

The Ascent Reimagined

**Human-Powered Backcountry
Access for Sit-Ski Athletes**



 **TU Delft**



Design for inclusion in mountain adventures.

By investigating opportunities for sit-skitouring. Can a design for a sitskitouring setup enable physically challenged athletes with lower body impairments to experience and explore the mountains on their own terms?

MSc. Graduation Thesis
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‘When you’re in a wheelchair, people often try to do everything for you. But I want to do things myself. If I can’t do something yet, I still want to try.’

Sarah van der Glas,
sitski athlete

Foreword

Dear reader,

I took my time searching for a topic to graduate on. I wanted project where I could push myself to grow as a designer, that was close to my heart and would make a meaningful difference in people's live.

That's when I heard of an adventure by Remco Mensinck and Sarah van der Glas. Remco is an experienced freerider and alpinist who skitours frequently to reach his dreamlines. Sarah is an enthusiastic sitski athlete, pushing her own limits and the limits of sitskiing. Together, they tried to figure out how Sarah could go on a skitour. Their curiosity and dedication inspired me.

As a passionate freerider and Landes-qualified ski & snowboard instructor, I have been lucky to spend a lot of time in the mountains. I find joy in discovering the mountains by foot. Being present in an epic environment, where the places you want to reach and the risks you are willing to take are entirely up to you. This freedom is a totally different experience. With this project, I saw an opportunity to contribute to a future in which sitski athletes can experience that same freedom.

Of course, this thesis marks the final step in completing my MSc Integrated Product Design at TU Delft. But more importantly, I hope this project shows how design can make a meaningful difference in people's lives. By developing equipment that is better tailored to the physical capabilities and ambitions of sitski athletes, I hope to contribute to making the mountains more inclusive.

I hope you enjoy reading this thesis.

Mick Röer

Delft, June 2026



Acknowledgments

As a designer, working on a project individually is challenging. Although this was an individual project, I could not have done this alone. I believe design is a cumulation of the environment it has been created in, shaped by conversation, inspiration and collaboration. I therefore want to express my gratitude to the people around me during this project. I want to start by thanking my supervisory team for their genuine interest and guidance throughout the project.

Arjen Jansen has been there every step of the way. Over a year ago, I walked into your office not having a clue what I wanted to graduate on. By coincidence, it later turned out I had walked into the right office and we were going to be great match for this graduation project. I appreciated your sharp observations and detailed feedback.

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I would like to thank Babette & Lianne for creating an atmosphere which felt like we were in a design studio together.

I want to extend a special thanks to Bastiaan who has felt like a true teammate, in and outside this graduation project. After the way

our IDE careers at TU Delft kept crossing, it felt only appropriate to conclude our master's together. The many moments of collaboration on both our graduation projects have made this journey feel like a group project. I too believe we will have many more of those to come in the future.

I would like to thank anyone who has invested time, resources or their network into this project. Roland Falkner, Alex Gritsch, Michael Fiegl, Patrick Wuggenig, Tyler Walker, Sarah van der Glas, Remco Mensinck, Alfons Dornauer and Rémi Vallin, your help has been a vital contribution to this project.

Thanks to TESSIER for their contribution to this project and for borrowing me a sitski.

Metalltechnik Schöpf sponsored this project by building prototypes on short notice and gifting them. They also made their workshop available for me, which made it possible to perform an on-snow test on the last day of the season when I had almost given up.

Thanks to Koch Alpin for meeting me in Innsbruck and providing Contour climbing skins and Tubbs snowshoe parts essential for the prototype.

Last but not least, I would like to thank FAST for their generous €10,000 donation, which enabled prototyping and future development toward independent sit-ski touring.

Figure 1. Bami Design studio & Associates



Abstract

This thesis presents a MSc Integrated Product Design graduation project conducted at the Delft technical university of Technology. This project was self initiated and completed without a client, out of a curiosity if it would be possible for a sitskier to climb a mountain.

Skitouring allow athletes to ascend in remote mountain terrain through their own physical effort. However, physically challenged athletes using a sit-ski are currently limited in their ability to access these environments independently. Existing sitski equipment is mainly developed for downhill performance and does not enable athletes with lower-body impairments to ascend snow-covered mountain terrain using upper-body power over longer distances. As a result, sitski athletes are restricted to lift-accessed terrain or dependent on others to pull them uphill.

This graduation project investigates how a sit-ski touring setup can support autonomous participation of physically challenged athletes with lower-body impairments in mountain adventures. Through a User-Centred Design

approach user needs, context of use, biomechanics were explored and translated into design opportunities. Interviews with athletes, manufacturers and adaptive outdoor sport pioneers revealed a clear need for equipment that enables sit-ski athletes to become more independent in the backcountry.

Iterative concept creation and development led to **Capra Ibex**: a retrofittable sitski touring concept based on a rowing-like pulling motion. It introduces a new approach to human-powered propulsion on snow, where the upper-body is used to generate the required power from a seating position. The proposed design demonstrates how a sitski can evolve towards the becoming the foundation for physically challenged athletes to venture out into nature and experience mountain adventures.

Capra Ibex enables physically challenged athletes with lower body impairments to become the engine of their own backcountry adventures.

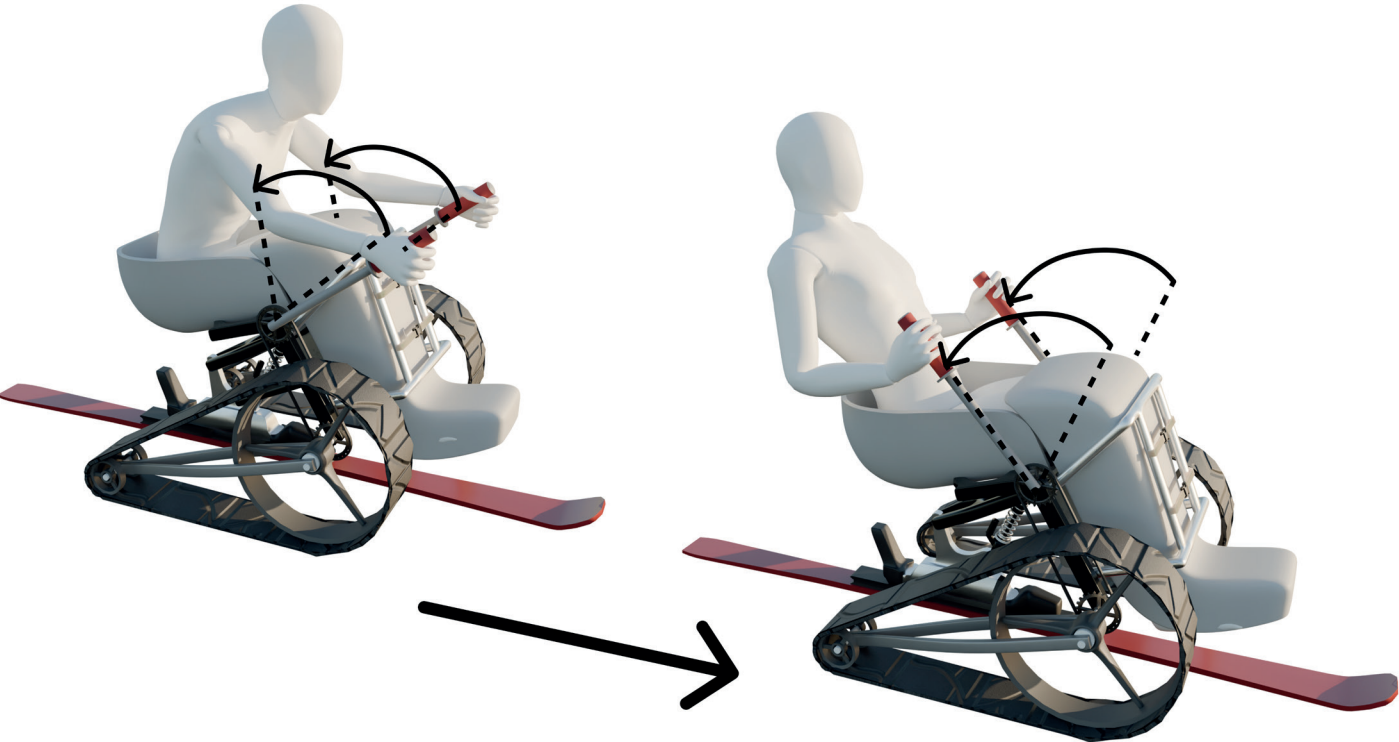


Figure 2. Capra Ibex in motion

Terminology and abbreviations

- UCD:** User-Centred Design.
- RtD:** Research through Design.
- ROM:** Range of Motion
- FTP:** Functional Threshold Power
- VO₂max:** Maximal oxygen uptake.
- W:** Watt. A watt is a unit of power used to describe the rate at which work is performed.
- Backcountry:** Terrain outside official boundaries of a ski resort.
- Freeriding:** Refers to skiing or snowboarding outside marked slopes
- Outrigger:** An outrigger is a short pole with a small ski at the end, used by sit-skiers for balance,
- Retrofit:** A new component can be added to an existing product without replacing the entire product.

