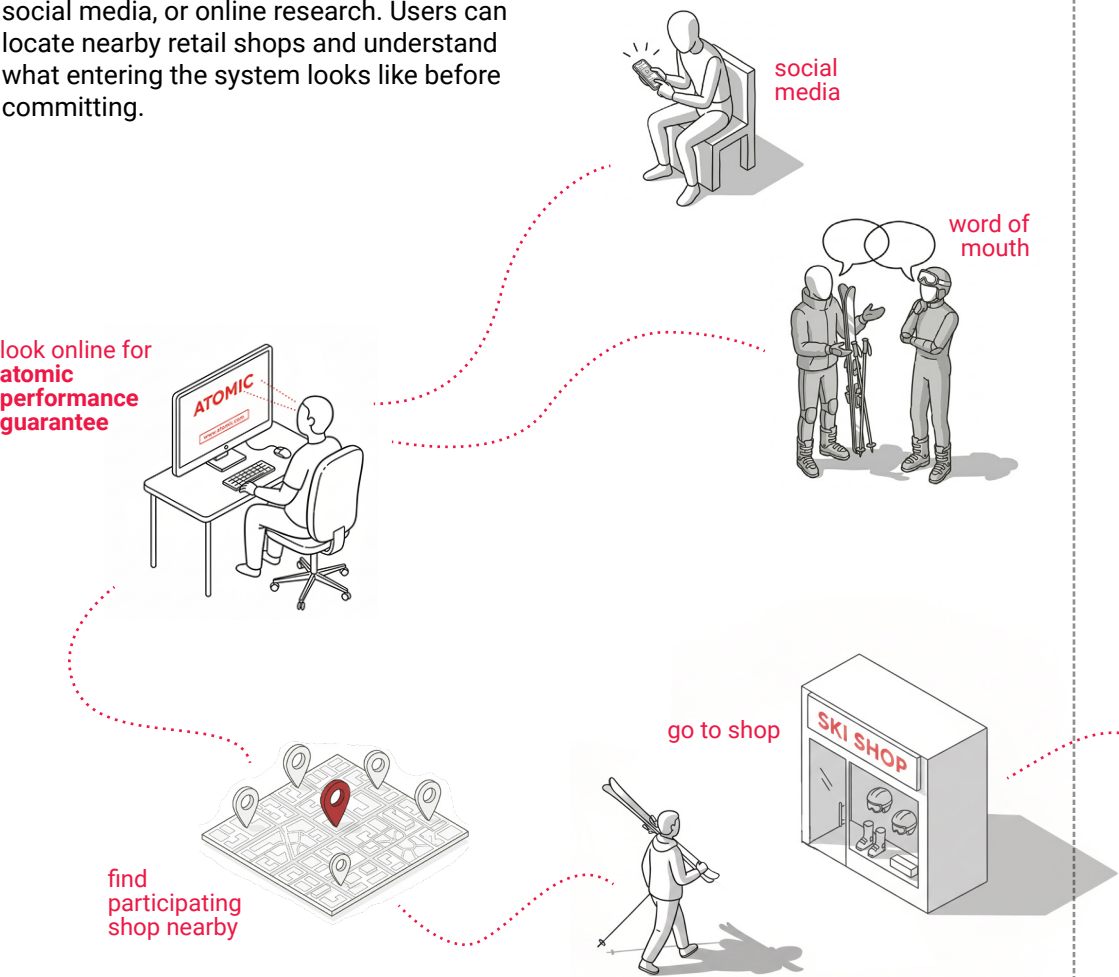
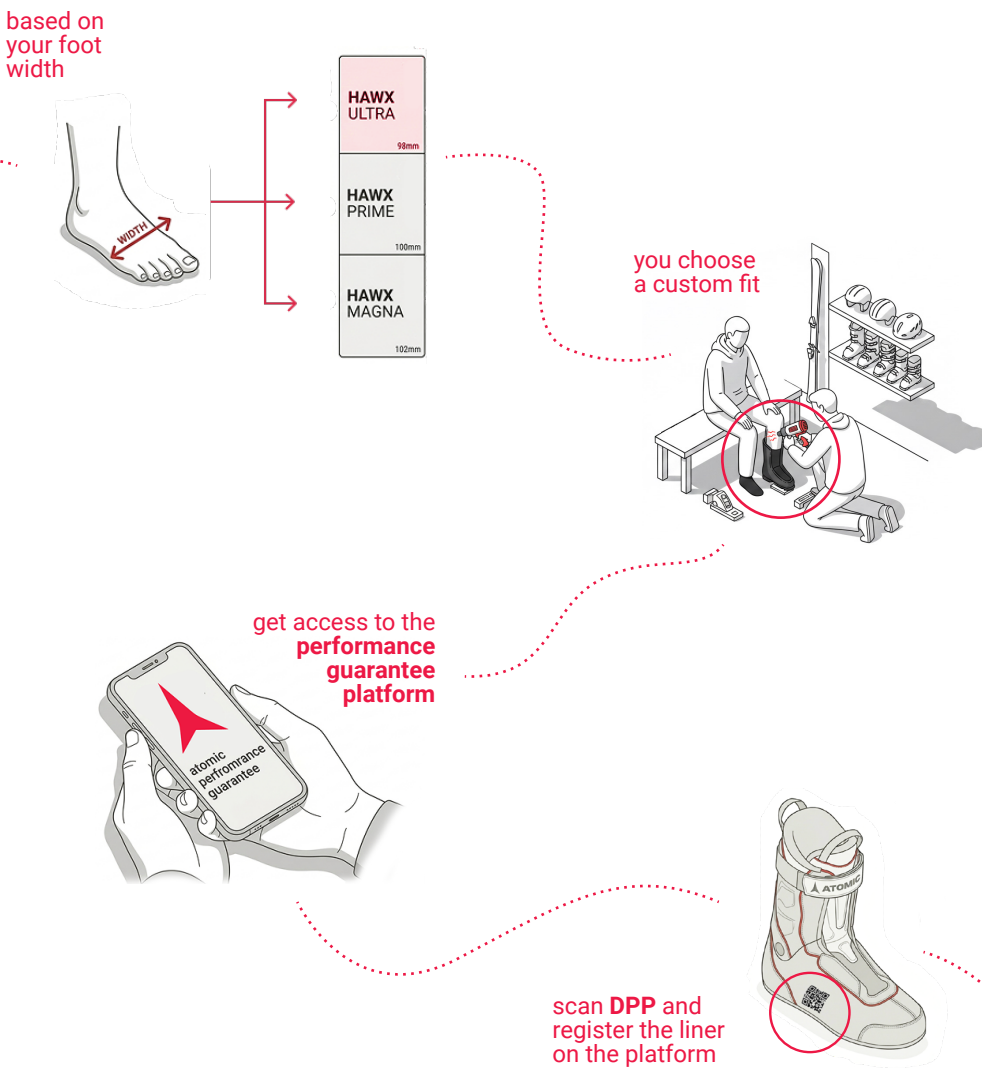


Figure 44: User Journey

SALE

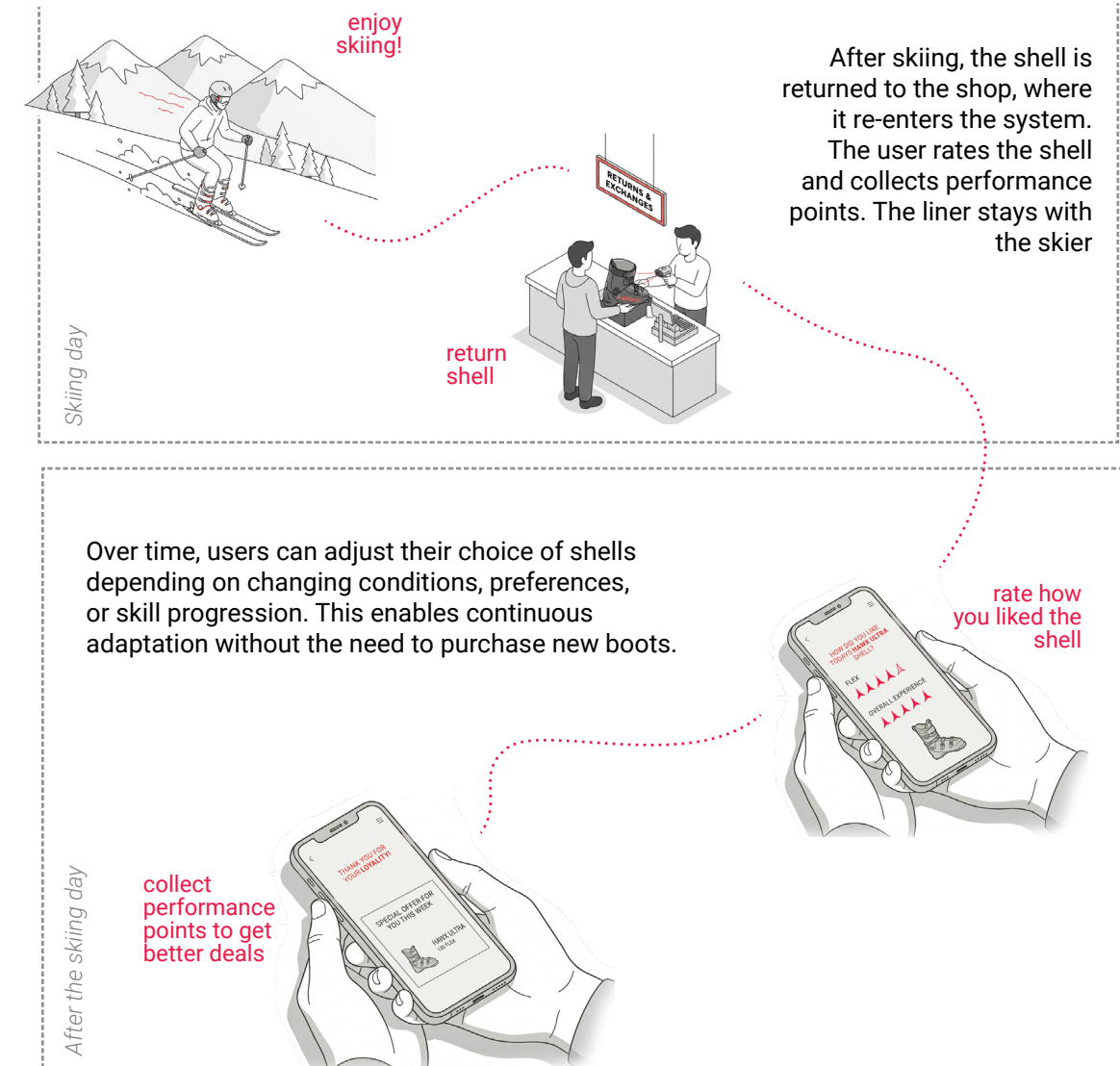
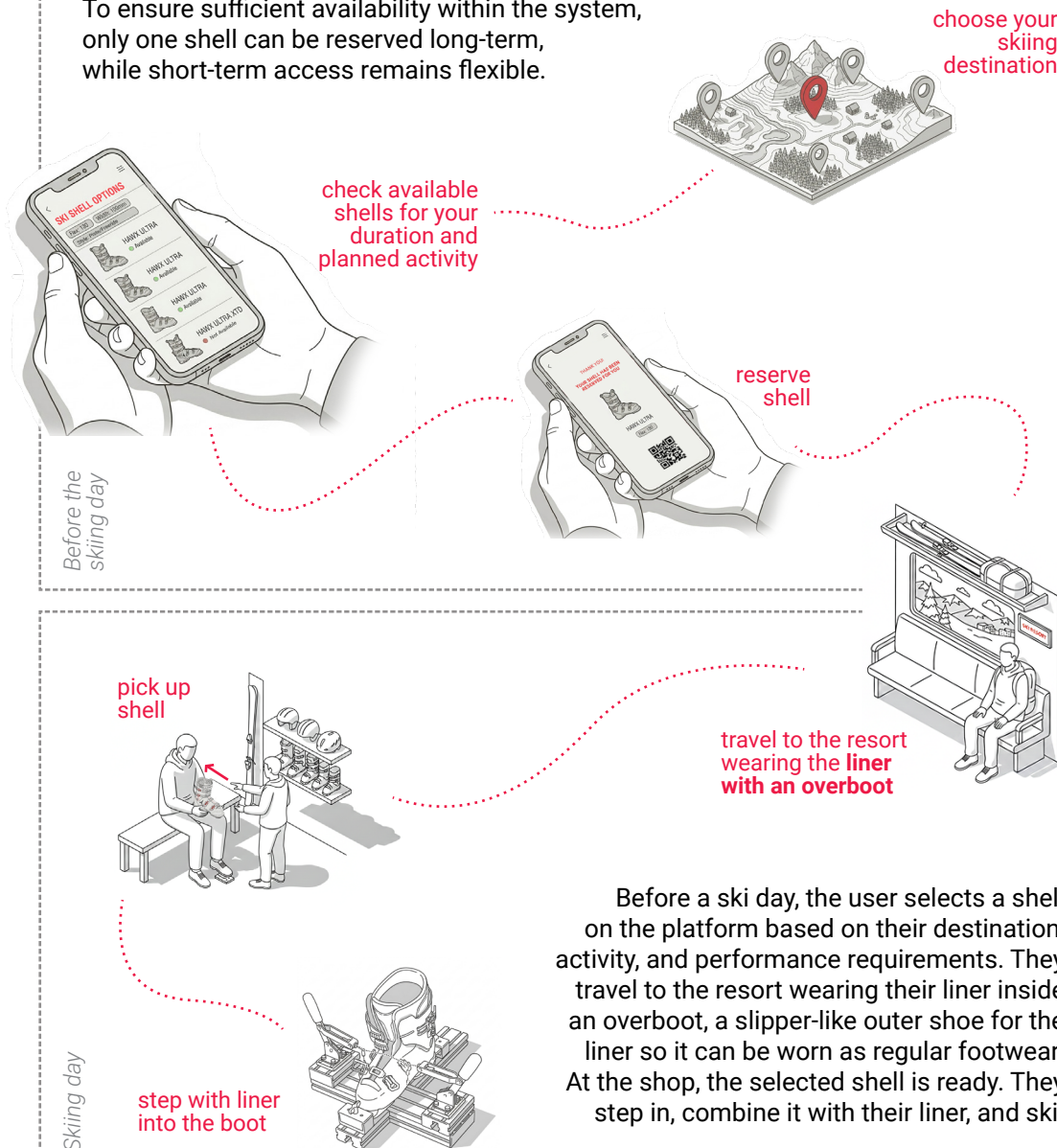
In the retail shop, the user selects and is fitted with a personalised liner, which ensures fit and comfort. The liner is designed as a durable, long-term component that remains consistent across different use cycles. The liner is registered on the Atomic Performance Guarantee Platform, granting access to the full system. From this moment, the skier is a member of the Atomic Performance Guarantee.



POST-SALE

Shells can be accessed in two ways, reflecting the distinct usage patterns identified in Surveys 1 and 2. Frequent skiers, those with ten or more days on snow per season, can reserve a shell on a subscription basis for an entire ski season, maintaining consistency in their primary discipline. Occasional skiers, who typically do one to two ski trips per year, or those who want to try a different discipline or travel to a resort without additional equipment, access short-term shells on a pay-per-use basis.

To ensure sufficient availability within the system, only one shell can be reserved long-term, while short-term access remains flexible.





ONE SHELL, MANY LIVES



Figure 45: one shell, many lives

6.3 VALUE CREATION

The proposed concept introduces a Shell-as-a-Service model for performance-oriented skiers who currently own their own boots and value fit and consistency. Performance is no longer tied to owning a single boot, but to accessing the right one when needed. This shift creates value across multiple stakeholders. The detailed Value Proposition Canvas can be found in Appendix D. The diagram below illustrates how value flows between them within the circular system. (Figure 46):

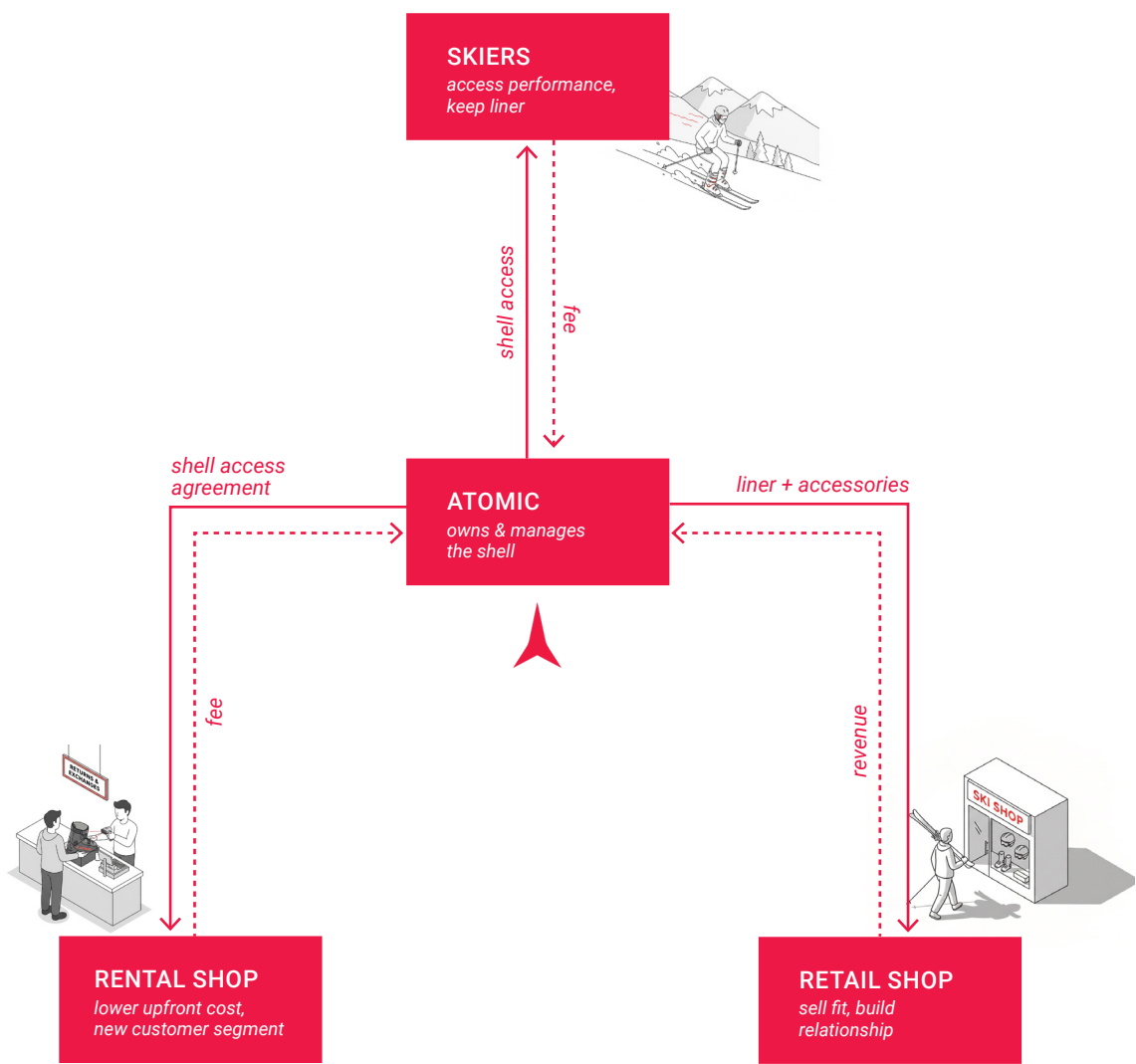


Figure 46: Value flow overview

SKIERS

*Performance that evolves with you.
Always the right boot for your terrain, your level, and your moment.*

Performance Without Compromise

Users always ski a shell that meets their flex and performance expectations. Instead of committing to a single boot configuration, users can access discipline-specific shells for piste, freeride, or touring, each with different performance characteristics. This reduces the risk of purchasing an unsuitable boot, identified as the main difficulty (38%) in Survey 2.