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1 Introduction

1.1 Project introduction

Freeriding, or backcountry skiing, means skiing or snowboarding outside marked ski areas where there are no lifts or groomed slopes. The number of people going into the backcountry has grown strongly in recent years. In the western United States, participation increased almost eightfold between 1995 and 2017 (Birkeland et al., 2017), and this growth accelerated during the COVID-19 pandemic (Peipert, 2021). Freeriding can also improve physical health. Studies have shown that downhill skiing supports cardiovascular fitness, coordination, and muscle control (Burtscher et al., 2018). Freeriders describe the feeling of moving through remote winter mountain landscapes as something special that few other things can match. It gives a sense of freedom, focus, and satisfaction that comes from relying on your own skills and effort (Sæther et al., 2022). To access remote areas, skiers walk up using specialized skis before skiing down. This is called ski touring and is also referred to as ski mountaineering (Donno et al., 2025).

Physically challenged athletes using a sitski, are unable to walk uphill for obvious reason of not being able to use their legs. And currently available equipment does not allow sitskiers to use their upper body to ascend for a long period time. This means they are limited to lift-accessed terrain or have to rely on friends pulling them up.

Sit-skiing has progressed fast, allowing tricks like backflips on rails and big cliff drops in Alaska. Athletes like Bastien Perret and Nathanael Schaeffer have completed several skitours, including summiting +4000m peaks with friends assisting their climbs (R. Vallin, personal communication, 2025). Existing sitski equipment is built for downhill performance, which results in it being extremely durable. Nevertheless, it is also heavy and missing the functionalities needed for a sitski athlete to perform a skitour autonomously.

1.2 Problem definition

Human-powered mountain travel is largely based on the strength and endurance of the legs. As humans, we are physically adapted to cover long distances by walking or running, using large muscle groups such as the gluteus

maximus and quadriceps. (Mattson, 2012)

When muscle groups in the legs cannot be used, covering long distances under human power becomes significantly more demanding. Especially when elevation gain and variable surfaces are involved. For sit-ski athletes, this challenge is even more specific. They require equipment that allows them to scale a mountain and bring their sitski allong, only using muscles in the upper body. After reaching the top, the sitskier needs to be able to ski down and bring all equipment.

This thesis aims to investigate opportunities for a sit-skitouring setup, enabling human powered backcountry access for physically challenged athletes. Through a user-centred design process, knowledge of user needs, user capabilities, human-powered propulsion and biomechanics is synthesised into a sit-ski touring concept.

Ultimately, this project is about more than developing a product. It is about enabling a new form of freedom in the mountains: allowing sit-ski athletes to become the engine of their own backcountry adventures.

1.3 Scope

This project is limited to athletes categorized within the LW11 and LW12 classes. More details on classification in sitskiing are available in chapter 3.2

The skitour considered for this project has the following specifications:

- Maximum slope angle of 25%
- Minimum elevation gain of 500m
- A pace of 200m vertical elevation per hour

No propulsion assistance is included in the consideration. Further information can be found in the chapter 4 *Needs*.

The considered users are athletes with impairments in their lower bodies. These athletes are skilled sit-skiers and are enthusiastic about outdoor exploration. They have experience with other adaptive endurance sports and enjoy pushing their physical limits.

Figure 3. Skåla, Norway, August 2024 (Dollé, 2024)

Project aim

Investigate opportunities for a sit-skitouring setup, enabling human powered backcountry access for physically challenged athletes.

2 Design process & Methodology

2.1 Research objectives

Main research Objective
MRQ. How can a sit-ski touring setup be designed to support autonomous participation of physically challenged athletes with lower-body impairments in mountain adventures?

Sub-objectives
SRQ1. How does the context in which sitskiing exists, frame skitouring for sitski athletes?

SRQ2. What biomechanical and physical requirements and limitations must be considered to enable sit-ski athletes to generate uphill propulsion?

SRQ3. What needs, limitations, and pain points do sit-ski athletes and relevant stakeholders experience in relation to current sit-skiing and backcountry access?

2.2 Approach

The goal of this graduation project is to generate new academic knowledge in the field of adaptive sports. Research through Design (RtD) (Stappers & Giaccardi, 2017), where the act of designing serves as the primary tool to generate new academic knowledge, has been used to throughout this project.

To reduce bias, this project adopts a User-Centred Design approach (Van Boeijen et al., 2020), characterised by high user involvement throughout the design process. This process is divided in 5 phases: Front end user research, Define, Create, Prototype and Evaluate. Figure 3 showcases the User-Centred Design approach through an adoption of the multi-diamond model (Van Boeijen et al., 2020).

These phases are used in this thesis to bring logic and clarity to the process that has led to the outcome of this project. Although presented linearly, the process will consist of numerous iterative design phases, making use of prototypes and Research through

Design (RtD) to explore and validate insights in context.

2.3 Methods

A range of design methods were used during this project. Figure 4 gives an overview of what design methods were used and at what point in the design process. Each method will be further elaborated on in the relevant phase. (Van Boeijen et al., 2020)

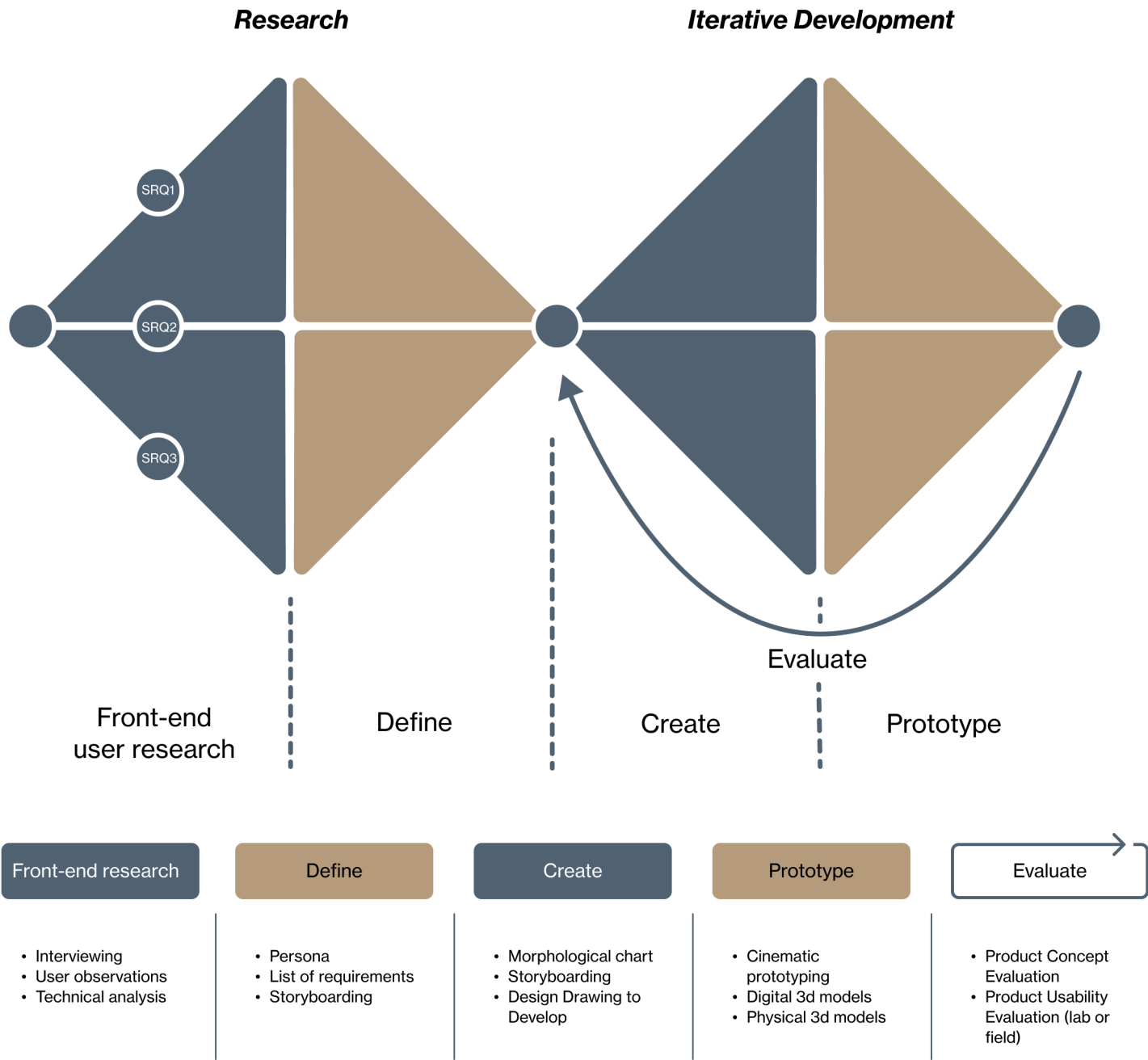


Figure 4. User-centred design adopted multidiamond-model, with corresponding methods.

Front-end user research

This segment of the report presents initial knowledge generation and corresponding methods, informing later stages of the design process. Front end user research consists of three analysis and which are documented in corresponding chapters. Chapter **Context of use** consists of **context analysis**, performed to help frame the problem and understand the environment the design intervention has to take place in. Chapter **Needs** describes a **user analysis** where the needs and values of the target audience are mapped and explored. A understanding of the capabilities and limitations of the target group was gain through a **biomechanical analysis** within the scope of this project in chapter **Biomechanics**.

3 Context of use

3.1 Able-bodied skiing

Dating back approximately 7000 years, skiing has been a way of moving, born out of a spirit of survival. This form of transportation has seen various evolutions in its usefulness, impacting its practical application as well as its involvement in sport and recreational fields. The first official recreational ski-mountaineering expedition is widely credited to Swiss pioneer Christoph Iselin and German explorer Wilhelm Paulcke in 1890, marking the birth of recreational skitouring. (Martinescu-Bădălan & Stănciulescu, 2019)

Nowadays skiing has evolved into different disciplines, which can be summarized in three clusters: Nordic, Resort, Backcountry. Figure 5 shows how these clusters interrelate with each other. A technical analysis on the interrelation of backcountry equipment can be found in Appendix B. This technical analysis was used

to identify the subfunctions present in existing ski touring and sitskiing equipment and to examine the solutions that address these subfunctions. Then, the subfunctions and solutions were compared between ski touring and sitskiing equipment. This comparison facilitated the determination of subfunctions along the vertical axis, which was used to organize and structure (sub)ideas for the morphological chart method, a method that proves useful in ideation during the creation phase.

Ski touring requires equipment that allows efficient uphill movement while maintaining control on the descent. Each component of the setup contributes to balancing mobility, weight, and performance. A skitouring setup consists of the following components: In figure 5, an overview of relevant skitouring equipment can be found.

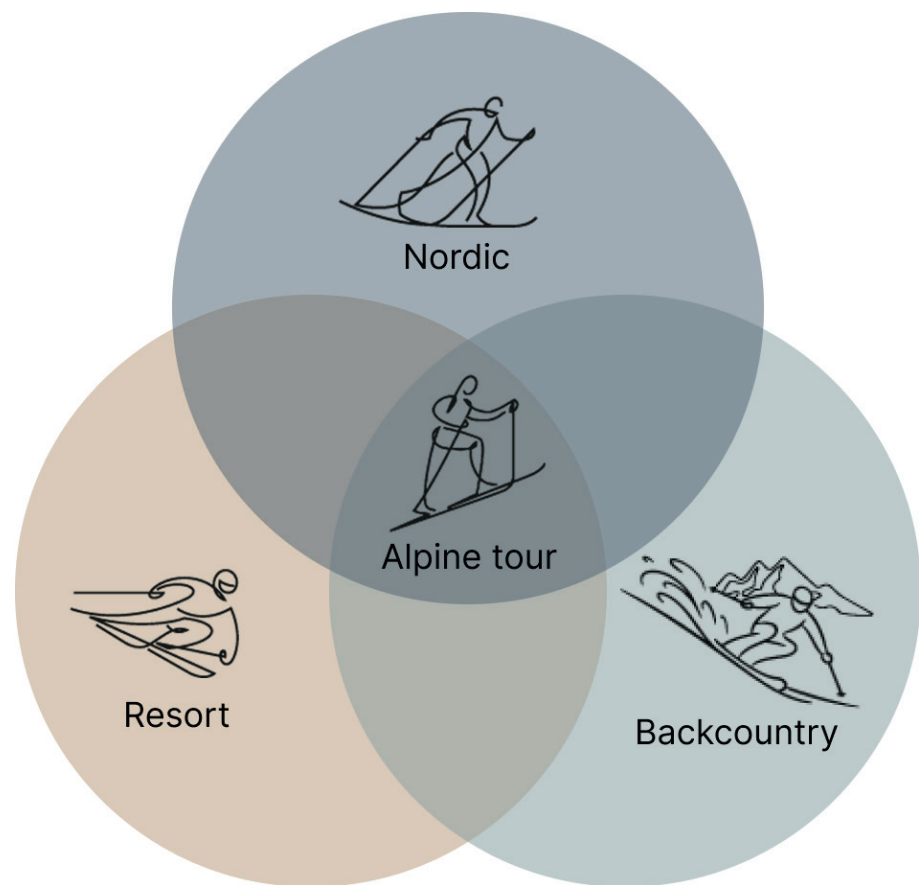


Figure 5. Interrelation skiing disciplines

Crampons provide grip on hard surfaces during ascend

Telescopic **poles** allow users to adjust the length for different terrain.

Skins attached to the base of the skis, preventing sliding backward while ascending



Boots offer a larger range of motion in the ankle compared to traditional alpine boots, allowing a longer stride during ascents.

Skis can vary in weight, width and construction: lighter skis make uphill movement easier, while heavier skis improve downhill stability.

Bindings, connecting the skier to the skis. These bindings have one of various systems allowing the foot to rotate longitudinally for a longer stride.

Figure 6. Overview of skitouring equipment. Adapted from Simond (2025).

3.2 Adaptive sports

Adaptive sports are forms of athletic activity that have been modified to allow people with physical, visual or cognitive impairments to participate. These modifications involve specialized gear and/or modified rules that guarantee accessibility while preserving the sport's competitive nature. (Mass General Brigham, 2024). About **15% of the world population** experiences a significant disability (World Health Organization, 2023), providing a sizable pool of potential participants in adaptive sports. Participation in adaptive sports has significant benefits beyond physical activity. Athletes with physical disabilities who practiced adaptive sports reported significantly higher scores in physical, psychological, and social **quality of life** compared to non-participants (Yazicioglu et al., 2012).

In adaptive sports, athletes have different types and levels of impairments, so competitions need to be fair. To make this possible, athletes are grouped through a process called classification. Classification decides who can compete and places athletes into classes based on how much their impairment affects their ability to perform the specific movements needed in that sport. Classification systems can also inform the design process by defining scope and requirements of the development of adaptive sports equipment. See Appendix F for eligible impairment types as published by Connick et al. (2018).

In adaptive rowing, athletes are classified mainly based on their availability of muscles to generate power using the upper body and trunk. While in sit-skiing, classification focuses more on balance and trunk control. Because of this similarity in functional demands, the adaptive rowing classes are also considered within this exploration and compared to sitskiing classes.

It is important to note that the classifications largely align and categorize adaptive athletes into groups that are beneficial to scope this project.

3.3 Sitskiing

Sitskiing is an adaptive form of alpine skiing that allows people with limited or no use of their legs to ski independently. Research suggests skiing can positively influence self-perceptions and motor performance for individuals with disabilities. It also suggests that risks of recreational sports appear manageable and comparable to the general population (Nasuti & Temple, 2010).

A sitski consists of a molded seat mounted on a metal frame that connects to a ski through a standard binding interface. Under the seat, a suspension system absorbs shocks and helps maintain contact between the ski and the snow surface. The skier uses short poles with small skis on the ends, called outriggers, to balance, steer, and push forward on flat terrain (Canadian Adaptive Snowsports, n.d.). In figure 7, an overview of sitskiing equipment can be found.

There are two main configurations: mono-skis and bi-skis. A mono-ski uses a single ski and is designed for users with good upper body control and balance. A bi-ski has two skis for increased stability and is often used for beginners or for skiers with higher-level impairments who require more support (Canadian Adaptive Snowsports, n.d.). Modern sit-skis use adjustable components such as shock absorbers and seating angles to fine-tune performance to the skier's ability and the terrain (Outside Online, 2023).



Figure 7. Overview of sitski equipment.

3.4 Environment

The environment in which ski touring can take place ranges from the edges of marked slopes to anything outside the marked slopes. This means varying snow-surface and snowpack conditions are to be expected. Snow can be powdery and glistening, or it can be wet and heavy on the ground. It can also be granular and hard, with a brittle crust that gives way underfoot. Generally speaking, snow surfaces can be divided into two groups: hard-packed, supportive surfaces and soft, non-supporting surfaces. See figure 8. (Schöttner et al., 2025)

Moreover, natural mountain terrain is rarely flat or uniform. When traversing a slope or making hairpin turns to overcome steeper sections, the athlete is often positioned on an incline. This creates a height difference between the left and right side relative to the athlete.

Weather conditions influence the shape of snow crystals, which affects the friction they generate (Mushtaq et al., 2025). Tests by Frühwirth et al. (2018) showed that climbing skins provide much more grip than glide. The grip friction coefficient describes the resistance

that prevents the ski from sliding backwards. At a snow temperature of -3°C, this coefficient was about ten times higher than the sliding friction coefficient measured during forward motion.