"You never know if you actually bought the right boot until you are on the slope. It is hard to know in the store if the boot actually fits or if it's the right stiffness that matches my skiing style."

- Anonymous, Survey 1
(Question: What do you dislike about your ski boots?)

Flexibility Instead of Commitment

Users are not tied to a single boot over multiple seasons. Shells can be adapted to different terrains, skill progression, or changing preferences.

"I will be riding more in the park this year, so I will need to buy another boot. My current boots will be unusable."

- Anonymous, Survey 1
(Question: What do you dislike about your ski boots?)

Lower Upfront Investment

Rather than paying the full price for a premium boot, users pay for access to performance. This reduces the financial barrier and avoids investing in equipment that is only used occasionally.

"It was an investment."

- Anonymous, Survey 1
(Question: What do you dislike about your ski boots?)

Personal Fit Remains Personal

The liner remains user-owned and personalised. Since better fit was a key reason for buying ski boots in Survey 2 (27%), this ensures consistent comfort across different shells.

Simplified Travel and Storage

Users only need to transport their liner, reducing bulk and simplifying travel.

ATOMIC

Retain the shell. Capture value beyond the first sale.
By retaining ownership of the shell, Atomic can generate value across multiple use cycles instead of a single sale.

The Shell-as-a-Service model shifts Atomic from selling ski boots to capturing the value of their products over time. Instead of creating value at the moment of sale, the shell remains in circulation and generates value across multiple use cycles through refurbishment and redistribution.

Importantly, this model builds on initiatives already under development at Atomic, including expanding repair practices, establishing a repair centre in Altenmarkt, developing a durability index, and piloting shell recycling. The proposed model connects these efforts into a coherent system.

Economic Value
Each shell generates recurring revenue as it moves through multiple use cycles. By retaining control over the shells and recovering them at the end of their lifecycle, Atomic can reduce its dependency on virgin materials through closed-loop recycling.

Strategic Value
Retaining ownership provides visibility over where products are and how they degrade. This creates a feedback loop between use and design that supports more informed product development.

Sustainability Value
Extending the use of the shell reduces the need for new material production and distributes its environmental impact over a longer period. Closed-loop recycling becomes the final step after the product’s functional value has been fully utilised, rather than the primary strategy.

RENTAL SHOPS

Upgrade rental to performance.
Reduce risk while reaching new customer segments.

The proposed business model reframes rental from a lower-tier alternative to also a performance-oriented service. It captures a user group that traditionally remains outside the rental market.

Economic Value
No upfront investment in ski boots reduces capital lock-in and financial risk. At the same time, the model opens access to a new, performance-oriented customer segment through the Atomic Performance Guarantee.

Operational Value
At the end of the season, shells are returned for inspection and refurbishment. This reduces maintenance effort and eliminates the need for long-term storage.

Strategic Value
Rental shops can offer both high-performance and standard rental boots within one system, allowing them to serve a wider range of users and differentiate themselves from competitors.

RETAIL
SHOPS

Sell the fit. Build relationships beyond the first sale.

Economic Value

The liner becomes a standalone product, creating additional revenue beyond full-boot sales. The system increases demand for higher-margin custom-fit liners and enables the sale of accessories such as the overboot (the slipper for the liner).

Operational Value

Because the liner can be sold and replaced independently, shops can offer services such as upgrades, replacements, and refitting without requiring customers to buy a new boot. This creates repeat visits.

Strategic Value

Retail shops can differentiate themselves through expertise in liner fitting rather than competing mainly on price. Instead of relying on one-time sales, they build long-term relationships with customers through continuous service.

The aim of design for a circular economy is to maintain product integrity across multiple use cycles, focus on closing loops, and simultaneously build economically viable product-service systems (Sumter et al., 2020). The following sections will answer how this is done in the case of the proposed business model for Atomic.

6.4 HOW THE SYSTEM OPERATES

To make the business model work in practice, several system enablers are required. This section introduces the key elements that allow the shell to circulate within the system.

6.4.1 SYSTEM ENABLERS

The model can be broken down into six system enablers that close the loop. These form the foundation of the business model and together address the durability mismatch, the loss of lifecycle control, and the economic barriers to circularity identified in earlier chapters.

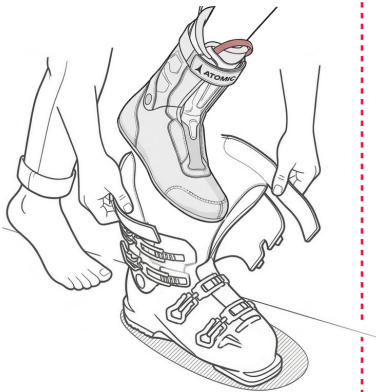
1. Access and Use Model

Each shell carries a Digital Product Passport (DPP), which records its full history: inspection results, flex measurements, refurbishment actions, and circulation path. This makes quality grading transparent and ensures that transitions between performance tiers are controlled and traceable, both for operational reliability and for communicating condition honestly to the skier selecting it. The DPP is also scanned at the point of liner purchase, registering the user and granting access to the platform.



2. Liner-shell compatibility

The personalised liner is fitted to the skier's foot width, which determines their compatible shell category — Ultra, Prime, or Magna. Since these models differ in last width, each liner is paired with one category throughout the system. This is not a practical constraint. Shell categories are already defined by foot morphology, meaning a skier fitted for one category would not benefit from, or comfortably use, another.



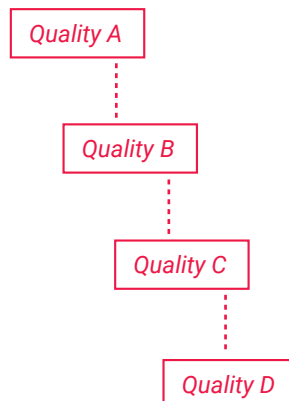
3. Retained Ownership and Distribution

At the core of the system is the retention of ownership of the shell. Atomic will enter into a financial agreement with rental companies that will allow Atomic to retain ownership. This approach addresses a key barrier identified in the current system: the loss of lifecycle control after sale. By retaining ownership, Atomic ensures that shells are returned to the system at the end of each season, enabling structured refurbishment and redistribution.

"If you are not getting it back, it's not scalable. It's a systemic barrier."
-S. Dodge,
Ellen McArthur
Foundation, personal
communication,
January 15, 2026

4. Cascade Usage and Performance Grading

Shells circulate across multiple use cycles and are reassigned to different user groups, identified in Chapter 3.2.1, based on their condition and corresponding performance needs. Rather than following a fixed, time-based lifecycle, their use is determined by performance. High-performance shells are allocated to performance-sensitive users. As shells degrade, they are reassigned to less demanding use contexts, such as traditional rental environments. This cascading use across performance levels extends the functional lifetime of each shell and aligns product performance with user requirements over time.



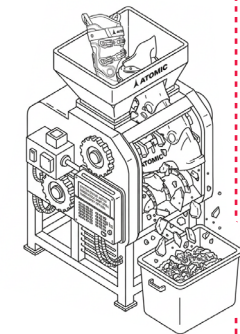
5. Refurbishment Between Use Cycles

Between circulation cycles, shells are inspected and refurbished. This includes cleaning, aesthetic renewal (as explained in more detail in Chapter 7), and, when necessary, replacing high-wear components identified in Chapter 3.1.4. Refurbishment is essential not only to maintain functional performance but also to address aesthetic degradation, which was identified as a primary driver for premature replacement. By restoring both function and appearance, refurbishment enables shells to remain desirable across multiple users and use cycles.



6. End-of-Life and Material Recovery

Shells remain in circulation until they no longer meet minimum performance or safety requirements. Only then are they removed from the system and processed for closed-loop recycling. In this model, material recovery is positioned as the final step after the product's functional value has been fully utilized, rather than as the primary sustainability strategy.



6.4.2 COMPONENTS LIFECYCLE WITHIN THE SYSTEM

The shell lifecycle in the proposed system illustrates how shells circulate through the system over time, moving across different performance levels and use contexts. Figure 47 provides an overview of this lifecycle, showing how shells move from high-performance use towards lower-demand contexts before reaching end-of-life.

For the purpose of explanation, the lifecycle is described in linear phases, although in practice, reassignment is based on performance grading rather than fixed time intervals, meaning that the shell most likely won't downgrade after every season.

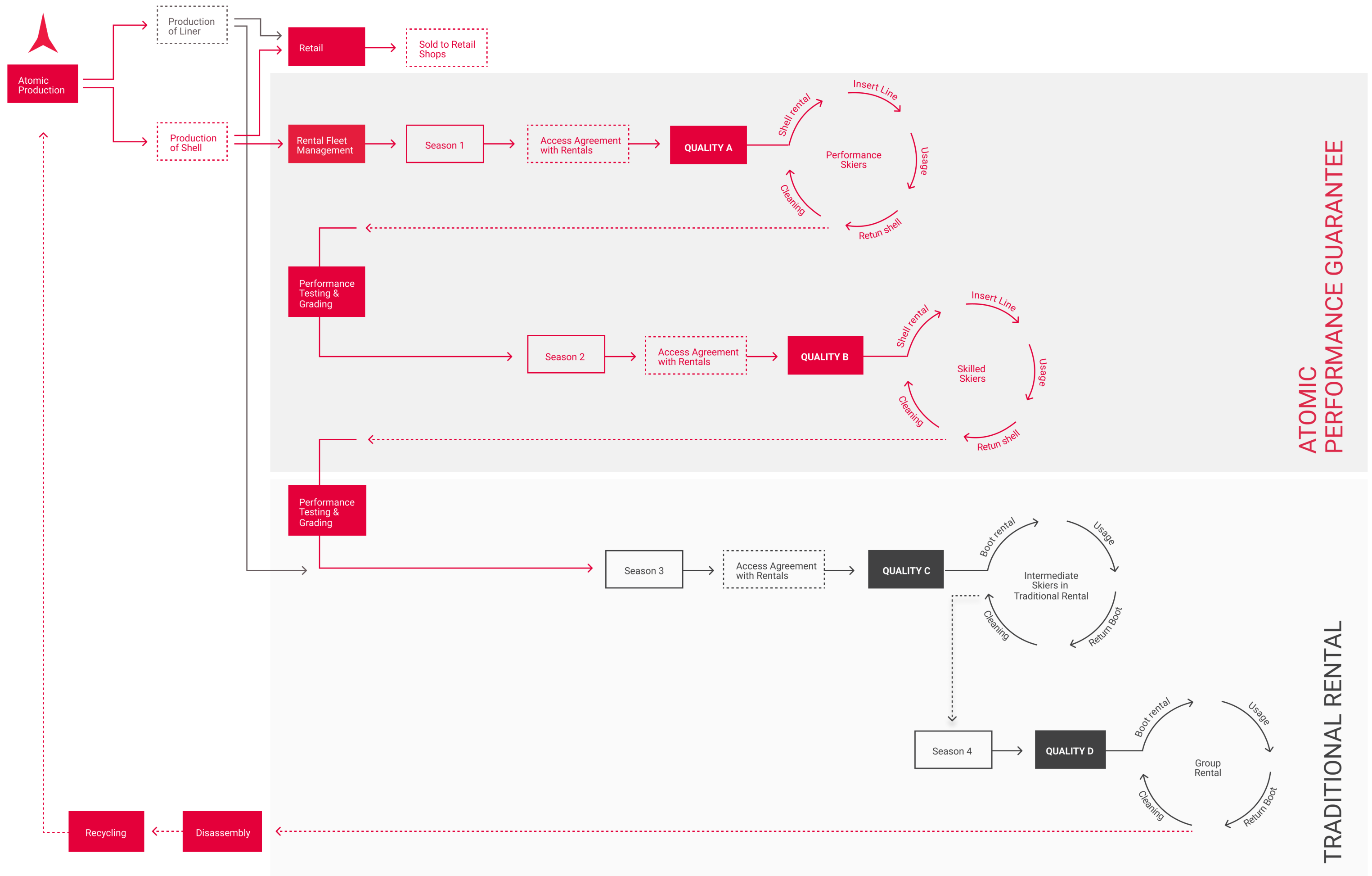


Figure 47: Proposed Business Model

THE SHELL

Phase 1 – Performance Skiers

At the beginning of its lifecycle, the shell enters circulation in its highest performance grade coming directly from the factory. While it is distributed to rental shops, ownership remains with Atomic. The shell is rented to performance-oriented skiers under the Atomic Performance Guarantee, delivering maximum stiffness, responsiveness, and access to the latest technology. Users combine the shell with their personalized liner to ensure a consistent fit. Once the shell is returned to the rental, they handle cleaning and minor maintenance. At the end of the season, shells are returned to Atomic, where they are tested, graded, and refurbished. If performance no longer meets the requirements of this user group, the shell is reassigned.

Phase 2 – Skilled Skiers

Following initial use, the shell remains fully functional but may show slight reductions in stiffness. It is reassigned to skilled recreational skiers who require control and comfort without peak-level performance. The shells continue to be used with personal liners under the Atomic Performance Guarantee. After each season, shells return to Atomic for grading and refurbishment, enabling continued circulation.

Phase 3 – Intermediate Skiers

As performance and, therefore, stiffness characteristics continue to decline, the shell transitions into traditional rental contexts. At this stage, rental liners are integrated, as users in this segment typically prefer rental over ownership due to lower usage frequency and not enough commitment to invest in a ski boot. From this phase onwards, shells remain within the rental shop's internal system. Based on existing rental practices, shops assess whether the shell is still safe for use. If not, it is removed and returned to Atomic for recycling.

Phase 4 – Entry-Level Skiers

In later cycles, the shell is used in entry-level or group rental contexts. Here, performance requirements are lower, and accessibility and basic functionality become more important than stiffness or precision. The shell remains structurally safe and functional, allowing the final functional value to be extracted before reaching minimum performance thresholds.

Phase 5 – Exit and Material Recovery

Once the shell no longer meets defined safety or performance thresholds, it is removed from the system. Only at this point does it enter the disassembly and recycling processes. The functional value of the shell has been maximised across multiple use cycles.

THE LINER

In contrast to the shell, the liner does not circulate within the system. It is purchased and owned by the user and remains consistent across different use cycles. The liner defines fit, comfort, and hygiene, and is reused across multiple shells over time. This distinction is essential: while the circulating shell enables long-term value retention, the personal liner ensures familiarity and user acceptance.

Alignment with Current Atomic Developments

The five proposed lifecycle phases do not introduce a completely new rhythm but instead align with Atomics' existing product-redesign cycle for the Hawx Range. A new generation is launched in Year 1, followed by a carry-over in Year 2, a colour refresh in Year 3, and another carry-over before the cycle restarts and the boot's shape changes. These moments create natural intervention points for refurbishment and reintegration into the system. For instance, during aesthetic updates, returned shells can undergo visual renewal before re-entering circulation. If these shells transition into the traditional rental fleet, aligning their appearance with the current generation helps prevent visible aging from signaling reduced value. In addition, the proposed model builds on several developments already underway at Atomic. This includes the introduction of an overboot, a "slipper" for your liner, which allows users to wear their liner outside the shell and travel to and from the resort without additional footwear. Atomic is also working on a more durable premium liner, designed to maintain fit over time and reduce performance degradation. Furthermore, the planned testing and repair centre in Altenmarkt and the development of a durability index (A. Magnetti, 2026) support key mechanisms of the system, such as performance grading and refurbishment. Together, these developments provide a strong foundation for implementing the proposed business model.

While the proposed business model also offers opportunities for system and user-level design, this thesis focuses on the product level. The redesign of the shell aligns more closely with my personal learning goals and enables a deeper exploration of how circular strategies can be embedded directly into the product.

PRODUCT IDEATION FOR LIFECYCLE EXTENSION

chapter 7

The proposed circular ownership model introduces multi-cycle use of the ski boot shell, shifting the focus from single-product sales to long-term value retention. This leads back to the central design question of this thesis:

How can a circular business model for ski boots be realised, and what product adaptations are required to support it?

This chapter focuses on the implications at product level. The analysis in Chapter 3.1 shows that the current ski boot design limits value retention in two key ways: perceived performance decline and poor repairability, due to the use of rivets, which are particularly hard to open (Chapter 3.1.2).

To enable repeated use cycles, the ski boot shell must allow the refurbishment and replacement of high-wear components without compromising the structural shell. The heatmap in chapter 3.1.4 identifies the components that require regular renewal to maintain desirability:

- buckles
- shell
- grip pads
- power strap

As labour time is a key cost driver, the product architecture must minimise disassembly time, simplify inspection, and enable efficient component replacement.

7.1 REQUIREMENTS

These considerations are translated into a set of design requirements across system, product, and user levels in the following section.

Requirements derived from the System-Level

These requirements arise from the circular ownership model and its operational logic.

1. The shell must enable time-efficient refurbishment to minimise labour per cycle.
2. The architecture must allow non-destructive disassembly.
3. Disassembly must require minimal tools and low complexity.
4. The shell must support digital traceability across multiple cycles.
5. Performance characteristics such as flex must be updateable and not permanently printed on the shell.
6. The shell must remain compatible with end-of-life disassembly and material recovery strategies.

Requirements derived from the Product-Level

These relate to the shell's physical architecture and material logic.

7. The structural shell must maintain safety and performance across multiple refurbishment cycles, including repeated disassembly and component replacement.
8. High-wear components must be replaceable without damaging the structural shell.
9. The TPU shell must enable the use of recycled content while still allowing seasonal differentiation.
10. The shell must allow aesthetic renewal without replacing the structural core.