The researchers also found that the choice of material strongly affects performance. Common climbing skins are made from nylon, mohair (angora goat hair), or nylon-mohair blends. Nylon skins are durable and provide strong grip, while mohair skins provide the least sliding friction. Blended skins combine both qualities and are therefore more versatile. Understanding these material differences is valuable for the design phase, since the selected skin composition directly influences traction and glide efficiency.

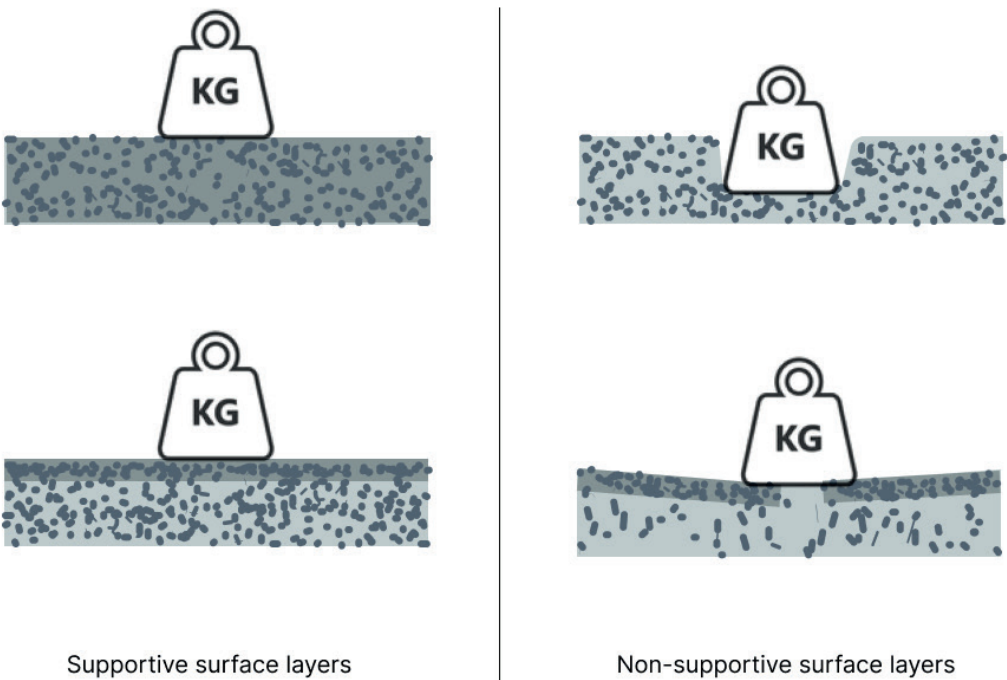


Figure 8. Supportive & non-supportive snow surfaces

3.5 Market analysis

The project is situated within a highly specialised niche market with unique dynamics and regional preferences.

To better understand the range of sit-ski products currently available, the C-box method was used to map existing models against each other. This method allows for a structured comparison of products and helps identify patterns in innovation, target users, and potential areas for new product development (Van Boeijen et al., 2020).

The C-box, shown in Figure 9, uses state of the art on the horizontal axis and intended target group on the vertical axis. Since Tessier is the largest player in the sit-ski market, selling approximately five times

more units annually than any competitor, its models were highlighted in the analysis (R. Vallin, personal communication, 2025).

The analysis shows the conservative nature of the sit-ski market, with most models concentrated around existing solutions. Although some innovative concepts exist, they remain a minority. Innovative concepts can bridge the gap between imagination and reality (Polestar, 2024). This could help inspire the sitski market into a new wave of innovation.

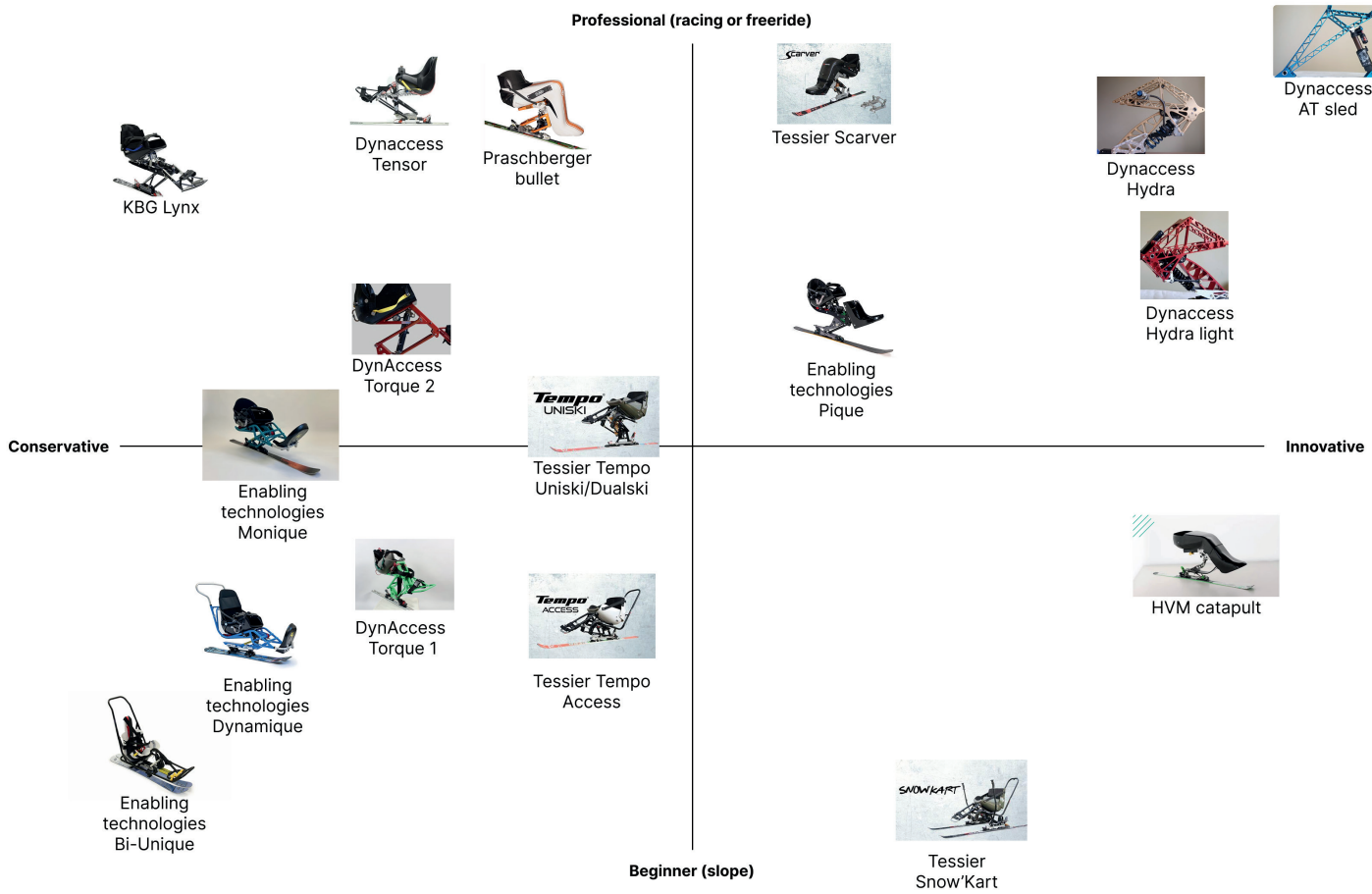


Figure 9. Sitski market analysis C-box.

3.6 Exploring solution space

Solutions from adaptive outdoor sports that address challenges similar to sit-skiing were explored and analysed. First, existing ski-touring approaches used by sit-ski athletes were analysed. Then, adaptive climbing, rowing and mountain biking were examined to gather relevant insights for the design process.

Sitskitour approaches

Pulled team work approach:

The sit-skier is pulled uphill by friends on touring skis. The pulling team ranges between 1 and 10 people, depending on the intensity of the tour and the sitskiers ability to assist (figure 10).

The T. Walker approach:

Using modified hand covers and a simple sled type design, pushing with the hands in the snow.

DynAccess AT frame:

The DynAccess AT frame explored how a sitski could be adapted for human-powered backcountry use. The design focused strongly on weight reduction, using a stripped-down binding mechanism and simplified suspension. This made the system very light. Although very light, this suspension leveraging a single pivot lever arm pushed the rider backwards and forwards while suspending, which is not preferable. See figure 11.

Adaptive climbing

Adaptive climbing is a form of rock climbing that enables people with physical disabilities to participate. It adapts traditional climbing methods and equipment to suit the climber's physical abilities, allowing them to safely ascend indoor walls or outdoor rock faces. This is relevant since adaptive climbing has been done since the 1980 and also focuses on working against gravity to gain altitude.

Climbers without functional use of their legs use a harness that allows them to sit in a stable and safe position. To ascend, they use an ascender: a device that can slide smoothly up a rope but locks to prevent downward movement. By pulling on a horizontal bar attached to the ascender, the climber can lift

themselves and gain altitude. See figure 12.

Adaptive rowing

Adaptive rowing is practiced using adapted equipment set-ups for different types of disabilities involved. These adaptations enable athletes to practice the sport. Here are a few examples for innovations as described by Mazzoni et al. (2023).

Boats used by athletes in the PR1 sports class can be equipped with flotation systems known as pontoons (figure 13). These stabilizers are fixed to the oarlocks of the boat to ensure further lateral balancing (pontoons are optional for PR2 rowers). Straps are utilized for stability: chest straps are necessary for PR1 rowers, and knee straps are used for PR2 rowers to prevent knee flexion or extension during rowing. Sitskiers could benefit from stabilizers similarly.

Adaptive mountainbiking

Analysing innovations in adaptive mountain biking is relevant, as they aim to find solutions for similar challenges. Adaptive mountainbiking just deals with a different surface and the constraints that come with it.

In general 3 main types of hand mountain bikes exist.

- Two wheel versions
- Three wheel versions or trikes (Bowhead Corp, ICE & TESSIER) and four wheel version (figure 14)
- Four wheel versions (Gravity quads & The Rig by notawheelchair). (figure 15)

Two wheeled versions are used by athletes who have enough functional use of their legs to prevent falling over when standing still. The three and four wheeled versions come in human powered and electric assistance versions. The mountain bikes that are meant to go uphill as well, like the Bowhead reach, come with electric assistance to allow hand mountain bikers to go further and steeper uphill. (Oregon Adaptive Sports, n.d.)



Figure 10. Nathanael Schaeffer joining a skitour with his friends. (Schaeffer, 2007)



Figure 11. Alpine Touring frame (DynAccess, z.d.)



Figure 12. Mark Wellman climbing 914m face El Capitan (Wellman, 1989)



Figure 13. Pontoons attached to a rowing boat (Canadian Paralympic Committee, n.d.)



Figure 14. Bowhead Reach in action (Bowhead Corp n.d.)



Figure 15. 'The Rig' four wheel all terrain not a wheelchair (Not-A-Wheelchair, n.d.)

Takeaways

- Sit-ski touring is a highly specific niche within both ski touring and adaptive skiing
- Adaptive sport participation is linked to improved quality of life.
- LW10 athletes fall outside the scope of this project
- Dual-ski configurations are more suitable than single-ski configurations for soft, non-supporting snow surfaces.
- The current sit-skiing market can be considered conservative, creating a need to look beyond existing sit-ski products for inspiration.
- Adaptive outdoor sports use different technical principles to overcome physical barriers, such as ascenders in climbing, pontoons in rowing, and electric assistance in mountain biking.

4 Needs

This chapter explores the needs, motivations, and experiences of key stakeholders involved in adaptive skiing and related sports. Through a series of qualitative interviews with manufacturers, users, and elite adaptive athletes, insights were gathered to understand what sit-ski touring could and should become.

4.1 Sitski manufacturers

An interview with TESSIER provided insight into the manufacturer's perspective on sit-ski touring. As a leading manufacturer, TESSIER confirmed that they occasionally receive requests for lightweight equipment that can be used for both ascending and descending, indicating a clear but niche demand for sit-ski touring solutions. Currently, a small group of sitski athletes use a method which involves a group of able-bodied skiers pulling them up. TESSIER noted:

'Sit-skiers want to participate to go up and assist their partners, not fully rely on being pulled.'

Below, key takeaways have been listed.

- The fundamental conflict of uphill vs. downhill performance in ski touring equipment design is highly relevant to sit-skiing as well.
- Equipment with an uphill focus requires it to be lightweight for energy efficiency. While equipment with a downhill focus requires strength, rigidity, and high-performance suspension for safety and control on variable and challenging terrain
- Several opportunities for weight reduction were identified, such as removing the chairlift loading mechanism and exploring lighter seat construction.
- There is a gap between current freeride-oriented sit-skis and the needs of athletes who want to access backcountry terrain through human-powered ascent.

4.2 Sitski users

Multiple sitski users were interviewed to gain insights into their experiences. Amongst them were Paralympians and pioneers in the sport.

An interview with Sarah van der Glas shows that sit-ski touring is strongly connected to participation and independence. Sit-skiing allowed her to join others again after long COVID limited her physical capacity. She has tried to go for a skitour together with Remco Mensinck, an able-bodied skier who assisted her up using a rope. Independence is highly important to Sarah.

'When you're in a wheelchair, people often try to do everything for you. But I want to do things myself. If I can't do something yet, I still want to try.'

Below key takeaways have been listed.

- Existing outriggers are not suitable for propulsion in soft snow. Sarah's outriggers sank into the snow and provided little support.
- Core fatigue is an important design consideration. Because Sarah does not use a backrest, she constantly needs to stabilize herself. Waiting and remaining upright becomes tiring, especially for her core muscles.
- Independence is a key user need

The interview with Tyler Walker, double Paralympic sitski medalist highlighted challenges he experienced with sitski equipment and capabilities of his body. Over the past years, he has been working on various designs and prototypes to 'explore the world by hand'. His perspective led to an interesting conversation, of which key takeaways have been listed below.

- Heavy suspension is not always necessary in the backcountry. The suspension needed for racing and high-speed resort skiing adds weight and complexity. According to Tyler, soft backcountry snow already provides damping, meaning a simpler and

- lighter frame could be more suitable.
- High seating position creates safety risks in deep snow. A typical monoski seat height of around 15 inches improves downhill skiing performance, but becomes risky in powder. If a sit-skier falls over in deep snow, getting upright again can be very difficult.
- Upper-body propulsion is much less efficient than leg-powered touring. Walker notes, *"legs are so much more efficient and powerful in every way... my upper body is pretty strong but as strong as I could possibly get it. It's never going to compare to legs."*
- Towing by others is not a sustainable solution. Being pulled uphill by friends can make backcountry access possible, but it creates dependence. Tyler noted that even very supportive friends are unlikely to tow someone every weekend.

Athletes who have tried the previously mentioned pulling method, reported the following pain points. (R. Vallin, personal communication, 2025)

- It has been reported that being pulled for two hours creates significant, painful pressure on the back of the seat. He expressed a need for a high backrest for uphill comfort, but he would want to remove it for downhill skiing to allow more freedom of movement.
- A custom seat has been developed with sides that could open sideways for easier entry and exit in the mountains. However, this custom solution was "not very strong" and is not considered a primary design requirement for most users.

Figure 16. Sitski representative

4.3 Adaptive sport athletes

Bowhead Corp founder Christian Bagg spoke in an interview with Singletrack World about his attempt to handcycle up a trail with 1,600 meters of vertical elevation (Dobson, 2022). He used the latest prototype of the Bowhead RX, a handbike designed for mountain bike trails and equipped with an electric motor that provides assistance.

'As good a friends as you could possibly have... They're not going to pull you up a mountain every weekend.'

Tyler Walker,
Paralympic medalist



'Scaling mountains is something I did before becoming paralyzed. I am not about to let my physical challenges stop me from doing what I love.'

Karen Darke,
Paralympic gold medalist
(Darke, 2023)

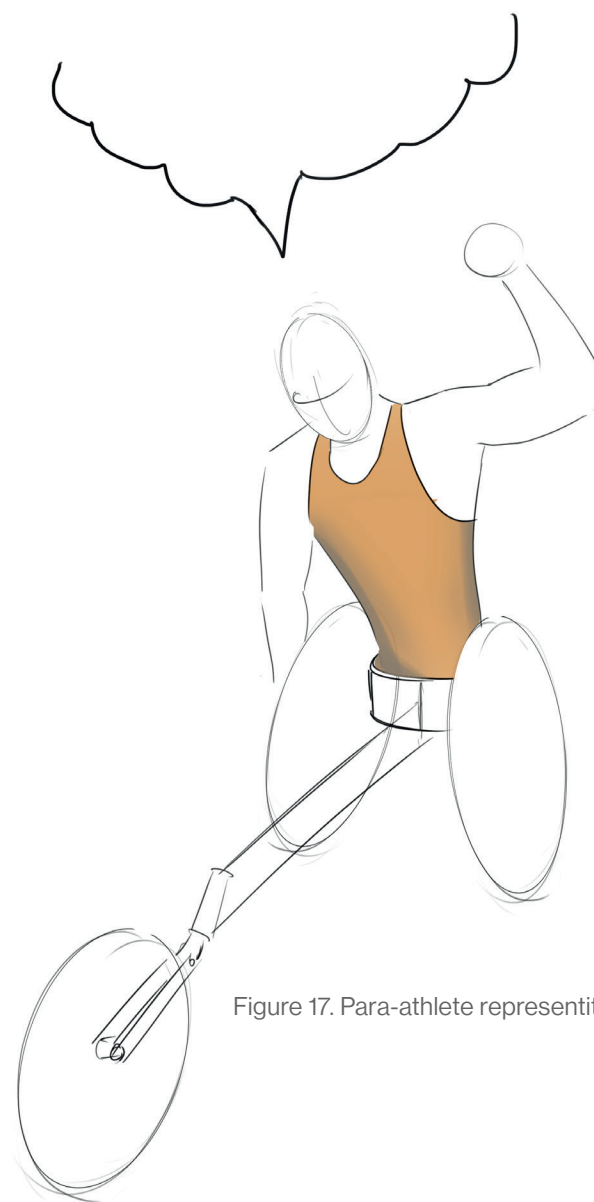


Figure 17. Para-athlete representative

'I was a mountain biker before I was injured and wanted to be a mountain biker after I was injured. But the technology just wasn't there. I would have never thought that I would handcycle up a mountain. You get this sort of euphoric that you don't get in a motorized vehicle.'