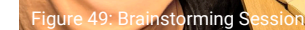
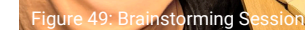
Requirements derived from the User-Level

These relate to perception, usability, and rental acceptance.

11. The visual design must remain desirable over multiple seasons.
12. The shell must facilitate easy liner removal and reinsertion to support user handling.
13. Refurbished shells must appear well-maintained and trustworthy within performance-oriented rental environments.

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To further explore how the requirements can be met, a brainstorming session was held on February 13, 2026, with five fellow design students at TU Delft. The 6-3-5 brainwriting method was used as a structured approach to generate a broad range of ideas, followed by a discussion round to evaluate and cluster the most promising directions.



Looking back at the disassembly map (Chapter 3.1.2), some requirements can be addressed relatively straightforwardly. The refurbishment of buckles, power strap, and grip pads can be enabled through minor design adjustments. In contrast, refurbishment of the shell remains more challenging, as no solution currently exists to restore its appearance and maintain product desirability. The following chapter, therefore, explores different options.

7.2.1 SURFACE REFURBISHMENT

To explore ways to refurbish the shell surface and reduce visible scratches, four methods were tested in small-scale experiments (Figure 50). Both subtractive and additive approaches were explored, alongside solutions integrated into the original design. All methods were evaluated using a Harris profile.

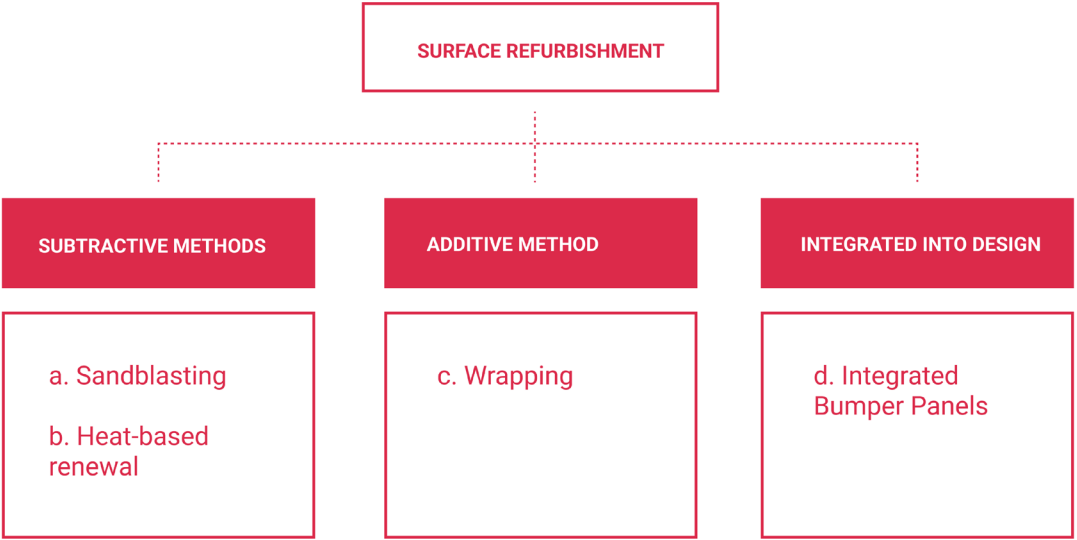
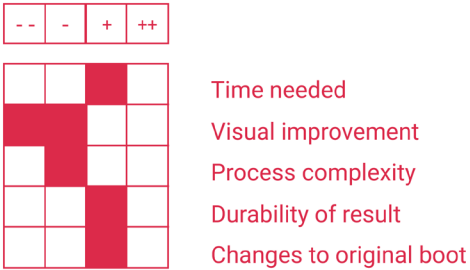
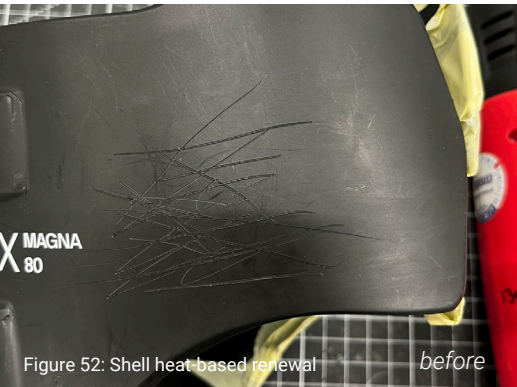
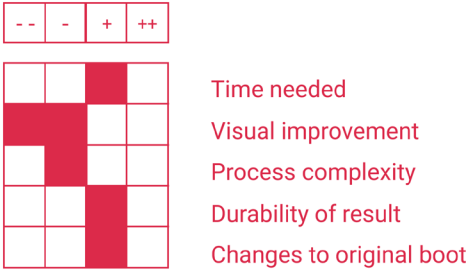


Figure 50: Surface treatments overview

a. Sandblasting & Sanding
The TPU shell is too soft for sandblasting, while manual sanding is labour-intensive. Removing material is problematic, as it can unpredictably affect material properties. In addition, sanding does not effectively remove deeper scratches and often worsens the surface appearance.

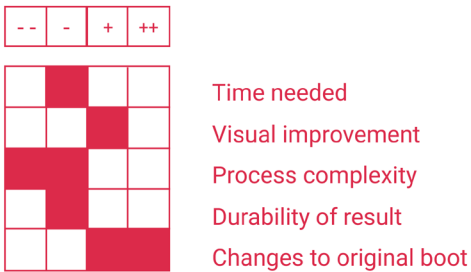


b. Heat-based renewal
Heating up the TPU shell can reduce the visibility of small scratches by slightly reflowing the surface. However, the process is difficult to control, time-consuming, and requires precise, detailed work to achieve consistent results. It may also affect the material properties in unpredictable ways.



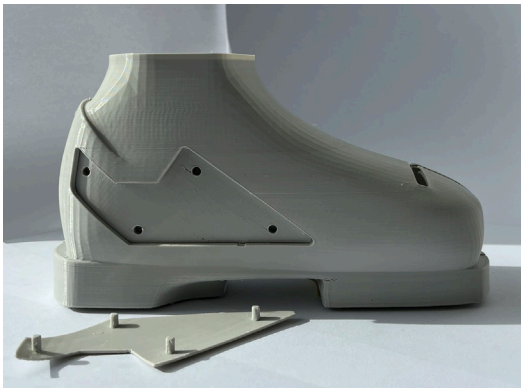
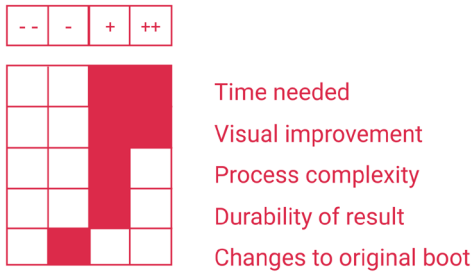
c. Wrapping

Applying a vinyl wrap to the shell is labour-intensive and may require partial disassembly of the boot. The result can appear uneven, and the foil is prone to tearing during use and may eventually detach, making the boot appear more worn than before.



d. Integrated Bumpers

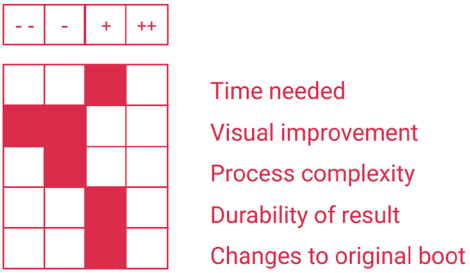
Integrating a bumper into the shell design builds on existing protective elements, such as grip pads. The bumper is a thin panel located on the boot's high-wear areas designed to protect the shell. Implementing this solution requires minor adaptations to the shell geometry.



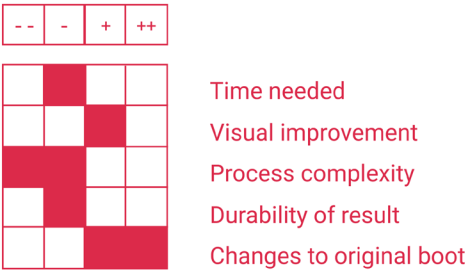
Based on the Harris Profile (Figure 55), the Bumper side panels were selected as the most promising direction, as they directly address the key challenge of aesthetic value loss while aligning with efficient refurbishment. Unlike sanding, heat-based methods, or wrapping, they provide a consistent and durable visual improvement without relying on labour-intensive or difficult-to-control processes. By externalising wear to a replaceable component, side panels enable quick, low-skill refurbishment and support repeated use cycles. In addition, they allow for seasonal updates through changes in colour, texture, or finish, helping to maintain product desirability over time. At the same time, they require only specific changes to the existing shell.

Heat-based renewal and polishing can be used as additional methods to improve the overall appearance of the shell before it re-enters the system.

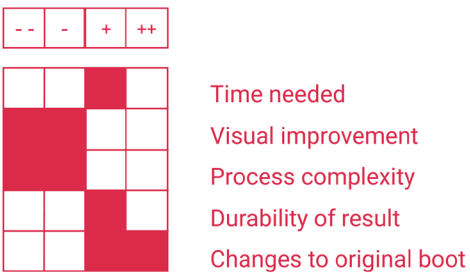
Sanding



Wrapping



Heat-based



Bumper

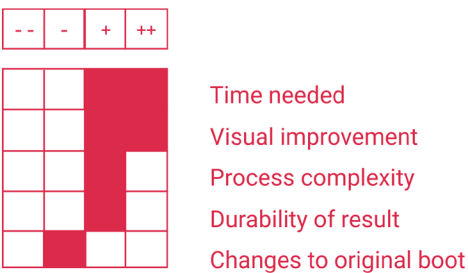


Figure 55: Harris Profiles

7.2.2 IDEATION AND SHAPE EXPLORATION ON BUMPER

Taking the wear heat map in chapter 3.1.4 as a starting point, an iterative exploration was conducted to investigate how protective bumpers can be integrated into the ski boot shell. The aim was not only to cover high-wear areas, but to do so in a way that aligns with the existing design language. As identified in Chapter 3.2.3, sustainability is not a primary concern for customers in rental or retail. Therefore, the solution should not appear as an added feature for sustainability, but integrate seamlessly into the Atomic's design and even strengthen its visual identity.

The exploration focused on forms that follow the shell's geometry, ensuring the bumper reads as part of the boot rather than an external add-on. Multiple styles were developed, varying in size, placement, and coverage (Figure 57). Styles that appeared visually intrusive, required many separate parts, or disrupted the existing design language were discarded.

To evaluate these, both sketching and physical mock-ups were used. While sketches enabled quick iteration, applying tape directly onto the boot helped to assess scale, curvature, and visual integration on the actual product.



Figure 56: Ideation on the boot

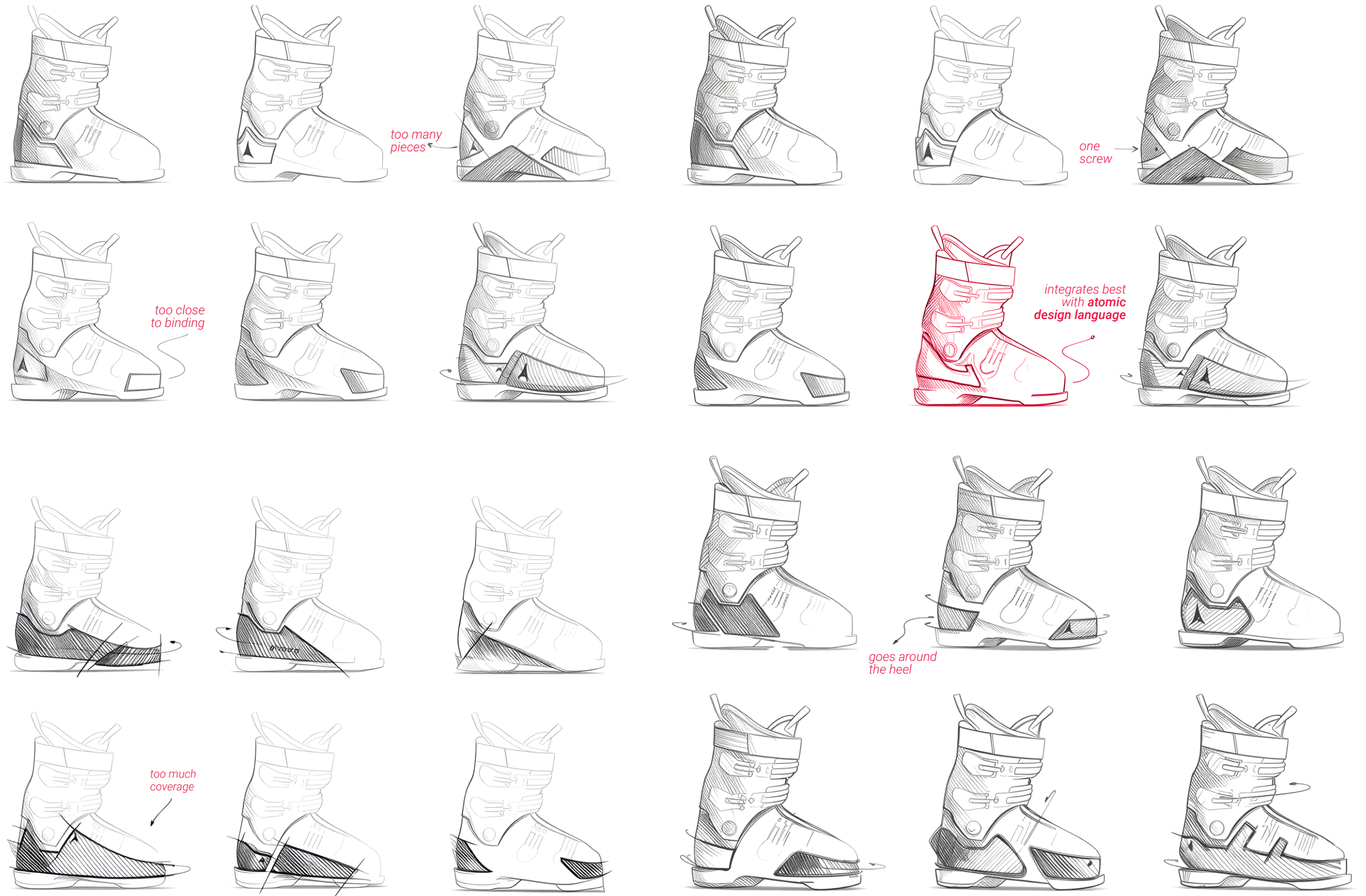


Figure 57: Shape exploration

7.2.3 PROTOTYPING

To develop the bumper concept further, several physical prototypes were created to test form, integration, and attachment. Through iterative prototyping, including mock-ups and 3D printed parts, different geometries were evaluated directly on the boot.

Learnings

The prototyping revealed that increasing coverage adds complexity to refurbishment and would require more extensive changes to the boot, while multiple parts negatively affect visual integration.

Testing different attachment methods also revealed an important structural constraint. The shell is only a few millimetres thick, leaving no available volume to integrate the bumper into the existing geometry. To achieve a seamless integration and avoid the bumper appearing as an added layer, the shell needs to locally increase in thickness so that the panel aligns with the shell surface rather than sticking out. At the same time, the attachment should not require to many holes in the shell, as this might allow water to enter during skiing and wet the liner. The attachment solution should also be fast and easy to disconnect, enabling quick replacement without specialised skills, while still being secure enough to withstand skiing forces and impacts. Local thickening is feasible, as similar variations in wall thickness already exist in current designs, and the affected area is mainly around the heel, where it has a limited influence on flex behaviour.

Based on these insights, the design shifted towards a single-piece panel that follows the existing shell geometry. This reduces component quantity, simplifies refurbishment, and integrates more naturally into the overall form.



7.2.4 FINAL BUMPER DESIGN

The final bumper concept balances protection with minimal design disruption by integrating a replaceable panel directly into the lower shell, covering the primary high-wear zones identified in the heat map. The panel is positioned around the heel and side areas, where most scratches occur.

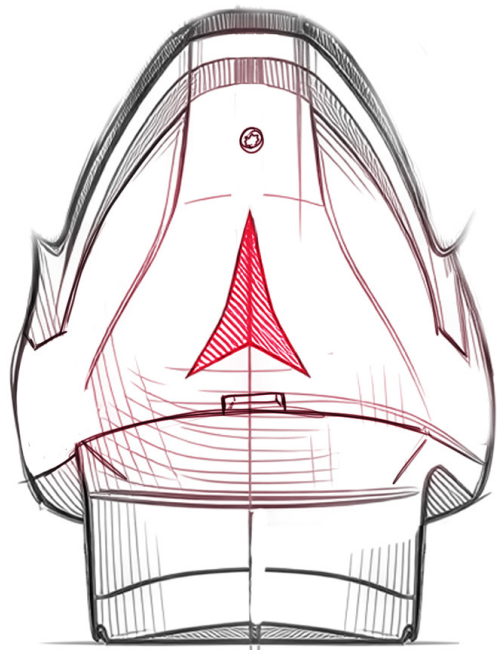


Figure 60: Back view

Protecting the shell

The bumper acts as a sacrificial layer, absorbing aesthetic wear while protecting the structural shell. The bumper is made from a thin TPU panel.

Once scratched, it can be easily replaced, enabling fast refurbishment. Using TPU also ensures compatibility with existing closed-loop recycling streams.