Christian Bagg (Dobson, 2022)

This shows Baggs' drive to push both his own limits and the limits of technology in pursuit of his dream. It also shows that physically challenged athletes in other sports have successfully developed design solutions for similar outdoor challenges.

Jean-yves Michellod was a famous, event winning freeride skier back in 2004. An avalanche accident left him partially paralyzed, but that did not stop him. The sitski has allowed Michellod to resume his passion. Michellod has summited Mont Blanc with help from friends. (Fish, 2015)

"Freeriding for me is just about being free to ski; There are no gates and nobody is telling you where you have to go."

Jean-yves Michellod, (Fish, 2015)

These examples show that many physically challenged athletes are motivated to refuse letting their physical challenges define where they can and cannot go.

Takeaways

- User research revealed a strong motivation among physically challenged athletes to explore the backcountry with more freedom, independence, and participation.
- Interviews with manufacturers, athletes, and users confirm a small but clear demand for lightweight sit-ski touring equipment that supports both uphill and downhill use.
- Current solutions are limited and mainly consist of user-modified equipment rather than dedicated sit-ski touring systems.

5 Biomechanics

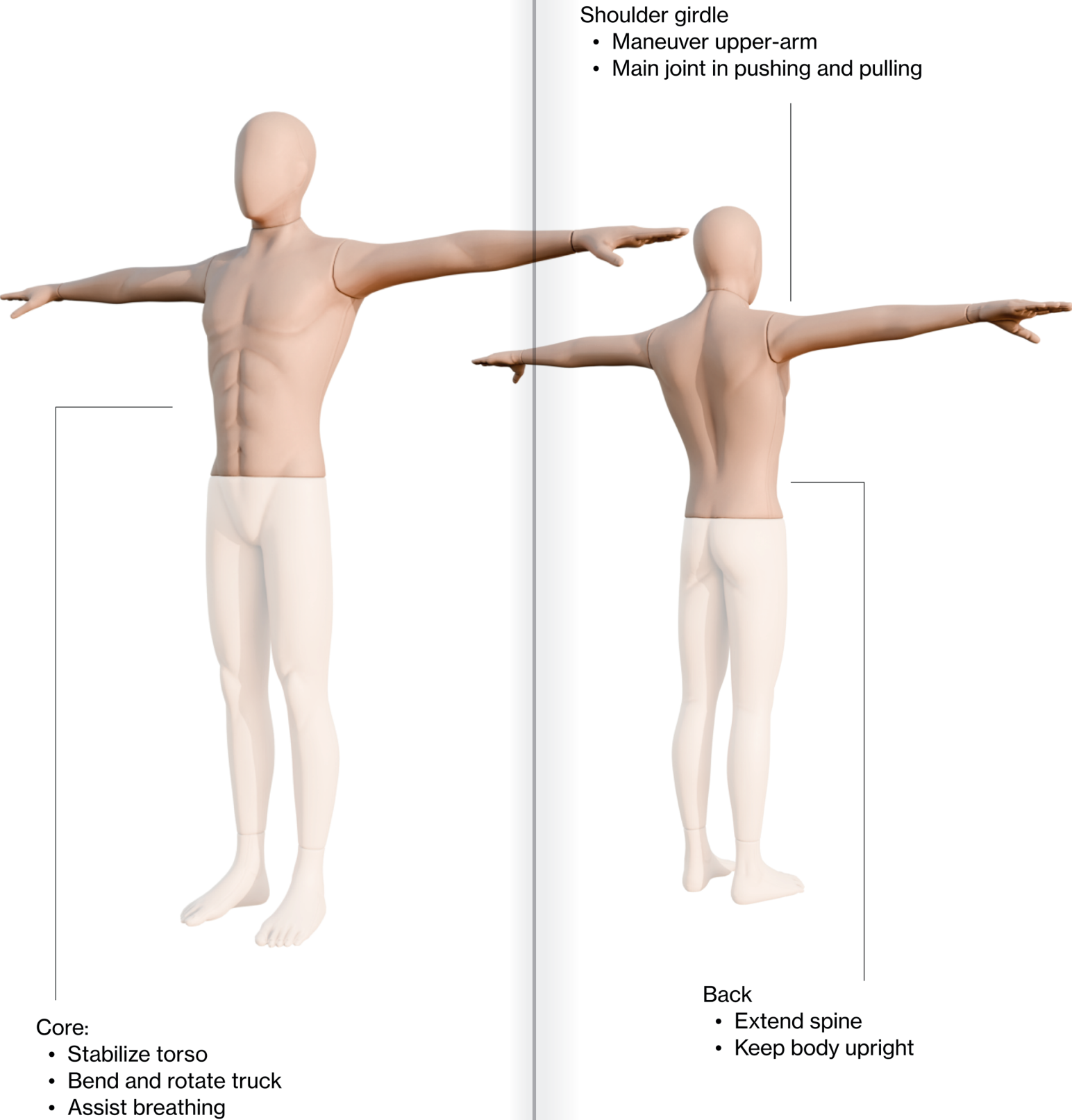
This chapter explores data on the biomechanics of physically challenged athletes to gain a better understanding on their capabilities. A clear understanding of human anatomy is essential when designing equipment that interacts closely with the body, such as a sit-ski. The design must accommodate users with a wide range of physical challenges, which may include spinal cord injuries, limb amputations, reduced muscle strength, or limited joint mobility. Knowledge of anatomy helps identify how users generate movement, maintain posture, and transfer forces through their bodies.

5.1 Relevant anatomy

According to Gray’s Anatomy for Students (Drake, Vogl, & Mitchell, 2024), the human trunk forms the structural core of the body. It is built around the vertebral column (spine), which consists of 33 stacked bones divided into the cervical (neck), thoracic (mid-back), lumbar (lower back), sacral, and coccygeal (tailbone) regions. The spine provides both structural support and flexibility and protects the spinal cord, which connects the brain to the muscles of the body. Nerves leave the spinal cord through small openings between the vertebrae to innervate the muscles. These nerves transmit the electrical signals that cause muscles to contract.

The muscles of the trunk can be grouped into those at the front (abdominal muscles) and those at the back (spinal extensors). The abdominal muscles include the rectus abdominis (the “six-pack muscle”), the external and internal obliques (muscles that wrap around the sides of the abdomen), and the transversus abdominis (the deepest abdominal layer). Together, they bend the trunk forward, assist in rotation, and stabilize the torso. These muscles also play an important role in breathing and maintaining internal pressure in the abdomen. For sitski users, strong and well-supported abdominal muscles are important for stability and control, especially when leaning forward or absorbing shocks.

The back muscles, particularly the erector spinae group (which includes the iliocostalis,



longissimus, and spinalis muscles), extend the spine and keep the body upright. These muscles run vertically along the spine and are supported by deeper stabilizing muscles such as the multifidus. In skiing, they are active when maintaining an upright posture and controlling the body’s tilt while turning or absorbing uneven terrain. Depending on the user’s condition, some or all of these muscles may be weakened or inactive.

The shoulder girdle (shoulderblade and collarbone) and upper limb muscles are also crucial for propulsion and maneuvering the sit-ski. The pectoralis major (chest muscle) pulls the arms forward and toward the center of the body, while the latissimus dorsi (broad back muscle) extends and rotates the upper arm. Together, they generate much of the force used for pulling and pushing. Other key muscles include the trapezius and rhomboids (upper back muscles that stabilize the shoulder blades), the deltoid (shoulder cap muscle responsible for lifting the arm), and the triceps brachii (muscle at the back of the upper arm that extends the elbow). These muscles are particularly important for users with reduced lower-body function, as they become the primary source of propulsion and control.

Finally, the lower limbs vary widely in function among sit-ski users. Some athletes have partial or full lower-limb function but use the sit-ski for balance or health reasons, while others have complete paralysis or amputations. The main muscles of the lower limbs, such as the quadriceps (front thigh muscles), hamstrings (back thigh muscles), and gluteal muscles (buttocks), are typically responsible for power generation and stability in standing skiers. In sitskiing, their absence or limited function shifts the physical demands toward the trunk and upper limbs. As a result, the seat design, center of gravity, and mechanical interfaces must be optimized to transfer forces from the upper body instead.