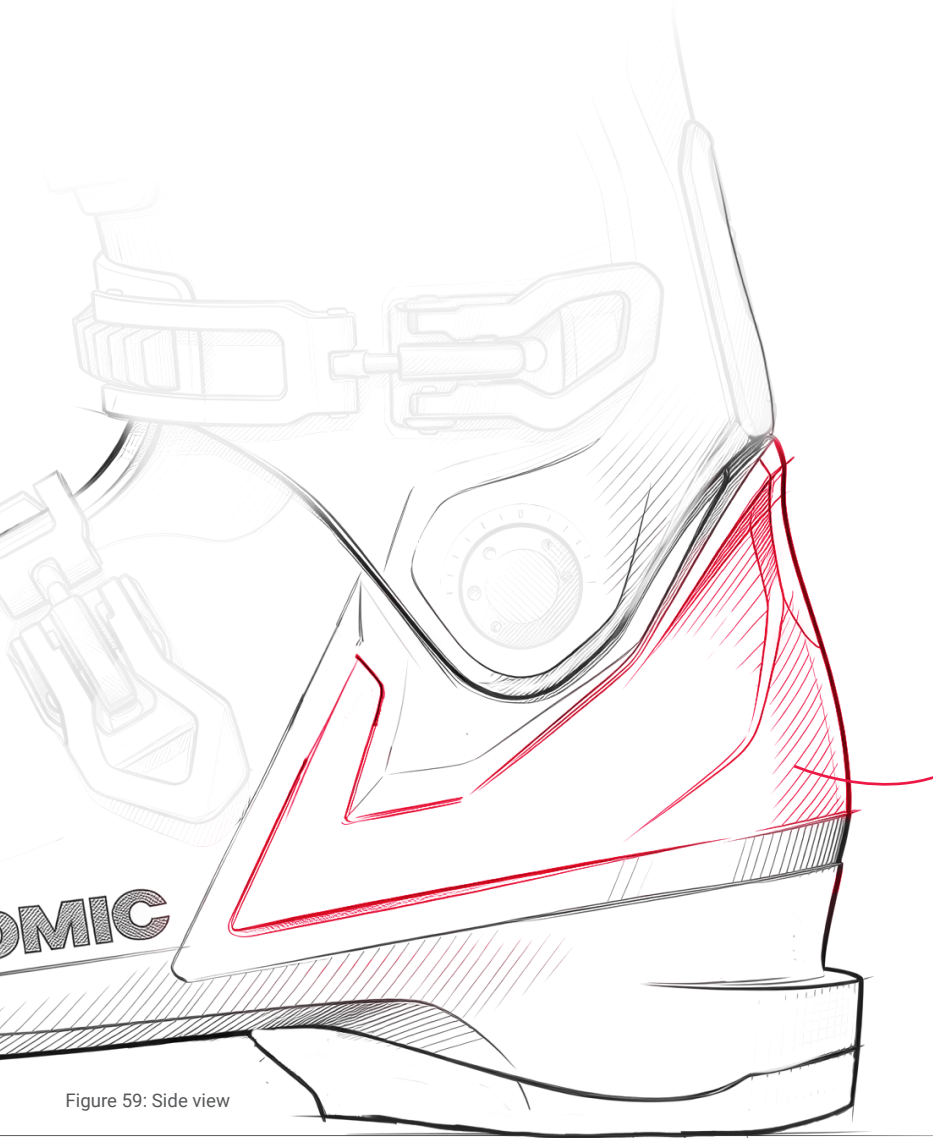
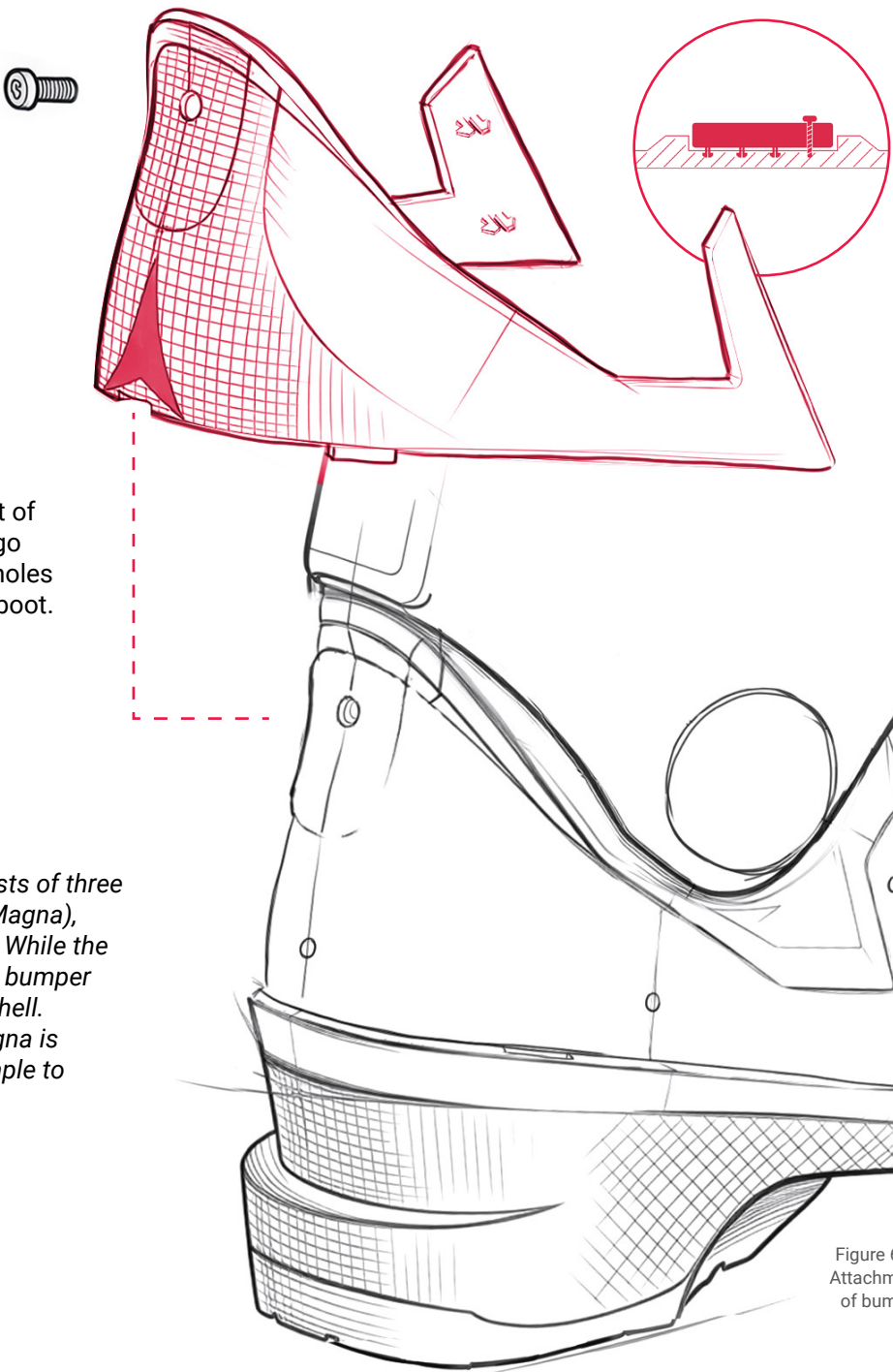


Figure 59: Side view

Attachment Strategy

The bumper is attached using a combination of fixation methods to ensure it stays in place while still being easy to replace. At the back, it is secured with one Phillips 2 screw in a reinforced area of the shell to prevent it from coming off unintentionally. At the bottom, the panel is clipped in on both sides, while along the sides it is held in place with seven reversible snap-fits that provide additional support.



Due to the local reinforcement of the shell, the screw does not go all the way through, avoiding holes that could let water enter the boot.

The Atomic Hawx range consists of three shell variations (Ultra, Prime, Magna), each with distinct geometries. While the same design logic applies, the bumper needs to be adapted to each shell. In the following, the Hawx Magna is used as a representative example to demonstrate the integration.

Figure 61: Attachment of bumper

A SKI BOOT DESIGNED FOR BEYOND THE FIRST USE

chapter 8

Building on the need for focused refurbishment identified in the previous chapter, the final ski boot design translates these requirements into a product architecture that supports repeated use cycles. Rather than replacing the entire boot, the design focuses on enabling the renewal of high-wear components while preserving the structurally durable shell.

To achieve this, the design introduces targeted interventions. A replaceable bumper protects and renews the most affected areas of the shell, a revised colour strategy enables aesthetic updates, and an adapted product architecture supports disassembly and component exchange. In addition, a Digital Product Passport enables tracking across multiple use cycles and supports circular value retention at the system level.

Together, these elements form a ski boot that is no longer designed for a single lifecycle, but for continuous use beyond the first use. The following sections explain these interventions in more detail.



Figure 62: Final boot design - right view

The final ski boot design rethinks the product as something that can be used and renewed over time, rather than replaced after a single use cycle. Instead of seeing wear as the end of the product, it becomes an opportunity to update and refresh it.

The boot builds on the proven Atomic Hawx design, keeping its performance and fit. At the same time, its structure is adapted: the shell serves as a durable core, while high-wear parts such as the bumper, grip pads, and power strap are designed for easy replacement. This approach is also visible in the design. The shell is designed in a neutral grey, enabling the use of recycled material, as identified in Chapter 3.3.4. Coloured and branded parts highlight the elements that can be changed and updated. This turns the ski boot into a product that can be maintained, updated, and kept desirable over time.



Figure 63: Final boot design - left view



Figure 64: Final boot design - bottom



Figure 65: Detail Side

8.1 PRODUCT ARCHITECTURE CHANGES

Digital Product Passport (DPP)
Flex is no longer printed directly onto the shell as flex degradation is identified as an opportunity to extend product lifetime within the proposed business model and will change with usage. Instead, flex and additional product data are accessed via the DPP QR code. The DPP also stores information on rental cycles, refurbishment history, and replaced components.

Bumper
A replaceable bumper protects the shell from aesthetic wear, preserving the structural core.

Grip Pads
Grip pads can be replaced once worn.

Power Strap
The power strap can be easily removed by loosening two Phillips PH2 screws, allowing quick replacement or updates.

Buckles
Buckles can be visually refreshed through tampo printing to maintain a clean appearance.

Screws instead of rivets
Rivets are replaced with screws to enable non-destructive disassembly and easier component replacement.



Figure 66: Exploded view of final boot design

8.2 COLOUR AS A REPLACEABLE LAYER

Colour variation enables seasonal updates without requiring changes to the core shell. The shell is designed in a neutral grey, allowing the use of recycled material, as only darker colours can be achieved with recycled inputs, as identified in Chapter 3.3.3.

Visual updates are achieved through removable components. By applying colour only to components that can be easily removed and replaced, the appearance can be refreshed each season while the structural shell remains unchanged. Elements such as the bumper can be produced in different CMF (colour, material, finish) variations, enabling design updates without changing the entire shell.

Branding follows the same logic. The logo is printed onto the bumper, so it is refreshed as the part is replaced over time. Buckles can be made to look fresh again through tampo printing, using an already established production process.



Figure 67: CMF variation



Figure 68: Boot in usage



Figure 69: Change of Bumper



Figure 71: Boot in Snow



Figure 70: Performance Grading and Flex Test



Figure 72: Custom-fit Liner

VALIDATION

chapter 9

This chapter evaluates the proposed ideas through two complementary validation approaches: a design critique and a lifecycle assessment.

The design critique assesses the concept from a strategic and practical perspective, focusing on feasibility, stakeholder alignment, and implementation challenges. In parallel, the LCA evaluates the environmental impact of the model, quantifying its potential to reduce CO2 emissions compared to the current linear system. Together, these methods provide both qualitative and quantitative insights into the viability of the proposed solution.

9.1 SYSTEM DESIGN CRITIQUE

To assess the feasibility, viability, and desirability of the proposed business model, validation was conducted internally at Atomic. Due to competitive considerations, Atomic did not permit external validation with rental or retail partners. Furthermore, as the concept represents a forward-looking shift in ownership and service logic, no direct validation with end users was conducted at this stage. Instead, indications of desirability are derived from conducted surveys, expert interviews, and analyses of Reddit discussions. While this does not provide full market validation, it provides initial support for the concept’s underlying assumptions.

Two roundtable discussions were conducted with key stakeholders at Atomic to evaluate the proposed concept. The first session, held on March 10, 2026, involved H. Holzer (Director Anticipation & Advanced Research) and G. Pfusterer (Customer Service Manager). The second session, also held on March 19 2026, included J. Roe (Business Unit Director Ski Boot Alpine) and R. Schwarzenbrunner (Sustainability Manager).

The discussions surfaced three themes that structure the findings below (Figure 73): the strategic potential and market positioning of the concept; the operational and logistical conditions required for implementation; and the stakeholder dynamics that will determine its adoption pathway.

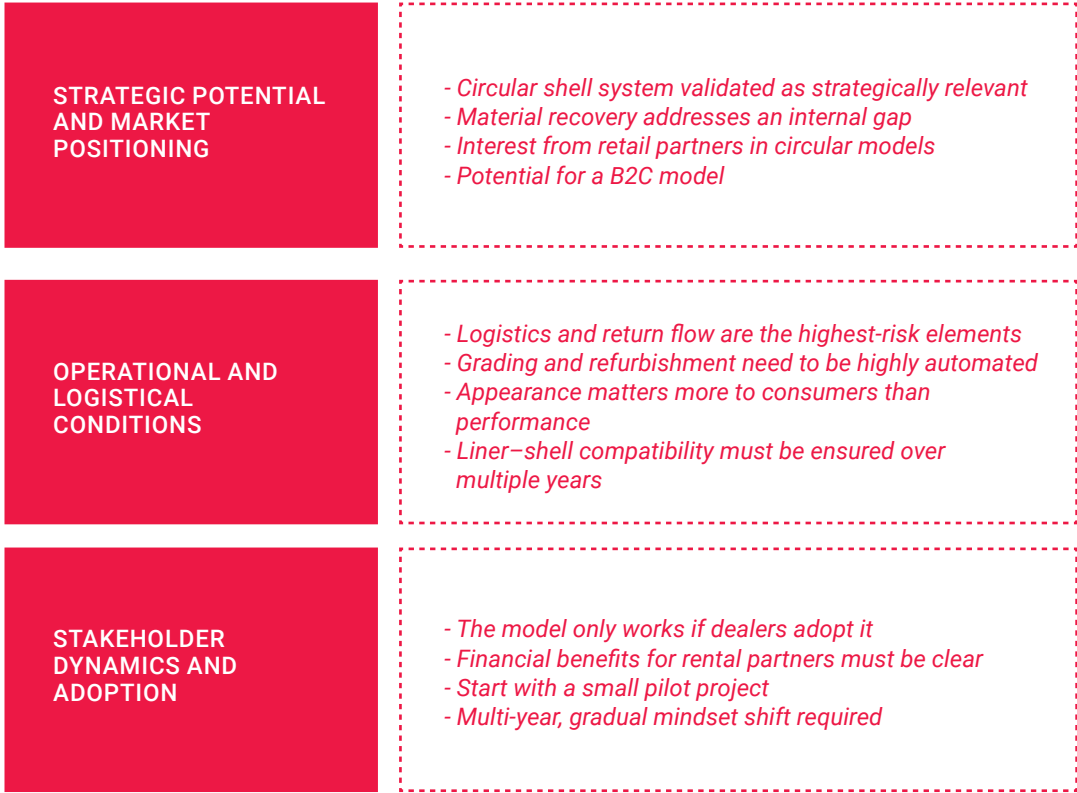


Figure 73: Overview of validation outcomes

1. Strategic potential and market positioning

Both sessions show strong conceptual support for the circular shell system. The separation of a durable shell and a personal liner is seen as a promising approach to extend product lifetimes and enable circular value retention. The concept is perceived as a relevant and timely response to emerging circularity requirements within the industry. Both sessions also confirmed that material recovery has long been an internal objective for which no concrete mechanism currently exists, positioning the proposed model as a direct answer to an identified strategic gap.

One participant highlighted that there is already active demand from retail partners for a circular collaboration framework, further supporting the concept’s relevance.

“We have retailers that are looking for a circular business model together with us, and we just don’t have a really good suggestion so far. I could imagine that they would be happy if we propose that idea.”
- R. Schwarzenbrunner, personal communication, March 19, 2026

Beyond circularity, the second session positioned the model as an opportunity to build a more direct relationship with end users and to capture value beyond a single use cycle. This suggests that it could be strategically interesting for Atomic to explore such a service independently of rental partners as well. In this way, the proposed business model addresses something retail partners are structurally unable to offer: direct-to-consumer financing. This positions Atomic not as a competitor to its retail channel, but as offering a complementary and differentiated value proposition.

The consumer-facing value proposition was identified as strong.

“The idea is extremely good, but it will certainly be a long road. However, we are in the driver’s seat. You just have to start with a few innovative dealers.”
- H. Holzer, personal communication, March 10, 2026

2. Operational and logistical conditions

Across both sessions, logistics and operational complexity emerged as the most consistently cited challenge, and the one with the greatest potential to undermine the business case if left unresolved. The system requires reliable processes for transport, grading, tracking, and refurbishment, while clearly allocating responsibilities and financial risks across all parties involved.

“The system has to be 100% secure for the rental shop, Atomic, and the end consumer.”
- G. Pfusterer, personal communication, March 10, 2026

A related risk concerns product loss and liability. Shells that are stolen, damaged, or not returned require clearly defined contractual and insurance frameworks before the model can function at scale. Participants were consistent in their view that any weak link, whether a dealer unwilling to return shells, an ambiguous damage policy, or an inconsistent grading outcome, would erode trust rapidly, particularly in the early stages of adoption.

In addition, technical constraints such as liner-shell compatibility and backward

compatibility must be considered to ensure that components function reliably across different configurations and product generations.

Transport costs were flagged as a potentially underestimated variable, with the risk of weakening the model's economic viability. To remain cost-viable, the grading and refurbishment process must be highly automated, with minimal manual labour per boot.

Both sessions also confirmed that appearance matters more to consumers than technical performance when choosing a rental boot. Participants strongly indicated that grading systems based on flex testing alone are insufficient, and that aesthetic refurbishment is a functional requirement for maintaining rental acceptance:

"I think it's going to come down to how does the boot look more than it's going to be about the flex. If the boot looks beaten up, it's not going to be rented anymore; nobody's going to want it."

- J. Roe, personal communication, March 19, 2026

This confirms that the aesthetic refurbishment process must be treated as a primary criterion alongside the performance grading.

3. Stakeholder dynamics and adoption

The third theme focuses on who needs to be convinced, and how. Both sessions were clear on one point: getting dealers and rental partners on board is the biggest hurdle. Rental operators will not take on additional work and logistics unless there is a clear financial benefit.

"If both sides don't cooperate perfectly, the system is doomed from the start."

-G. Pfusterer, personal communication, March 10, 2026

This means the business case and advantage for rental partners must be clearly communicated from the start. Both participants made the same point: dealers act on their own interests, not on the strength of an idea.

"If the dealer sees a clear advantage for themselves, they will be on board. The package just has to work."

- H. Holzer, personal communication, March 10, 2026

Both sessions recommended starting small, with one to ten carefully chosen, Atomic-aligned rental partners. A pilot allows the model to be tested and adjusted before scaling.

On the consumer side, a short-term, flexible access model was seen as potentially too complicated. A seasonal or long-term rental structure was considered more realistic, as it simplifies the system's logistics. Direct financing for end consumers was also raised as a promising direction, lowering the entry barrier through leasing or subscription-based access while keeping Atomic in control of the product at the end of use:

"We could offer financing for the end consumer. I think it could work more easily, and then we finally find a way to do something that the dealers can't offer."

- J. Roe, personal communication, March 19, 2026

Finally, both sessions acknowledged that adoption will be a long-term process, drawing a parallel to other access-based models that required time for both users and retailers to adopt (like seasonal ski rental). The model requires not only operational infrastructure but a gradual shift in consumer and dealer mindset.

Conclusion

The concept was received positively across both sessions, with its core strength lying in the combination of liner ownership and extended product lifetimes, enabling circular use cycles without sacrificing personal performance.