Understanding these anatomical systems provides the foundation for making informed design choices later on.

Figure 18. Relevant anatomy

5.2 Upper-body strength in physically challenged athletes

Evidence suggests that people with lower-limb amputations can develop upper-body strength and power comparable to or even greater than able-bodied individuals, particularly when they engage in regular or competitive sports. This is relevant for sit-ski touring, because the proposed propulsion method depends mainly on the arms, shoulders and trunk rather than the lower limbs. As shown in Appendix H: Muscle function and corresponding sit-ski class, the degree to which athletes can contribute through trunk control and upper-body movement differs between sit-ski classes. This makes it important to understand not only whether upper-body power can be developed, but also which muscle functions are available to different users.

In a study examining aerobic and anaerobic arm-cranking performance, Hutzler et al. (1998) found that athletes with lower-limb amputations achieved peak anaerobic power outputs up to 18–23% higher than able-bodied athletes of similar age and training background (figure 19). The authors explained this as a consequence of increased reliance on the

upper limbs for mobility and propulsion, leading to long-term adaptations in the shoulder, arm, and trunk musculature. Athletes who trained intensively showed the highest power values, suggesting that training exposure rather than disability itself determines the degree of upper-body enhancement.

However, not all individuals with amputations automatically exhibit stronger upper bodies. Henson et al. (2021) demonstrated that muscle adaptations depend on the level and type of amputation. Using high-resolution magnetic resonance imaging (MRI), they found selective hypertrophy in muscles involved in compensatory movement, such as the gluteus medius and hip flexors, while other muscles showed atrophy. This indicates that altered mechanical loading rather than the absence of lower-limb muscle activity drives these changes. Similarly, Mazzoni et al. (2023) reviewed para-rowing literature and found that performance outcomes in athletes with physical impairments are largely determined by training load, neuromuscular coordination, and technique. When training opportunities are equal, para-athletes reach upper-body strength and endurance levels comparable to their able-bodied counterparts (figure 20).

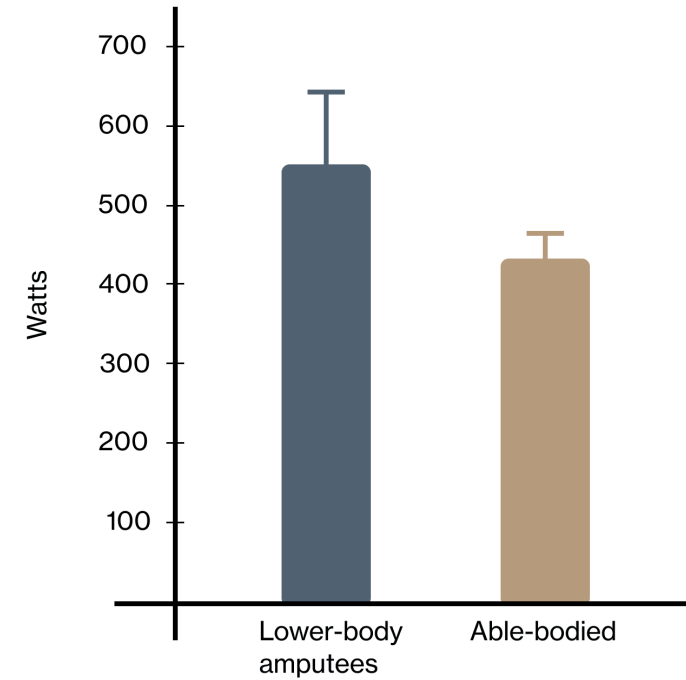


Figure 19. Anaerobic power output comparison. Adapted from Hutzler et al. (1998)

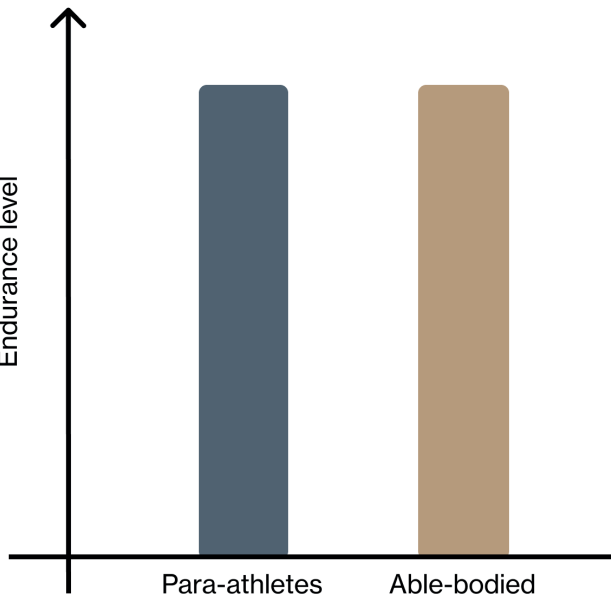


Figure 20. Endurance level comparison. Adapted from Mazzoni et al. (2023)

These findings were interpreted in relation to the movement demands of ski mountaineering. Appendix I: Kinematics of ski mountaineering shows that conventional ski touring relies on a repeated cyclical movement pattern in which propulsion is generated mainly through the lower limbs, supported by pole use and trunk coordination. For sit-ski athletes, this lower-limb contribution is absent. Therefore, the propulsion strategy has to be translated toward a seated movement pattern in which the arms, shoulders and trunk become the primary contributors to uphill movement.

In summary, lower-limb physically challenged athletes can develop strong or even superior upper-body capabilities. These capabilities, however, arise through functional adaptation and targeted training. In the context of sit-ski touring, this suggests that a human-powered uphill system should be designed around the available muscle function of the target sit-ski classes.

5.3 Factor influencing endurance performance

Endurance performance depends on how efficiently the human body can produce, use, and recover energy during prolonged effort. According to a Delphi consensus study by Krüger et al. (2022), there are 26 main factors, called the FENDLE factors (Factors for ENDurance Level), that together describe what enables high-level endurance performance. Among these, three are considered the core physiological foundations:

- 1. Maximal oxygen uptake (VO₂max): the body's ability to take in and use oxygen
- 2. Lactate threshold the highest intensity at which energy can be produced aerobically before fatigue builds up too quickly, and
- 3. Movement economy how efficiently the body converts oxygen into motion.

Other important factors include how quickly the body can recover between training

sessions, how effectively it can burn fats and carbohydrates, and how well it can buffer acid that accumulates during intense effort. The structure and composition of the muscles also matter. For example, athletes with a higher proportion of slow-twitch muscle fibres and well-developed mitochondria (the energy-producing parts of cells) can sustain aerobic performance for longer. The number of red blood cells and the amount of iron in the body affect how much oxygen can be delivered to the muscles, while hormones such as cortisol and testosterone regulate energy balance and recovery. Together, these elements show that endurance performance is not determined by a single factor but by the combined efficiency of the body's energy, muscular, and recovery systems (Krüger et al., 2022).

In practice, endurance athletes often use a Functional Threshold Power (FTP) test to measure performance. The FTP represents the maximum average power, measured in watts, that a person can sustain for about one hour. Dividing this number by body weight gives a watts-per-kilogram (W/kg) value, which allows fair comparison between athletes of different sizes. FTP is used to set training zones, monitor progress, and assess overall endurance capacity. It provides a functional, design-relevant measure of how well the body converts metabolic energy into mechanical power output (Valenzuela et al., 2019).

5.4 Required power output

Understanding the physiological factors that influence endurance performance provides the foundation for estimating what the human body can sustain in real-world movement scenarios. While parameters such as oxygen uptake, lactate threshold, and energy metabolism describe how endurance is achieved biologically, translating these into mechanical terms such as power output allows for design-relevant analysis. For the development of a sit-skitouring system, this connection between physiology and mechanics is essential.

To evaluate whether athletes with limited lower-body function can generate enough mechanical power to perform a ski tour, a series of comparative mathematical models was developed. The process began with an analysis of cycling uphill, which provides a well-documented and physically comparable activity where energy expenditure and mechanical power can be accurately measured. Using basic physics principles of motion, resistance, and gravity, a mathematical model was built to estimate the power required to move a given mass up a slope. This model was validated against real-world data from Stage 13 of the 2025 Tour de France, an uphill time trial from Loudenvielle to Peyragudes completed by Tadej Pogačar. After fine-tuning the parameters to match his measured power output, the model showed good accuracy and was then

adapted to simulate walking uphill and, finally, ski touring uphill conditions. See appendix G.