The model is particularly compelling for performance-oriented users, positioned between casual rental and full ownership. Rather than creating entirely new demand, it makes an existing market gap accessible by lowering the upfront cost of high-performance equipment.

Its success therefore depends less on desirability and more on resolving the operational and logistical conditions identified above.

9.2 VALIDATION OF PRODUCT CHANGES

To evaluate the proposed product changes, a feedback session was held with H. Holzer from Atomic on March 31, 2026 , focusing on the feasibility of the bumper and the use of screws instead of rivets. He confirmed that using screws is technically feasible. Rivets are currently used because they are faster and cheaper in production, but if the boot is used across multiple cycles and monetised accordingly, the slightly higher cost of screws becomes acceptable. He also did not see an issue with water entering the shell, as previous models have already used screw-based connections.

In addition, J. Roe (Business Manager Boots) highlighted a critical gap in the refurbishment approach, particularly regarding aesthetics:

"We don't have a solution to make the outside of the boot look better, that's the problem! You can replace the grip pads, but that's not the part that people are embarrassed about if it looks scratched."

- J. Roe, personal communication, March 19, 2026

This emphasises the importance of addressing visible wear through design, reinforcing the role of replaceable outer components such as the bumper in maintaining perceived product value over time.

9.3 CO2 IMPACT VALIDATION

The proposed business model aims to enable the circular use of ski boot shells. To evaluate whether this approach can effectively reduce CO2 emissions, a lifecycle assessment (LCA) was conducted in collaboration with A. Hochreiter, LCA expert at Atomic who provided the detailed data and the tool for the calculations.

The analysis is based on an Atomic Hawx Magna 130S, selected as a representative example due to its high-performance characteristics and its suitability for cascading across different user segments over time.

9.3.1 REFERENCE SCENARIO

As the model takes a forward-looking approach, several assumptions were required for the LCA. This scenario represents a small-scale implementation of the business model, as discussed during the validation sessions. The system is centered around a limited number of closely collaborating rental partners located near Atomic’s headquarters in Altenmarkt. The scenario is compared to a baseline scenario representing the current linear system.

A rental shop in Wagrain is used as a reference case, as it was named during the validation session as one that already runs pilot projects for Atomic. Following the Product Environmental Footprint Category Rules (PEFCR), the baseline assumes 150 days of use. In the proposed model, the product lifecycle is extended through multiple user phases. It is assumed that the shell remains in high-performance use (Quality A + B) for 150 days, followed by an additional 100 days in lower-performance rental use (Quality C + D). This results in a total lifetime of 250 days, extending the use phase by 100 days compared to the baseline.

Since the liner is considered a personal item that is used across multiple shells, its impact is therefore distributed over its total lifetime. The following section describes the lifecycle step by step (Figure 74).

First Refurbishment Cycle

After the first use phase, the boot returns in high condition and enters the first refurbishment cycle. At this stage, the goal is to restore appearance and maintain performance with minimal workload.

The boot is transported 13 km back from Wagrain to Atomics repair and refurbishment centre and back to Wagrain (total 26km). For transport, an average passenger car (EURO 4) is assumed to fit 10 pairs of ski boots. During this first refurbishment cycle, refurbishment focuses on replacing the TPU bumper. This component weighs approximately 0.0169 kg and consists of 34% primary and 66% secondary TPU. It is attached without adhesives, allowing quick, low-effort replacement while preserving the rest of the shell.

In this scenario, one buckle is assumed to be replaced. While this represents a worst-case assumption, it ensures a conservative LCA. The preferred approach is to reuse a refurbished component sourced from a discarded boot; however, to keep it conservative, a new one is used. Optical defects on the remaining three buckles are restored using a tampo printing process, allowing them to regain their appearance without replacement.

LIFE CYCLE INVENTORY // IMPACT CALCULATION				
TOTAL LIFE CYCLE HAWX MAGNA 130S BASELINE				63,02
TOTAL LIFE CYCLE HAWX MAGNA 130S CIRCULAR BUSINESS MODEL				44,50
Impact reduction (Carbon footprint in %)				-29,39%
		QUANTITY	UNIT	CARBON FOOTPRINT [kg CO ₂ e]
Product	HAWX MAGNA 130 S with additional TPU part for highly strained parts of the shell	1	pc	23,09
	Additional liners during life span	1,67	PR	9,85
	Sparepart 1: Additional TPU part on shell that is replaced (highly strained spot on shell) // clipped on shell, no additional screw or glue necessary // 2 pcs per boot			
		13490,9815	mm³	
		1,3491E-05	m³	
		1250	Density of TPU	
		0,0169	kg	
		34,0000	[%] Share of primary material	
		66,0000	[%] Share of secondary material	
		0,0057	[kg] Weight of primary material	0,03
		0,0111	[kg] Weight of secondary material	0,00
		1,0000	pcs. of sparepart	
Life time	150 days for quality A + B; 100 days additionally for C+D	250	DAYS	-
Refurbish Cycle 1	Transport Nutzung 1 Quality A to refurbishment cycle 1	26	km	0,29
	First trial with rental shop close to the factory (Wagrain)			
	Sparepart 1: Additional TPU part on shell that is replaced (highly strained spot on shell) // clipped on shell, no additional screw or glue necessary // 2 pcs per boot			
		13490,9815	mm³	
		1,3491E-05	m³	
		1250	Density of TPU	
		0,0169	kg	
		34,0000	[%] Share of primary material	
		66,0000	[%] Share of secondary material	
		0,0057	[kg] Weight of primary material	0,03
		0,0111	[kg] Weight of secondary material	0,00
		1,0000	pcs. of sparepart	
	Sparepart 2: Buckle			
	Optical defects are repaired using tampo printing process			
	Worst case: 1 buckle has to be replaced (Very unlikely)			
	Option a) new buckle has to be applied	Quantity [Pcs]		
		Pos 1	0	0,00
		Pos 2	1	0,38
		Pos 3+4	0	0,00
	Option b) refurbished buckle from other boot that is not used anymore is applied	Quantity [Pcs]		
	no burden considered except refurbishment via tampo printing process	3		0,10
	Flex test			
	Energy consumption for machine // check machine in boots workshop // Assumption 0,2 kWh	1	[1] yes, [0] no	0,06
Refurbish Cycle 2	Transport Nutzung 2 Quality B to refurbishment cycle 2	26	km	0,29
	Sparepart 1: Additional TPU part on shell that is replaced (highly strained spot on shell) // clipped on shell, no additional screw or glue necessary // 2 pcs per boot			
		13490,9815	mm³	
		1,3491E-05	m³	
		1250	Density of TPU	
		0,0169	kg	
		34,0000	[%] Share of primary material	
		66,0000	[%] Share of secondary material	
		0,0057	[kg] Weight of primary material	0,03
		0,0111	[kg] Weight of secondary material	0,00
		1,0000	pcs. of sparepart	
	Sparepart 2: Buckle			
	Optical defects are repaired using tampo printing process			
	Worst case: 1 buckle has to be replaced (Very unlikely)			
	Option a) new buckle has to be applied	Quantity [Pcs]		
		Pos 1	1	0,35
		Pos 2	1	0,38
		Pos 3+4	0	0,00
	Option b) refurbished buckle from other boot that is not used anymore is applied	Quantity [Pcs]		
	no burden considered except refurbishment via tampo printing process	2		0,06
	Sparepart 3: Grip pad // New grip pad screwed on boot, old ones are recycled	Quantity [Pcs]		
	New grip pad	2		0,53
	0,118087525	[kg] Weight per pc. of grip pad		
	34,0000	[%] Share of primary material		
	66,0000	[%] Share of secondary material		
	0,0000	[%] Share of glass fibre		
	Shell treatment			
	Minor scratches: Heat gun	1	[1] yes, [0] no	0,03
	Deep scratches: TPU coating	1	[1] yes, [0] no	0,10
	Flex test			
	Energy consumption for machine // check machine in boots workshop // Assumption 0,2 kWh	1	[1] yes, [0] no	0,06

Figure 74: LCA - reference scenario

The energy demand of this refurbishment cycle is low, estimated at 0.2 kWh, mainly for workshop operations such as inspection, flex testing, and tampo printing. The energy demand was verified with an expert interview (F. Lindebner, personal communication, April 3, 2026) Overall, this cycle has minimal material input and very low energy demand, as the structural shell remains untouched.

Second Refurbishment Cycle

After the second use phase, the boot returns in moderate condition, requiring slightly more repair and refurbishment while still maintaining the core structure. Again, the product is transported over 26 km. During this cycle, the TPU bumper is replaced again, following the same process and material composition as in the first cycle. The buckles are reassessed. Due to increased wear, the two most-worn buckles on the shell (see heatmap in Chapter 3.1.4) are replaced with new components, indicating a higher level of functional degradation than in the first cycle. The remaining buckles are retained and, where necessary, visually restored using tampo printing.

In addition, grip pads are replaced as part of a planned wear strategy. Two grip pads per boot are exchanged to ensure safety and compliance with ISO standards. Each grip pad weighs approximately 0.118 kg and consists of 34% primary and 66% secondary material. The removed components are directed into recycling streams. To address increased surface wear, additional shell treatments can be introduced. Minor scratches are treated with a heat gun, while deeper scratches can be repaired with a TPU coating, requiring minimal material input and low additional energy.

Additional energy is required for tampo printing and workshop operations, resulting in a slightly higher total energy demand compared to the first refurbishment cycle.

After completion of the second refurbishment cycle, the boot re-enters use for a final phase in the lower-performance rental segment (Quality C and D). In this phase, the product is used under less demanding conditions, extending the boot’s total lifetime by approximately 100 days beyond the initial 150-day baseline. As a result, the total energy demand increases slightly compared to the first cycle due to these additional processes. However, it remains significantly lower than the energy required for manufacturing a new product.

This scenario assumes that end-of-life treatment remains incineration, as closed-loop recycling processes are not yet in place and to avoid making the scenario overly optimistic.

Impact Assessment and CO2 Reduction

The lifecycle assessment results show a clear difference between the baseline scenario and the proposed circular business model. In the baseline scenario, the total lifecycle impact of the ski boot is 63.02 kg CO2-eq, based on a single-use phase of 150 days (Figure 75).

In contrast, the circular business model scenario, which extends the product lifetime to 250 days through two refurbishment cycles, results in a total impact of 44.50 kg CO2-eq. This corresponds to a 29.39% reduction in the carbon footprint.

Interpretation of Results

The reduction is primarily driven by the extended use of the shell. By retaining the shell across multiple use phases, the need to produce a new boot is avoided, thereby preserving a large share of the embodied emissions.

While additional impacts are introduced through:

- transport between rental and refurbishment,
- replacement of wear components (e.g. grip pads, buckles, bumper),
- and energy use during refurbishment,

these contributions remain comparatively small.

The stacked impact breakdown shows that the added processes form only a minor share of the total footprint.

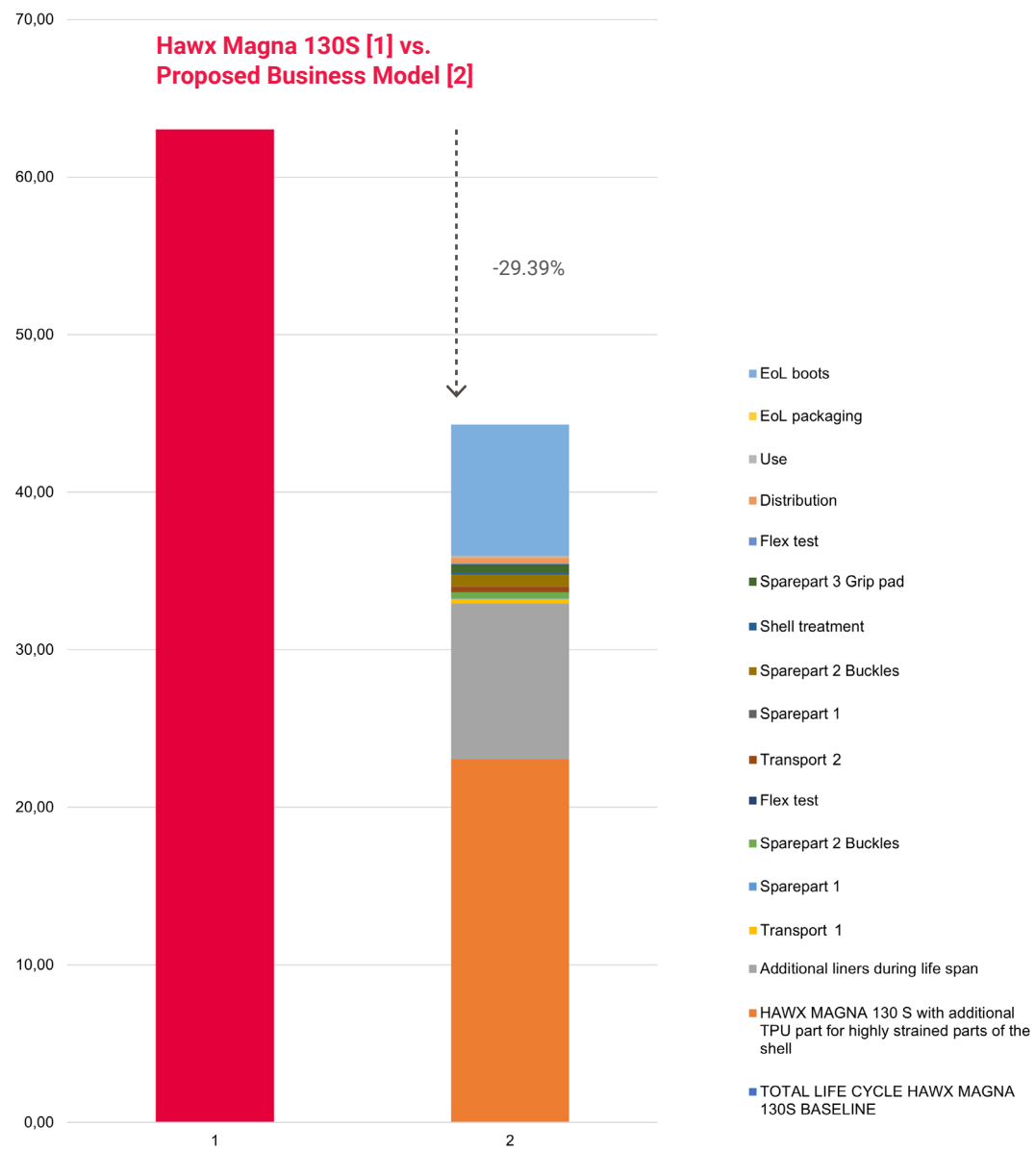


Figure 75: Comparison of baseline scenario with proposed business model

9.3.2 SENSITIVITY ANALYSIS

To assess under which conditions the proposed circular model remains environmentally beneficial, a limited sensitivity analysis was conducted. The reference scenario was compared with variations in three key parameters: total number of use days, transport distance and number of replaced buckles. These parameters were selected because they represent the model’s main system, refurbishment, and lifetime dependencies.

In each analysis, only one parameter was changed to keep the comparison simple. The results should therefore be understood as indicative, highlighting which parameters have a strong influence on the impact of the business model and which are less critical, rather than representing exact values (Figure 76).

USE DURATION	162 days minimum use required
TRANSPORT DISTANCE	more than 850 km transport distance from the rental shop to the refurbishment facility
BUCKLE REPLACEMENT	limited impact buckle replacement does not significantly impact the CO2 impact
END OF LIFE	8.35 kg of CO2 per boot avoided with closed-loop recycling

Figure 76: Sensitivity Analysis

Use Duration

To assess how strongly the environmental impact depends on the actual use duration of the ski boot, the total number of use days was varied while keeping all other parameters constant to the reference scenario before.

When the total use duration is reduced, the environmental benefit decreases accordingly. At 225 days, the reduction drops to 23.28%, and at 200 days, it further decreases to 15.64%. The analysis shows that the circular model requires a minimum use duration of approximately 162 days to outperform the baseline scenario. At this point, the CO2 reduction is 0.48%. Below this threshold, the model no longer leads to environmental benefits.

If the ski boot is used for the same duration as in the baseline scenario (150 days), the

circular model results in a 7.27% increase in CO2 emissions, mainly due to the additional impacts from refurbishment and transport.

This shows that the model only delivers environmental benefits if the product is used significantly longer than in the current system.

Transport Distance

To assess the influence of logistics on the environmental impact, the transport distance between the rental and refurbishment facility was varied while keeping all other parameters constant.

As the transport distance increases, the environmental benefit decreases. At 50 km, the reduction drops to 28.54%. At 500 km, the reduction drops to 12.65%, and the analysis shows that beyond approximately 850 km, the model no longer results in a reduction in CO2 emissions compared to the baseline.

These results show that transport distance does have an influence on the overall impact, but it is not the main driver within the system. While increasing distances reduce the environmental benefit, the model still performs well within the typical range of skiing areas in Austria (e.g. around 370 km to Vienna in the east and 380 km to Bregenz in the west, one way).

For implementation, this means that transporting boots used in other countries back to Atomic’s central facility in Altenmarkt is not feasible. Instead, more localised refurbishment centres distributed across countries would be required. These could potentially be outsourced to keep transport distances short and maintain the environmental benefit of the system.

Buckle replacement

Buckles are one of the highest-impact shell components. To test their influence, a scenario is considered in which all four buckles are replaced with new components in both refurbishment cycles. In this case, the CO2 reduction decreases to 24.39%, which is 4.96% lower than in the reference scenario.

The results show that while increased component replacement reduces the environmental benefit, the model remains effective as long as the boot’s core structure is retained.

End of life

If end-of-life is assumed to be closed-loop recycling instead of incineration, the impact associated with incineration (8.35 kg CO2e) is removed from the system. This reduces the total impact to 36.15 CO2-eq, resulting in a 42.64% reduction compared to the baseline scenario.

This shows that end-of-life treatment clearly influences the overall impact, but it is not the primary driver. The majority of the benefit comes from extending the use phase, while closed-loop recycling further improves the outcome as an additional optimisation rather than a critical dependency of the model.

DISCUSSION

chapter 10

This section critically reflects on the proposed concept, outlining its limitations, underlying assumptions, and implications for future work.

10.1 POTENTIAL TRADE-OFFS AND OPEN CHALLENGES

While the concept shows strong potential, it also introduces a set of trade-offs and open challenges that need to be addressed for successful implementation.

System-Level Trade-offs

The proposed system introduces a clear trade-off between circular value retention and increased complexity. Enabling multiple use cycles requires additional logistics, coordination, and contractual structures, which add operational effort and could also lead to higher associated emissions. The system depends on clearly defined grading standards, liability frameworks, and smooth coordination between stakeholders, all of which still need to be established.

At the same time, the model challenges existing business logic. It requires upfront investment while shifting revenue away from one-time sales towards longer-term value capture. This creates uncertainty around financial viability. Closely linked to this is the question of pricing: subscription or pay-per-use models need to be competitive with buying a boot that is then used for the average six-year lifetime of a boot identified in chapter 3.2.2, otherwise the added complexity is difficult to justify.

Another open question is how far user behaviour will adapt. The system introduces additional steps, and that may not align with current habits. Convenience remains critical, particularly in avoiding waiting times at rental locations, which is one of the key drivers for ownership today.

Strategically, there is also a tension between scalability and control. Working with existing rental partners enables faster implementation, while more controlled, Atomic-owned channels could strengthen the brand experience but would significantly increase complexity and investment.

Product-Level Uncertainties

At the product level, a key uncertainty lies in what drives perceived value loss over time. While the findings indicate that aesthetics play a significant role, it cannot be stated with full certainty to what extent replacement is driven by visual wear, measurable performance changes, or simply used as a justification for renewal. Further development is therefore needed to better understand the potential of aesthetic refurbishment to extend the perceived product lifetime.

In this context, the bumper plays a central role and needs to be evaluated in terms of how well it maintains visual quality and prevents deep scratches on the shell. Its current shape also requires assessment to ensure it covers all high-wear areas. The current design is symmetrical, but the inner side of the shell may require additional protection. This raises the question of whether a more extended design is needed.

This links to the broader need to explore different refurbishment methods and assess whether further design interventions beyond the bumper are required.

10.2 DESIGN OPPORTUNITIES FOR FURTHER DEVELOPMENT

Building on the identified challenges and uncertainties, the following opportunities outline areas where the concept can be further developed and validated.

1. Pick-up and Take-back System

Developing a seamless pick-up and return system to reduce waiting times and improve convenience at rental locations.

2. Improving Liner Insertion

The proposed business model requires frequent removal and reinsertion of the liner, which, although tool-free, can be difficult in practice. This was highlighted in discussions with Atomic and fellow students as a potential barrier to a smooth user experience. Further development could therefore focus on improving the ease of inserting the liner into the shell. Ideas include buckles that not only close but also help spread the shell, or additional straps that keep the shell open during insertion.

3. Performance Guarantee Platform

Designing a central platform to manage booking, tracking, and communication between users, rental partners, and Atomic.

4. Grading Framework Development

Defining a clear system to assess product condition, integrating both technical and visual criteria to support pricing and circulation.

5. Business Model Refinement

Exploring different access models, such as seasonal use or financing, to identify a balance between user attractiveness and system simplicity.

10.3 RESOLVING THE IDENTIFIED DESIGN TENSIONS

The proposed business model is the result of the insights gathered throughout this thesis. It builds on the five tensions identified in the current linear system, points where value is lost, component lifecycles are misaligned, and the system breaks down.

By addressing these tensions, the model outlines a way to keep value in use for longer, better align product components with their lifetimes, and shift both user behaviour and system responsibility.

- Tension 1:** Instead of losing embodied value, the shell is kept in use across multiple cycles.
- Tension 2:** The mismatch of component lifespans is resolved by separating the personal liner from the circulating shell.
- Tension 3:** Economic and technical constraints are balanced through controlled refurbishment and performance-based grading.
- Tension 4:** Linear user behaviour is shifted through structured return mechanisms, transforming a one-way flow into a managed system.
- Tension 5:** Ownership of the shell is brought back under control, closing the gap between design and lifecycle.

To answer the main design question of this thesis – *How can a circular business model for ski boots enable economically viable value retention, and what product adaptations are necessary to support its implementation?* – the results show that value retention can be achieved by combining a controlled circulation system with targeted product adaptations that enable repeated use cycles.

Rather than designing the product for a single ownership phase, the proposed model extends the lifecycle of the most durable component, the shell, through multiple users, while maintaining individual fit through a personal liner. Economic viability is enabled by capturing value across these cycles through graded resale and controlled redistribution, rather than relying on one-time sales.

To support this system, product adaptations focus on enabling refurbishment and maintaining perceived value over time. This includes replaceable high-wear components, reversible connections, and design interventions such as the bumper to manage aesthetic degradation. Together, these changes shift the ski boot from a product with a fixed lifetime to one that can be actively maintained and recirculated.

The project demonstrates that circular value retention is not achieved through isolated product improvements, but through the integration of product, business model, and system design. It positions design as a key driver in reshaping how value is created, maintained, and recaptured over time.

thank you for reading!

THANK YOU TO ...

This thesis would not have been possible without the incredible support I received along the way.

A very big thank you goes to my client Atomic. Especially, I want to thank Helmut. Thank you for giving me the opportunity—and the trust—to carry out my thesis with Atomic, and for allowing me to combine two topics that truly matter to me: our environment and the sport I love so much. I am very grateful for the freedom you gave me to shape this thesis into something I genuinely believe in.

A special thank you also to the entire sustainability team for creating such a supportive and inspiring working environment. I could not have wished for a better place to work. Thank you for all your encouragement and support throughout this journey. Thank you as well to Allegra and Leo for the great collaboration on parts of the research and for sharing your expertise. To everyone at Atomic who made my time there so special—thank you. From the very first day, I felt incredibly welcome. I not only gained valuable experiences, but also friendships that I truly cherish.

Special thanks to my supervisors Conny and Bas for your time your guidance, your expertise, and your continuous support throughout this process. It was a pleasure working together with you. Thank you for always having an open ear for me.

Ein ganz großes Danke an meine Mama, meinen Papa und meine Schwester, die mich immer unterstützt haben und mir diesen Master überhaupt ermöglicht haben. Worte können kaum beschreiben, wie dankbar ich euch bin – für all die Möglichkeiten, die ihr mir geschaffen habt, und dafür, dass ihr mich in all meinen Entscheidungen unterstützt und immer für mich da seid, auch wenn uns hunderte Kilometer trennen.

Thank you to my friends in the Netherlands for the incredible time at TU Delft and for being my family away from home. And thank you to my friends back home in Austria for always being there and welcoming me with warm hugs whenever I return.

A big thank you to João for being by my side throughout this journey, for supporting me in every decision, and for always believing in me, especially when I needed it most.



night-skitour in Zauchensee, AT

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APPENDIX

chapter 12

Appendix A - Surveys

LIST OF QUESTIONS SURVEY 1:

How old are you?
18–24 / 25–34 / 35–44 / 45–54 / 55–64 / 65 or over / Other

In which country do you live right now?
Open answer

Which of the following best describes your gender?
Woman / Man / Non-binary / Prefer not to say / Other

What type of skier are you mostly?
Piste / Freeride / Park / Racing / Touring / Other

How often do you typically go skiing in a year?
Less than 10 days / 10–20 days / 20–50 days / More than 50 days

What is your current ski level?
Beginner / Intermediate / Expert / Professional / Other

How many pairs of ski boots do you currently own?
Scale: 1–10

How many winter seasons did you use your last pair of ski boots before getting rid of them?
Scale: 1–10

Why did you decide to buy new boots?
Open answer

Rank the reasons why you decide to discard your previous boots
Performance (loss of flex and rebound) / Comfort (liner packs out, pressure points, cold) / Boot too old (desire for newer model) / Buckles or pivot points break / Sole worn out / Aesthetics (scratches, fading, yellowing) / Other

Where do you usually buy your boots?
Sport shop / Online directly from manufacturer / Online sport shop / Second-hand platform / Second-hand store / Other

What do you do with old ski boots once you stop using them?
Store at home / Sell / Bring back to dealer / Donate / Throw away / Other

How many ski seasons do you expect a pair of ski boots to last?
Scale: 1–10

When choosing ski boots, how do you prioritise the following factors?
Ranking: Comfort / Weight / Innovative features / Appearance / Brand image / Environmental impact / Availability of spare parts / Cost

How confident do you feel in understanding the technical aspects of ski boots?
Very confident / Confident / Somewhat confident / Not confident

How do you usually decide which ski boot is right for you?
Trying multiple boots in store / Asking a ski shop expert / Recommendations from friends or family / Online reviews / Brand reputation / Price comparison / Past experience / Renting or testing before buying / Other

Did a ski boot or a part of your ski boot ever break?
Yes / No / Other

If yes, where and how did it break? Could it be fixed?
Open answer

Have you repaired something on your ski boot or had it repaired?
Yes / No / Other

How confident do you feel in repairing your ski boot at home?
Very confident / Confident / Somewhat confident / Not confident

Have you ever replaced the following items of your ski boot?
Yes / No
Liner (inner boot) / Buckles / Boot sole / Power strap

Do you think recycled or regenerated materials can perform as well as virgin plastics in a ski boot?
Yes / No / Other

How appealing would you find a program where ski boots are collected, refurbished, and resold at a lower price?
Very appealing / Somewhat appealing / Not very appealing / Not appealing at all

If such a program existed, which of the following would apply to you? (multiple choice)
I would return my boots / I would return my boots only if I receive a reward or discount / I would keep my boots or sell them myself / I would not buy refurbished boots due to hygiene concerns / I would not buy refurbished boots due to performance concerns

What do you like about your ski boots?
Open answer

What do you dislike about your ski boots?
Open answer

Anything you would like to add?
Open answer

LIST OF QUESTIONS SURVEY 2:

How old are you?
18–24 / 25–34 / 35–44 / 45–54 / 55–64 / 65+

Which of the following best describes your gender?
Female / Male / Non-binary / Prefer not to say

In which country do you live right now?
Netherlands / Germany / Austria / Italy / France / USA / Canada / UK / Other

What is your current situation?
Student / Working / Looking for a job / Retired / Other

How often do you go on a ski trip per year?
I ski irregularly/not every year / 1 trip / 2 trips / 3 trips / 3–5 trips / 5–10 trips / 10+ trips

How many days in a row do you usually ski on one trip?
1 day / 2–3 days / 4–5 days / 1 week / 2 weeks / More than 2 weeks / Other

How would you describe your skiing level?
Beginner / Intermediate / Expert / Professional

How do you usually travel to the ski resort?
Car / Bus / Train / Plane / Other

Which best describes your situation?
I rent ski boots / I own ski boots

What were the main reasons you chose to rent ski boots instead of owning?
I ski too infrequently to justify owning ski boots / Lower costs / Overwhelmed by options / Beginner or not committed enough / No storage hassle / No transportation hassle / Flexibility to try different boots / Foot size or needs change over time / Other

Think about the last time you rented ski boots. What caused the most frustration, if any?
Poor fit or discomfort / Long waiting time / Boots were worn out / Hygiene concerns / Boots looked very used / Lack of fitting support / Boots did not match skis or skill level / Limited availability / Booking in advance / No major frustration / Other

What usually happens if the rental boots don't feel right while skiing?
I keep skiing anyway / I go back and change boots / I ski less or stop earlier / This rarely happens / Other

What are the main reasons you decided to buy ski boots?
Better performance / Better fit / Cheaper in the long run / More consistency / Hygiene concerns / Avoid rental shop time / No need to plan ahead / Other

What was the biggest difficulty when buying your ski boots?
Finding the right fit / Boots felt different on slope / High upfront cost / Lack of second-hand options / Unsure about matching boots to skiing style / No major difficulties / Other

What determined why you replaced your last ski boots?
Comfort decreased / Performance changed / Look outdated / Something broke / Bought the wrong boots / Felt it was time / Haven't replaced yet / Other

Where did you buy your last ski boots?
New – ski shop / New – online / Second-hand – ski shop / Second-hand – online / Second-hand – friends or family / Other

If you have ever bought used or second-hand ski boots, how much did the following criteria influence your decision?
Scale: did not influence at all / barely influenced / influenced / strongly influenced
Criteria: Price / Scratches on shell / Condition of liner / Comfort or fit / Perceived performance / Overall aesthetic / Scratches on buckles

How did you assess the performance of the second-hand boot?
Open answer

Any thoughts you would like to add?
Open answer

If you are open to a follow-up discussion, please leave your email address:
Open answer

LIST OF QUESTIONS SURVEY 3 - SKI BOOT IMPRESSION:

For each ski Boot 1 and 2:
How would you describe this boot in 3 words?
Open answer

What kind of skier do you think would use it?
Beginner / Intermediate / Advanced / Professional

How would you rate its expected performance?
Scale: 1–5 (1 = lowest, 5 = highest)

How would you rate its expected quality?
Scale: 1–5 (1 = lowest, 5 = highest)

How trustworthy does it feel?
Scale: 1–5 (1 = lowest, 5 = highest)

Based on what criteria did you assess performance, quality, and trustworthiness?
Open answer (e.g. scratches, buckles, overall appearance)

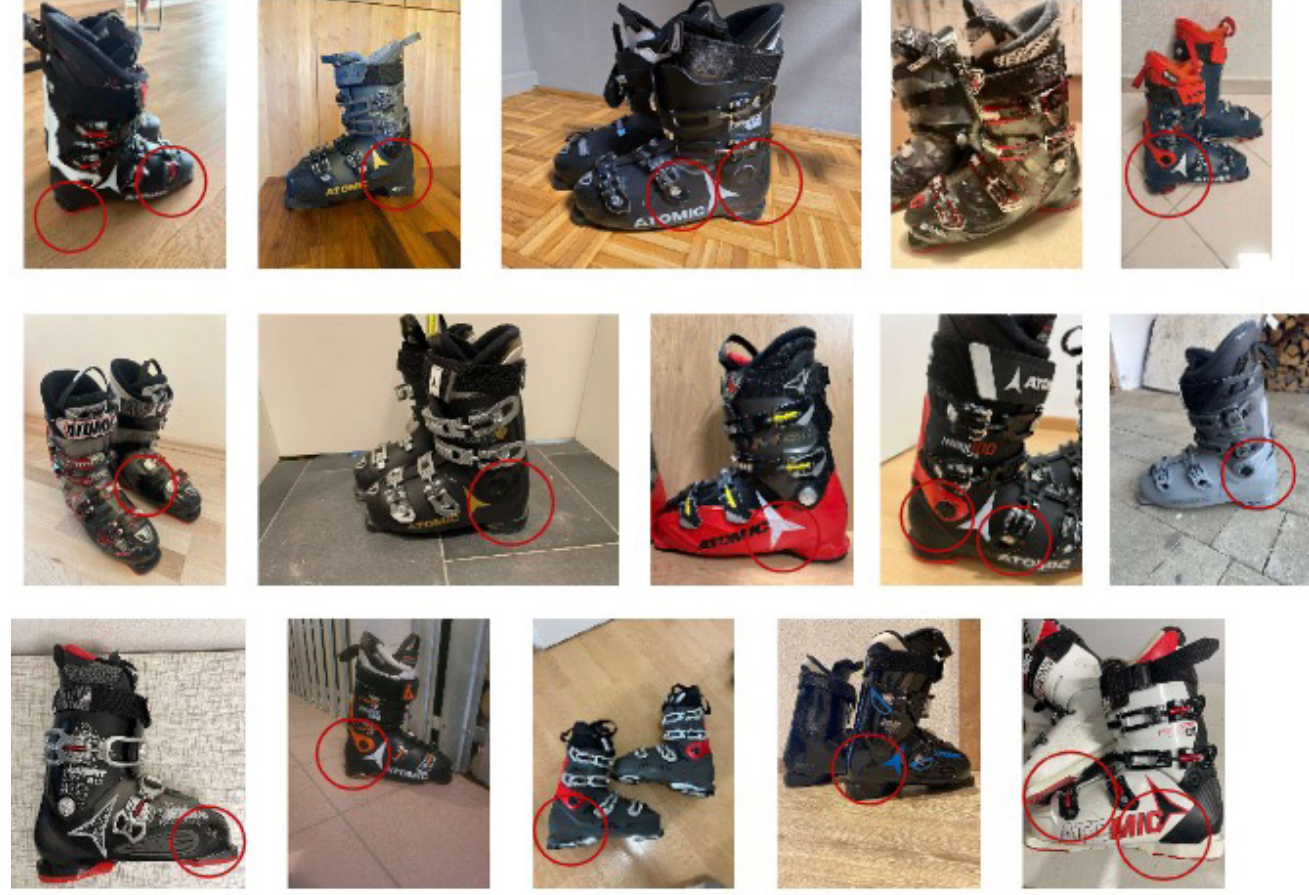
Anything else you would like to add?
Open answer



Boot 1



Boot 2



R-STRATEGIES

[illegible]

R0 - R2 // SMARTER PRODUCT USE

[illegible]

R3 - R7 // EXTEND PRODUCT LIFE

[illegible]

R8 - R9 // USEFUL APPLICATION OF MATERIAL

Appendix B - Statement Cards

BOOT BINDING SYSTEM IS VITAL

Space note: *Source: Andy Chapman (B&N)*

BLAST TO REPAIR THE COMBUSTION
Limping is a sign that which it comes to a bad thing, changes the job.

After establishing his best for finishing, he is to be taken in account, *Source: Andy B&N*, and to change their "savings".

PS: EDITORIAL

English in Motion - Quality Design

The book is not only a, also designed it, as the same is in thinking and it is there as an example.

After thinking, he is to be taken in account, *Source: Andy B&N*, and to change their "savings".

PS:

PERFORMANCE DEPENDS ON
WEIGHT AND FLEX BEHAVIOUR

Myers (Myers) - Interview Selection The best group has the best benefits for the senior business. The best group has the best benefits for the senior business. 01 - 02/15/16	Myers (Myers) - Interview Selection The best group has the best benefits for the senior business. The best group has the best benefits for the senior business. 01 - 02/15/16
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WEIGHT DRIVES LCA

Analysis: Analyzed 1000 samples for the They derived means approximately 10% in error, and the standard deviation of all 200 is in the order of one. There is a slight error part of it, all both through	Analysis: Analyzed 1000 samples for the The display represents a set of values, each value representing the total weight of the individual at 200 of the total weight. The display represents the weight of the individual at 200 of the total weight.
Q3. REDUCE	Q3. REDUCE
Current 1000 samples - currently 1000 samples Weight of the 1000 There is a small error part of the 1000 samples	
Q3. REDUCE	

INNOVATIVE PRODUCTION PROCESS TO LOWER CO2 IMPACT

Production – short run The firm is small and cannot really rent its fixed production factor. It would be too costly for a small plant to be able to vary its fixed resources. The key inputs cannot be varied in the short run. 10 percentages make the best fit for this.	Short-run production – short-run production Production has the biggest impact for a small firm. Most of the firm's total CO₂ emissions are generated during the production process.
01. RETURN	02. RETURN

weight drives LCA

NO TOTALLY NEW INNOVATIONS

John Doe, Account owner stopped doing business with you Account closed The cardholder is requesting money from the store but the store says they don't owe him anything The cardholder is asking for a refund but the store says they don't owe him anything What should the store do?	John Doe, Account owner stopped doing business with you Account closed The cardholder is requesting money from the store but the store says they don't owe him anything The cardholder is asking for a refund but the store says they don't owe him anything What should the store do?
10. KATHLEEN	10. KATHLEEN
John Doe, Account owner stopped doing business with you Account closed The cardholder is requesting money from the store but the store says they don't owe him anything The cardholder is asking for a refund but the store says they don't owe him anything What should the store do?	John Doe, Account owner stopped doing business with you Account closed The cardholder is requesting money from the store but the store says they don't owe him anything The cardholder is asking for a refund but the store says they don't owe him anything What should the store do?
10. KATHLEEN	10. KATHLEEN

REPAIR ON THE SHELL IS THEORETICALLY
POSSIBLE AS LONG AS THE TPU DOES NOT BREAK

[illegible]

THE LINER CAN NOT BE
REPAIRED

[illegible]

SKIERS ARE NOT CONFIDENT TO REPAIR THEIR BOOTS

Lesson Objectives be able to identify and explain the factors that influence the magnitude of the effect of a given factor on the dependent variable be able to explain the relationship between the dependent variable and the independent variable

SPARE PARTS

[illegible]

BACKWARDS COMPATIBILITY CREATED LOGISTICAL AND REPAIR BARRIER

7. What is the "right" answer? There is no "right" answer. In this type of question, the author will attempt to convince you to choose one or more of the answers. It is important to read the question and the answer choices carefully. 8. What is the "right" answer? There is no "right" answer. In this type of question, the author will attempt to convince you to choose one or more of the answers. It is important to read the question and the answer choices carefully.	9. What is the "right" answer? There is no "right" answer. In this type of question, the author will attempt to convince you to choose one or more of the answers. It is important to read the question and the answer choices carefully. 10. What is the "right" answer? There is no "right" answer. In this type of question, the author will attempt to convince you to choose one or more of the answers. It is important to read the question and the answer choices carefully.
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CONSUMER-LEVEL SPARE PARTS PRESENT SAFETY RISK

[illegible]

shell can be made repairable

skiers have low confidence in repairing their boots

liner is not repairable

smaller parts on the shell often
do get repaired

BOOT SHELL IS VERY DURABLE

[illegible]

ACTUAL LIFETIME MATCHES EXPECTED LIFETIME

1. The annual average inflation is zero. Shaping your business accordingly is not a good idea.

UNEQUAL DURABILITY: LINER VS SHELL

EX - 102 - INCIDENT, POLICE ...

DURABILITY DEPENDS ON THE SKILLS OF THE SKIER

Supply curve - downward sloping Quantity supplied is a function of the price and it is upward sloping. The price is the demand curve's price. As the price falls, the quantity supplied falls. As the price rises, the quantity supplied rises. As the price falls, the quantity supplied falls.	Demand curve Quantity demanded is a function of the price and it is downward sloping. The price is the supply curve's price. As the price falls, the quantity demanded rises. As the price rises, the quantity demanded falls.
Supply curve Quantity supplied is a function of the price and it is upward sloping. The price is the demand curve's price. As the price falls, the quantity supplied falls. As the price rises, the quantity supplied rises. As the price falls, the quantity supplied falls.	Demand curve Quantity demanded is a function of the price and it is downward sloping. The price is the supply curve's price. As the price falls, the quantity demanded rises. As the price rises, the quantity demanded falls.

shell and liner have different lifetimes

QUESTION: PROSODY

Which was NOT used in the Ames experiment to study the function of a cell wall in osmotic regulation? (score for right) 100.00 percent correct

100.00 percent correct

ANS: PROTOPLASM

QUESTION: PROTOPLASM

Which standard mammalian host cell is commonly used

100.00 percent correct

ANS: PROTOPLASM

[illegible]

Get a copy of <i>Introduction to Statistics</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>.	Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>.
Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>.	Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>. Get a copy of <i>Statistics for Scientists: A course in statistical thinking</i>.

[illegible]

Sejarah: <i>Indonesian Journal of Geomatics</i> Sejarah <i>IGI</i> sebagai <i>Indonesian Journal of Geomatics</i> dimulai dengan terbitnya <i>Indonesian Journal of Surveying</i> pada tahun 1974. Pada tahun 1990, <i>Indonesian Journal of Surveying</i> berganti nama menjadi <i>Indonesian Journal of Geomatics</i>. Sejak saat itu, <i>Indonesian Journal of Geomatics</i> telah berkembang menjadi salah satu jurnal geomatika terkemuka di Indonesia. IGI adalah jurnal geomatika yang diterbitkan oleh Himpunan Geomatika Indonesia (HGI) dan dikelola oleh Himpunan Geomatika Indonesia (HGI). IGI adalah jurnal geomatika yang diterbitkan oleh Himpunan Geomatika Indonesia (HGI) dan dikelola oleh Himpunan Geomatika Indonesia (HGI).	Sejarah <i>Indonesian Journal of Geomatics</i> Sejarah <i>IGI</i> sebagai <i>Indonesian Journal of Geomatics</i> dimulai dengan terbitnya <i>Indonesian Journal of Surveying</i> pada tahun 1974. Pada tahun 1990, <i>Indonesian Journal of Surveying</i> berganti nama menjadi <i>Indonesian Journal of Geomatics</i>. Sejak saat itu, <i>Indonesian Journal of Geomatics</i> telah berkembang menjadi salah satu jurnal geomatika terkemuka di Indonesia. IGI adalah jurnal geomatika yang diterbitkan oleh Himpunan Geomatika Indonesia (HGI) dan dikelola oleh Himpunan Geomatika Indonesia (HGI). IGI adalah jurnal geomatika yang diterbitkan oleh Himpunan Geomatika Indonesia (HGI) dan dikelola oleh Himpunan Geomatika Indonesia (HGI).
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1. Einleitung 2. Problemstellung 3. Ziele 4. Methodik 5. Ergebnisse 6. Fazit 7. Literaturverzeichnis 8. Anhang 9. Bibliographie 10. Index 11. Abbildung 12. Tabelle 13. Formel 14. Diagramm 15. Skizze 16. Zeichnung 17. Bild 18. Abbildung 19. Tabelle 20. Formel 21. Diagramm 22. Skizze 23. Zeichnung 24. Bild 25. Abbildung 26. Tabelle 27. Formel 28. Diagramm 29. Skizze 30. Zeichnung 31. Bild 32. Abbildung 33. Tabelle 34. Formel 35. Diagramm 36. Skizze 37. Zeichnung 38. Bild 39. Abbildung 40. Tabelle 41. Formel 42. Diagramm 43. Skizze 44. Zeichnung 45. Bild 46. Abbildung 47. Tabelle 48. Formel 49. Diagramm 50. Skizze 51. Zeichnung 52. Bild 53. Abbildung 54. Tabelle 55. Formel 56. Diagramm 57. Skizze 58. Zeichnung 59. Bild 60. Abbildung 61. Tabelle 62. Formel 63. Diagramm 64. Skizze 65. Zeichnung 66. Bild 67. Abbildung 68. Tabelle 69. Formel 70. Diagramm 71. Skizze 72. Zeichnung 73. Bild 74. Abbildung 75. Tabelle 76. Formel 77. Diagramm 78. Skizze 79. Zeichnung 80. Bild 81. Abbildung 82. Tabelle 83. Formel 84. Diagramm 85. Skizze 86. Zeichnung 87. Bild 88. Abbildung 89. Tabelle 90. Formel 91. Diagramm 92. Skizze 93. Zeichnung 94. Bild 95. Abbildung 96. Tabelle 97. Formel 98. Diagramm 99. Skizze 100. Zeichnung 101. Bild 102. Abbildung 103. Tabelle 104. Formel 105. Diagramm 106. Skizze 107. Zeichnung 108. Bild 109. Abbildung 110. Tabelle 111. Formel 112. Diagramm 113. Skizze 114. Zeichnung 115. Bild 116. Abbildung 117. Tabelle 118. Formel 119. Diagramm 120. Skizze 121. Zeichnung 122. Bild 123. Abbildung 124. Tabelle 125. Formel 126. Diagramm 127. Skizze 128. Zeichnung 129. Bild 130. Abbildung 131. Tabelle 132. Formel 133. Diagramm 134. Skizze 135. Zeichnung 136. Bild 137. Abbildung 138. Tabelle 139. Formel 140. Diagramm 141. Skizze 142. Zeichnung 143. Bild 144. Abbildung 145. Tabelle 146. Formel 147. Diagramm 148. Skizze 149. Zeichnung 150. Bild 151. Abbildung 152. Tabelle 153. Formel 154. Diagramm 155. Skizze 156. Zeichnung 157. Bild 158. Abbildung 159. Tabelle 160. Formel 161. Diagramm 162. Skizze 163. Zeichnung 164. Bild 165. Abbildung 166. Tabelle 167. Formel 168. Diagramm 169. Skizze 170. Zeichnung 171. Bild 172. Abbildung 173. Tabelle 174. Formel 175. Diagramm 176. Skizze 177. Zeichnung 178. Bild 179. Abbildung 180. Tabelle 181. Formel 182. Diagramm 183. Skizze 184. Zeichnung 185. Bild 186. Abbildung 187. Tabelle 188. Formel 189. Diagramm 190. Skizze 191. Zeichnung 192. Bild 193. Abbildung 194. Tabelle 195. Formel 196. Diagramm 197. Skizze 198. Zeichnung 199. Bild 200. Abbildung 201. Tabelle 202. Formel 203. Diagramm 204. Skizze 205. Zeichnung 206. Bild 207. Abbildung 208. Tabelle 209. Formel 210. Diagramm 211. Skizze 212. Zeichnung 213. Bild 214. Abbildung 215. Tabelle 216. Formel 217. Diagramm 218. Skizze 219. Zeichnung 220. Bild 221. Abbildung 222. Tabelle 223. Formel 224. Diagramm 225. Skizze 226. Zeichnung 227. Bild 228. Abbildung 229. Tabelle 230. Formel 231. Diagramm 232. Skizze 233. Zeichnung 234. Bild 235. Abbildung 236. Tabelle 237. Formel 238. Diagramm 239. Skizze 240. Zeichnung 241. Bild 242. Abbildung 243. Tabelle 244. Formel 245. Diagramm 246. Skizze 247.
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1. Problem Statement: How can we improve the efficiency of our data processing pipeline? 2. Objectives: The primary objective is to reduce the execution time of the data processing pipeline by 20%. 3. Scope: The project will focus on optimizing the data ingestion and transformation stages.	1. Background: The current data processing pipeline is inefficient due to its sequential nature. 2. Methodology: We will employ a parallel processing approach using Apache Spark to distribute the workload across multiple nodes. 3. Tools: The project will utilize Apache Spark, Hadoop, and Python for data processing and orchestration.
4. Deliverables: The project will deliver a fully optimized data processing pipeline, a detailed report on the optimization process, and a presentation to the stakeholders.	5. Timeline: The project is scheduled to be completed within a 4-week period.

sustainability is not a buying decision

OBSOLESCENCE

Scatterplot: Long arm disease There are some studies which suggest a link with genetic factors that can lead to Long arm disease. This is due to the location of the gene on the long arm of the chromosome. It is not clear if this is a genetic or an environmental disease. 1st problem	problem 2/3rd level Long arm disease is a genetic disease. It is caused by a mutation on the long arm of the chromosome. This is a genetic disease. It is not clear if this is a genetic or an environmental disease. The first problem is that there is no clear link between the gene and the disease. This is due to the location of the gene on the long arm of the chromosome. It is not clear if this is a genetic or an environmental disease. 2nd problem
Long arm disease Long arm disease is a genetic disease. It is caused by a mutation on the long arm of the chromosome. This is a genetic disease. It is not clear if this is a genetic or an environmental disease. Long arm disease is a genetic disease. It is caused by a mutation on the long arm of the chromosome. This is a genetic disease. It is not clear if this is a genetic or an environmental disease. 1st problem	Long arm disease Long arm disease is a genetic disease. It is caused by a mutation on the long arm of the chromosome. This is a genetic disease. It is not clear if this is a genetic or an environmental disease. Long arm disease is a genetic disease. It is caused by a mutation on the long arm of the chromosome. This is a genetic disease. It is not clear if this is a genetic or an environmental disease. 1st problem

University of West Virginia Central West Virginia State College is a four-year college located in Martinsburg, West Virginia. The college is a public institution and is a member of the National Association of State Colleges and Universities. The college is a member of the National Association of State Colleges and Universities. West Virginia State College West Virginia State College is a four-year college located in Martinsburg, West Virginia. The college is a public institution and is a member of the National Association of State Colleges and Universities. The college is a member of the National Association of State Colleges and Universities.	University of West Virginia Central West Virginia State College is a four-year college located in Martinsburg, West Virginia. The college is a public institution and is a member of the National Association of State Colleges and Universities. The college is a member of the National Association of State Colleges and Universities. West Virginia State College West Virginia State College is a four-year college located in Martinsburg, West Virginia. The college is a public institution and is a member of the National Association of State Colleges and Universities. The college is a member of the National Association of State Colleges and Universities.
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[illegible][illegible]

RENTAL

• **Primary** antibodies have **high** affinity for the antigen, recognise small number of epitopes, form weak aggregates

[illegible]

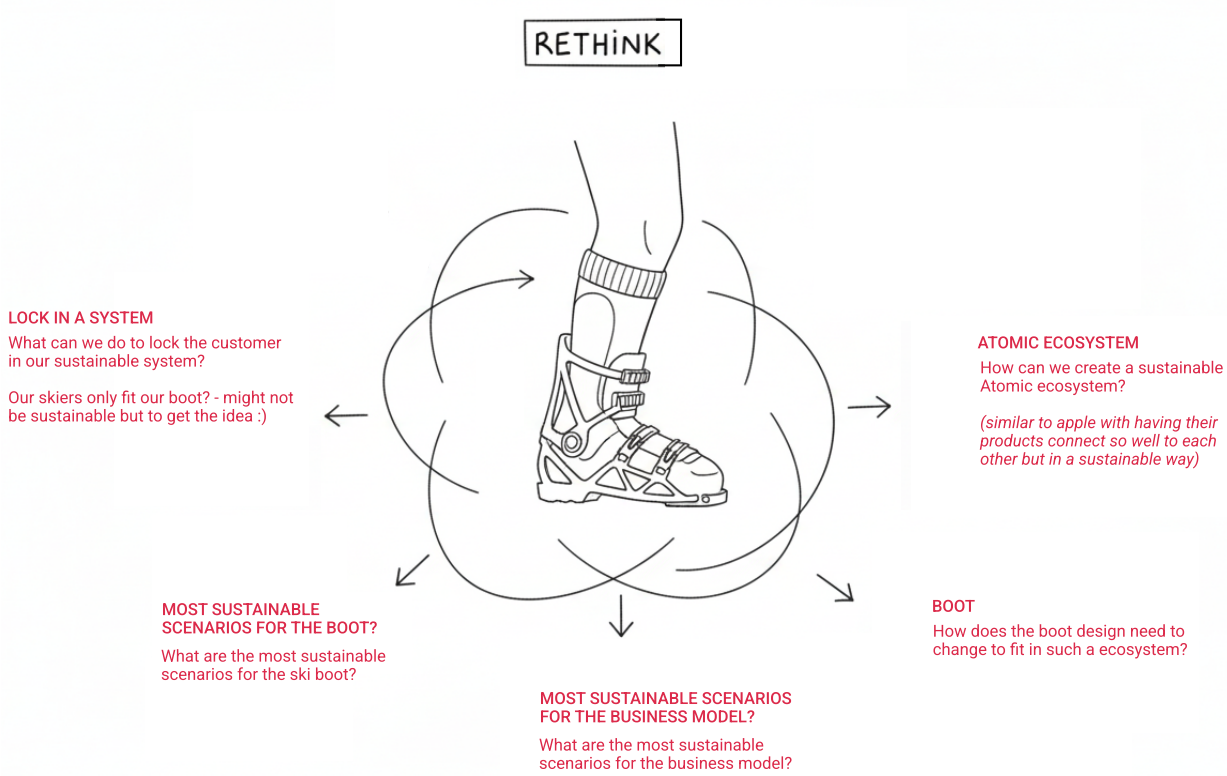
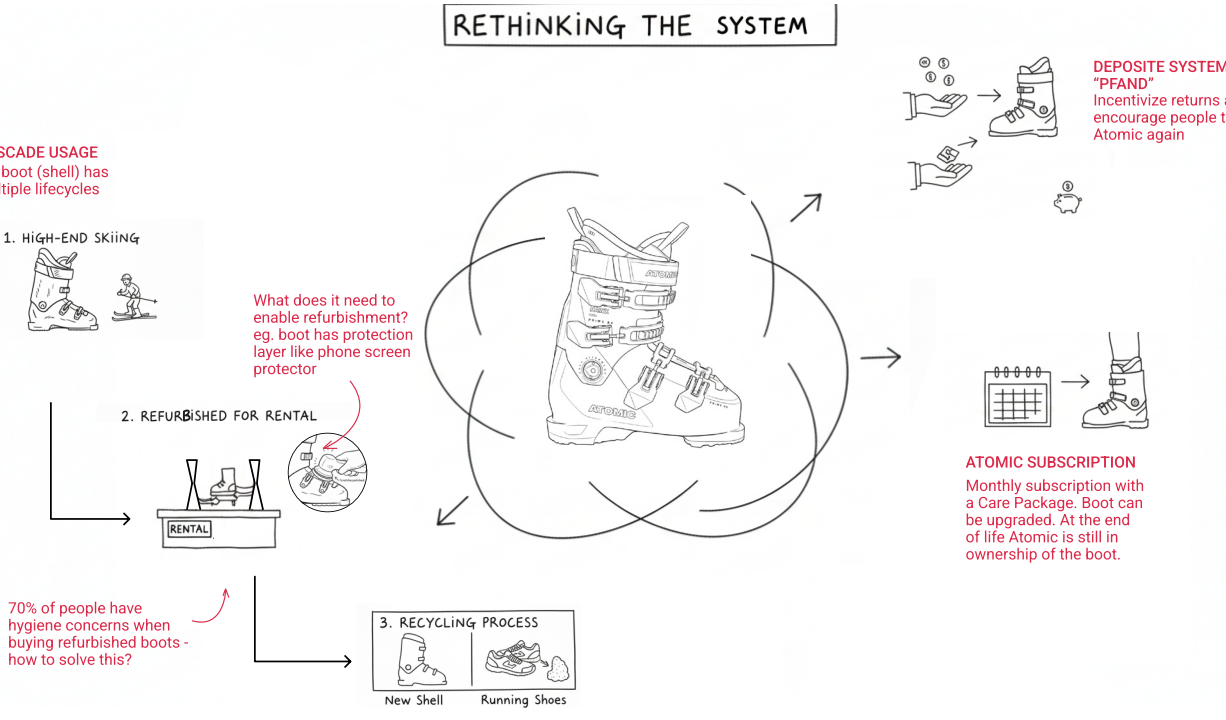
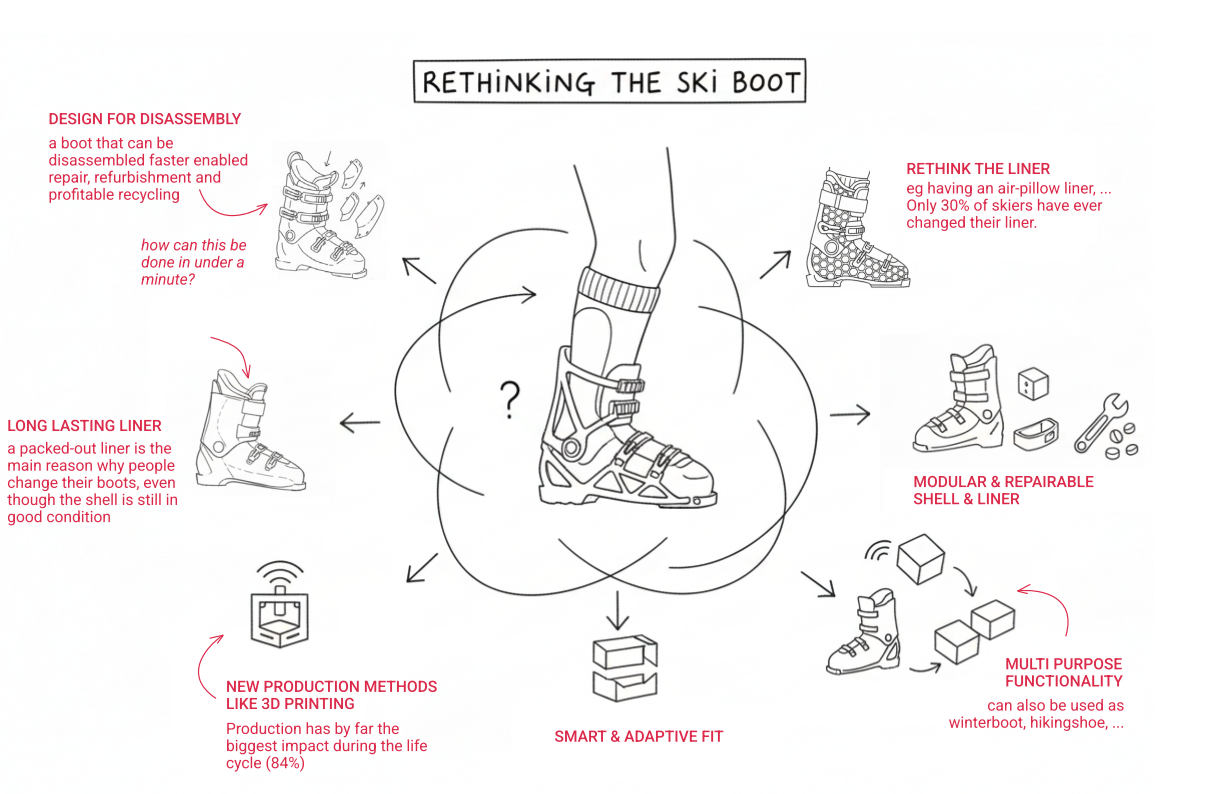
2. *Hydrophila* spp. *Hydrophila* is the most common fish pathogen found in ponds. It causes a disease called "bacterial hemorrhagic septicemia" (BHS). The disease is characterized by hemorrhages in the internal organs, especially the liver and spleen, and by a high mortality rate.

comfort is the most important criteria when buying a boot

comfort & performance are the main reason why people change their boots

people do not use the ski boots
till their end of life

Appendix C - Brainwriting Workshop



A Buckles:
exchange
Alu to steel
with "eligion" derivative
- colour elements

Separate fit and comfort

Buckles without A
looking or new coating

if you take the train
you get 30% at Atomic
rental operators

(just for Atomic customer product)

1 Cost $\rightarrow$ 2 Cost

ATP $\rightarrow$ ATP $\rightarrow$ ATP

q $\rightarrow$ value, b $\rightarrow$ refund

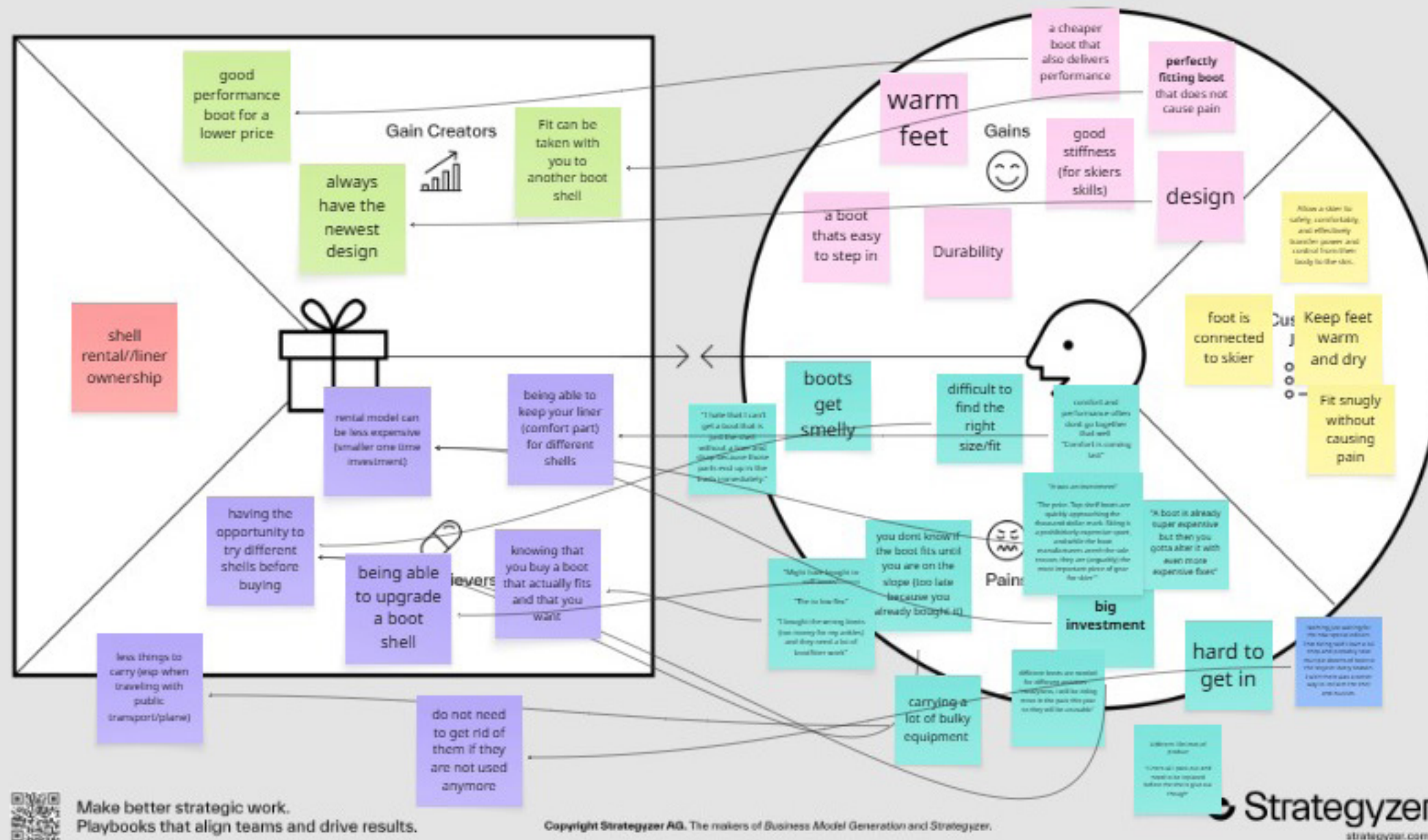
Appendix D - Value Proposition Canvas

perspective of people who own ski boots right now, based on user surveys

The Value Proposition Canvas

Value Proposition:

Customer Segment:

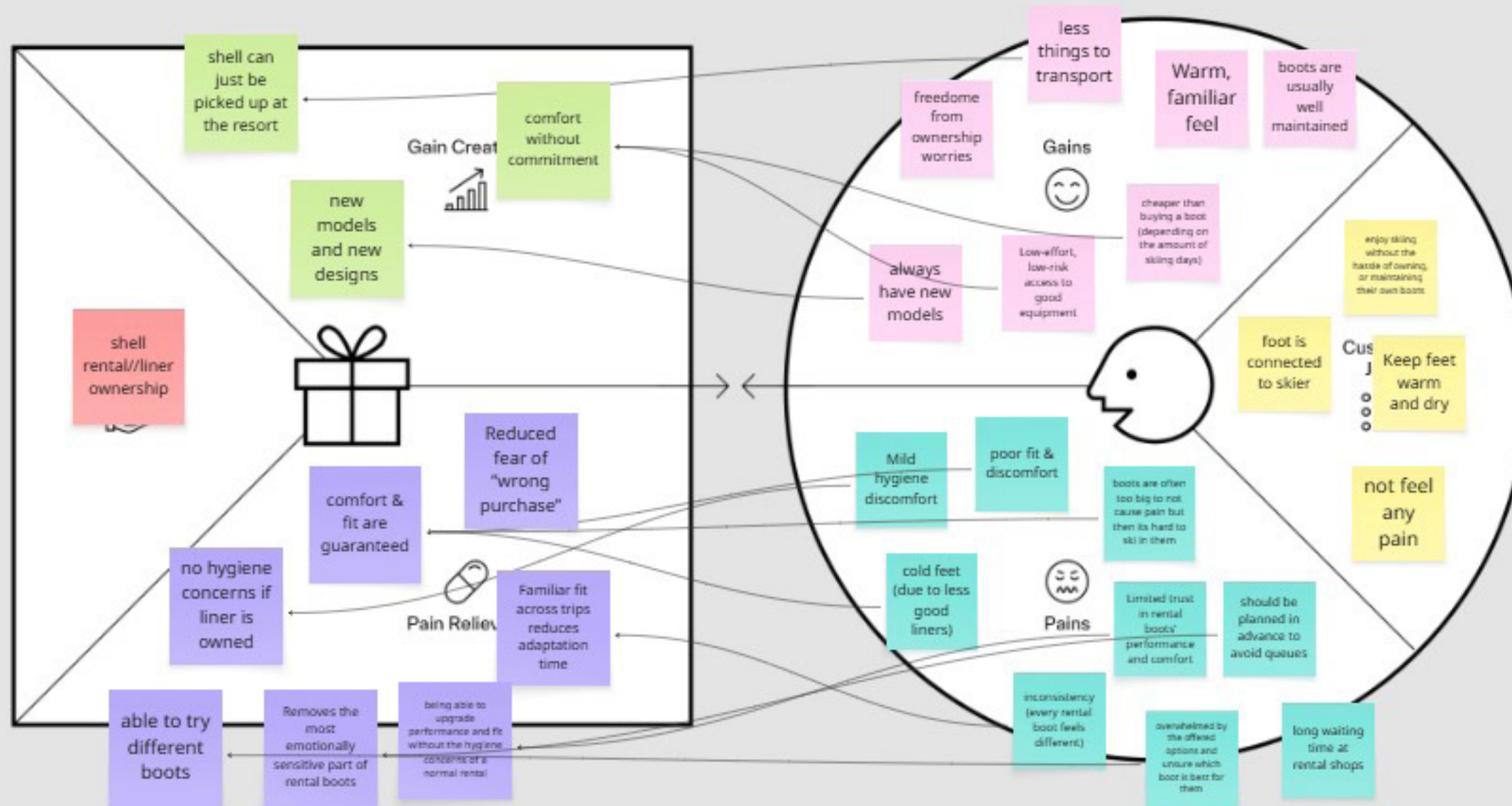


perspective of people who are renting right now

The Value Proposition Canvas

Value Proposition:

Customer Segment:



Make better strategic work.
Playbooks that align teams and drive results.

Copyright Strategyzer AG. The makers of Business Model Generation and Strategyzer.

Strategyzer
strategyzer.com

Appendix E - Project Brief

In this document the agreements made between student and supervisory team about the student’s IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project’s setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student’s registration and study progress
- IDE’s Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Mairhofer	IDE master(s)	IPD ☒	Dfi ☐	SPD ☐
Initials	MM	2 nd non-IDE master			
Given name	Magdalena	Individual programme (date of approval)			
Student number		Medisign	☐		
		HPM	☐		

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Conny Bakker	dept./section	Design for Sustainability	! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why. ! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter. ! 2nd mentor only applies when a client is involved.
mentor	Bas Flipsen	dept./section	Design for Sustainability	
2 nd mentor	Helmut Holzer			
client:	Atomic Austria GmbH			
city:	Altenmarkt	country:	Austria	
optional comments	I chose Conny Bakker and Bas Flipsen because their complementary expertise supports my goal to deepen my understanding of sustainability—Conny offers a holistic view, Bas focuses on the inner circles of the circular economy.			

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Name Conny Bakker

Date 20 Oct 2025

Signature

Name student Magdalena Mairhofer Student number

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Enhancing Design for Circularity in the Skiing Industry: a case study on skiing boots

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)

Sports tourism often depends on the natural environment, yet it frequently causes ecological harm (Malasevska et al., 2023). Among all forms of tourism, the winter sports industry holds a unique place in the climate crisis. Ski resorts visibly display the effects of global warming: glacial retreat, unpredictable weather, and rising temperatures highlight climate change in action.

At the same time, ski tourism attracts 300 -350 million skier visits annually, making it a multi-billion-dollar market (Steiger et al., 2017). A paradox emerges: while skiers rely on specific climatic conditions, their activities contribute to the very challenges that threaten the sport's future (Bischof et al., 2017). Equipment demand illustrates this tension, with 16% of the carbon footprint of a skiing day linked to gear (UTOPIES, 2025). The global market for winter sports apparel is forecast to reach 1.15 billion U.S. dollars by 2025 (Statista, 2025).

Human pressure on the environment through resource extraction and waste is widely recognised. The circular economy offers a way forward by reducing waste and maximising resource efficiency (Velenturf & Purnell, 2021). In skiing, equipment producers play a decisive role, as frequent replacement driven by wear, fashion, or technological updates has significant impact. Companies such as Atomic Austria GmbH could reduce this burden by rethinking business models and product life cycles. Since 80% of a product's environmental impact is determined at the design stage (Ellen MacArthur Foundation, 2022), integrating value retention strategies from the outset is essential. Ski boots will serve as a use case to explore this potential.

→ space available for images / figures on next page

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)

Every year, around 3.6 million pairs of ski boots are produced worldwide. Their average lifespan is three years in rental use and five in private ownership (Sporting Goods Recycling: New Life for Old Ski Boots, n.d.), with most ending up incinerated or landfilled after that. Their complex multi-material construction, consisting of around 60 materials that combine plastics, metals, and textiles bonded through glues and fixings, makes recycling technically and economically unviable. As a result, valuable materials are lost and significant carbon emissions are generated (Tecnica Group, 2021). An Atomic ski boot, for instance, has a lifecycle carbon footprint of 35.5 kg CO₂, with 97% of its impact occurring during production (84%) and end-of-life treatment (13.2%) (figure 1). Despite ongoing efforts to improve recyclability and extend product lifespan, the production stage remains highly carbon-intensive and continues to account for the majority of emissions (figure 2). To meet its 2030 goal of halving product-level CO₂ emissions and closing a 28% gap in its Scope 3 targets, Atomic must look beyond incremental material improvements. This requires rethinking not only the boot's materials and manufacturing processes but also its overall product architecture, value chain, and business model. The challenge lies in exploring how circular value retention strategies can be applied systemically to the ski boot to reduce embodied carbon while maintaining performance, comfort, and user experience in the winter sports context.

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:

(Re)Design a ski boot to explore circular value retention strategies for product development in the winter sports industry.

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)

This graduation project explores how ski boots can be reimaged through circular design. The exploration focuses on four research areas: technical, sustainability, user, and legislation, moving iteratively between research and sketching to uncover opportunities and gradually narrow them down into promising directions. Existing ski boots will be analysed in terms of materials, manufacturing, and disassembly to understand design logic and constraints. Sustainability will be assessed using lifecycle frameworks such as the 9R Strategies, while user behaviour and market perspectives will be explored through research and interviews. Relevant regulations will be reviewed to identify design requirements and limitations. Insights from this exploration will define design directions, a problem statement, and criteria for concept development. Concepts will be generated and iteratively refined with Atomic’s boot team and design students, evaluated through prototyping, user feedback, and performance testing to improve comfort, functionality, and circular value. The most promising concept(s) will undergo final validation to ensure a balance of performance, durability, and sustainability, demonstrating the practical application of circular design in high-performance ski boots.

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 meeting16 Okt 2025

Mid-term evaluation12 Dez 2025

Green light meeting26 Feb 2026

Graduation ceremony31 Mär 2026

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

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

Comments:

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)

Having grown up with skis on my feet, outdoor sports have always been central to my life. Witnessing the impacts of climate change firsthand has strengthened my connection to nature and inspired me to take responsibility as a designer. This thesis brings together my passion for skiing and my commitment to sustainable design, allowing me to create products that reflect both personal experience and environmental awareness.

Personal Learning Objectives:
LO1: I want to acquire in-depth knowledge and understanding of circular design and explore how circular value retention strategies can be applied to a product.
LO2: I want to build confidence in managing a large-scale project independently and strengthen my trust in my own abilities.
LO3: I want to expand my capacity to think broadly and tackle complex systems with multiple stakeholders involved.
LO4: I want to further develop my skills in rapid prototyping and CAD modelling.

Statement of Usage of AI

Artificial Intelligence tools (Consensus, ChatGPT, Gemini and Vizcom) were used throughout this thesis as supporting tools in specific phases of the research and design process. This thesis also served as an opportunity to explore and deepen my engagement with AI in design, particularly through the use of tools such as Vizcom for visualisation and concept development.

AI was not used to replace critical thinking or make autonomous design decisions. All analytical reasoning, interpretations, design choices, and conclusions remain the author's own work.

AI tools supported the following activities:

- Literature exploration
- Brainstorming and idea generation during early concept development
- Assistance with structuring chapters and refining argumentation
- Language support, including grammar and phrasing improvements.
- Support in analysing survey data patterns.
- Enhancement of visual sketches and concept renderings

AI outputs were critically reviewed. Responsibility for the content and accuracy of this thesis lies entirely with the author.

Magdalena Mairhofer

Delft University of Technology
Faculty of Industrial Design Engineering