The ski touring model estimated that an athlete would need to sustain an average mechanical power output of approximately **144 W** to complete an relatively average skitour of 8.5 km, 933 meter vertical ascent at a steady pace of 3.1 km/h. To assess whether such power levels are achievable using only upper-body effort, these results were compared to data from elite para-athlete performance studies. One particularly relevant reference is the case study of a Paralympic champion rower with a spinal cord injury (Laskin et al., 2018). In a 1,000-meter arms-only rowing time trial, the athlete produced an average power of 248 ± 25 W over 3.9 minutes, peaking near 293 W at the start and stabilizing around 235–240 W for most of the effort. Oxygen uptake reached 3.46 L/min, equivalent to about $38 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and blood lactate levels peaked at 15.8 mmol/L, confirming the exercise intensity was near maximal.

Since the rowing trial represented roughly a four-minute maximal effort, it is possible to estimate sustainable long-term power using the Jensen endurance scaling model (Ergrowing, n.d.). Based on this relationship, a four-minute mean power corresponds to about 110–115% of 20-minute power, suggesting that the athlete could sustain 225 W for 20 minutes and approximately **170 W**

for an hour (FTP). These values indicate that even when propulsion is generated exclusively by the upper body, highly trained athletes can maintain power levels close to, or above, those required for continuous uphill ski touring. For context, elite able-bodied rowers can produce around 400–450 W for six minutes over a 2 km race, but they benefit from the much larger muscle mass of the legs.

This comparison demonstrates that the mechanical power demands of ski touring fall within the feasible range for upper-body athletes depending on the given physical limitation, provided that efficient movement patterns and assistive equipment minimize energy losses. From a design perspective, this insight is valuable: it suggests that a sit-skitouring system can be engineered to work within realistic human power limits, focusing on optimizing mechanical efficiency, stability, and ergonomics rather than purely increasing power capacity.

Takeaways

- A pulling movement, such as rowing, activates several large muscle groups at the same time, including the trunk, back, shoulders, and arms. This makes it a promising movement pattern for generating upper-body propulsion.
- Athletes with lower-limb impairments can develop 23% higher upper-body power outputs compared to able-bodied athletes of similar age and training background.
- Para-athletes reach upper-body endurance levels comparable to their able-bodied counterparts.
- High-level endurance performance is mainly determined by VO_2max , lactate threshold, and movement economy, which together describe how much energy an athlete can produce aerobically and how efficiently this energy is converted into movement.
- Trained para-athletes appear able to generate sufficient upper-body power for ski touring, as the estimated required average power output of 144 W falls below the suggested upper-body functional power threshold of 170 W.

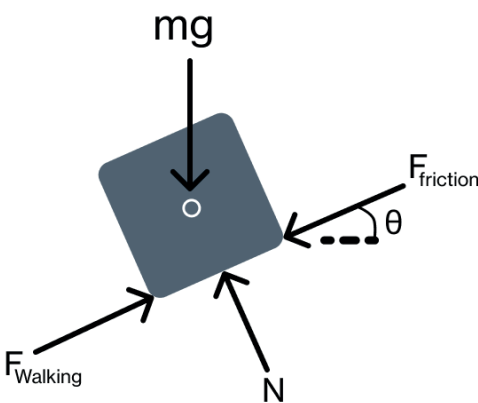


Figure 21. Freebody diagram skitouring model

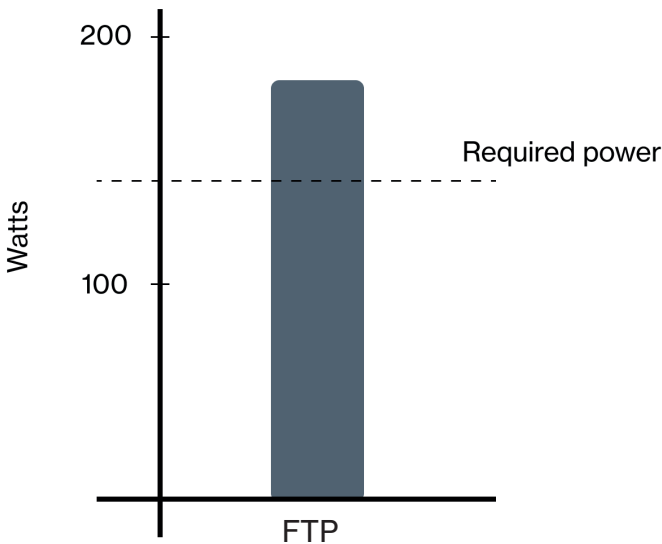


Figure 22. Estimated FTP vs required power for skitouring

6 Synthesis

This chapter concludes the front-end user research by synthesizing the investigated opportunities into an opportunity definition.

6.1 Contextual opportunities

In relation to SRQ1, ski touring can already be considered a niche sport. The combination of sit-skiing and ski touring narrows this niche even further. Nevertheless, the relevance of adaptive sport should not be underestimated. Around 15% of the world's population experiences some form of disability, and participation in adaptive sports has been associated with higher quality-of-life scores.

Classification systems are primarily used to create fair competition, but they can also help define the scope of design briefs for adaptive sport innovation. In the context of sit-skiing, this means that athletes classified as LW10 fall outside the scope of this project. These athletes have no or minimal control over their upper and lower abdominals and/or spinal extensors. Muscles which are essential for skiing soft snow.

Within sit-skiing, two main configurations exist: a single-ski configuration and a dual-ski configuration. A dual-ski setup offers more flotation and is therefore more beneficial in soft snow. This becomes especially important in soft, non-supporting surface layers, where the ski needs to distribute the user's weight over a larger surface area.

The sit-skiing market itself can be described as conservative. Therefore, solutions from other adaptive outdoor sports were explored to identify relevant principles. In adaptive climbing, ascenders allow athletes with no functional use of their legs to move up a rope step by step. In adaptive rowing, pontoons are used to provide lateral stability. In adaptive mountain biking, electric assistance is often used to compensate for physical limitations and enable access to challenging terrain.

6.2 User needs

To conclude SRQ3, the user research revealed a strong motivation among adaptive athletes to explore the backcountry independently. Interviews with manufacturers, athletes, and users highlight both the potential and the challenges of combining sit-skiing with ski touring. While a small but clear demand exists for lightweight equipment suitable for both uphill and downhill use, current solutions are still limited and mainly user-modified.

Manufacturers such as TESSIER and DynAccess emphasized the technical tension between weight reduction and structural strength. Users like Sarah and Tyler confirmed that current sit-ski models are too heavy to maneuver uphill, while also causing discomfort and fatigue. A need for a lighter equipment and improved propulsion systems was clearly expressed.

6.3 Biomechanical opportunity

To answer SRQ2, ski touring requires athletes to sustain a steady power output for a long period of time. The ski touring model estimated that an athlete would need to sustain an average mechanical power output of approximately **144 W** to complete a relatively average skitour of 8.5 km, 933 meter vertical ascent at a steady pace of 3.1 km/h. Literature and power calculations suggest that trained para-athletes can achieve a functional power threshold (FTP) of **170W** through upper-body propulsion.

This means physically challenged athletes with lower body impairments should be able to complete an average skitour on human power generated by the upper-body. The missing link is equipment that enables athletes to convert that power into propulsion.

6.4 Opportunity definition

The research on context of use, user needs, and biomechanics has been synthesized. The findings suggest that trained physically challenged athletes with lower-body impairments are able to produce sufficient and durable upper-body power for ski touring. In addition, athletes are motivated and have expressed a clear need for ski touring equipment. Combined with a gap in the current market, these insights reveal a clear design opportunity:

'To design a sit-ski that enables independent uphill propulsion through upper-body power transfer, while maintaining the ability to confidently ski down after reaching the top.'

Define

This chapter uses the *Synthesis* to define the design assignment. The assignment is defined through a specific problem definition, design drivers, a list of requirements, personas and a scenario. Together, these elements form the baseline for the *Iterative Development* phase.

7 Define

7.1 Problem definition

A minimum of 144 W needs to be generated by a human-powered propulsion system that can be retrofitted onto existing sit-skis. The propulsion system should be convertible in such a way that it does not hinder the user during the descent. Since the target group has control over the muscles above the waist, human power can only be generated through the muscles of the trunk and upper body. Therefore, the design should enable sit-ski athletes to perform a ski tour with greater autonomy.

7.2 Design drivers

Based on the *Front-end user research* a list of requirements was made. A list of requirement can be found in Appendix A. This list of requirements can be distilled into these 3 design drivers. They serve as a north star to drive the development and keep it on course. The identified design drivers are as followed:

- 1. Enabling autonomy
- 2. Being reliable in mountain environments
- 3. Providing a sense of inclusion



Figure 23. Persona Hedi

7.3 Persona

Front-end user research identified two types of target users.

The first persona, Hedi, is a skilled and motivated sit-skier who is looking for the next challenge. She has already performed a ski tour with the help of friends, but is now looking for more autonomy. Although her friends are happy to support her, she wants to experience what it is like to ascent by herself. Even though she knows she might not succeed immediately, she is motivated to try.

She is interested in freeriding and exploring the outdoors. Therefore, she spends her winters in the mountains, where she can enjoy the freedom and challenge of sit-skiing.

She is 25 years old and lives in Switzerland. Most of her friends are involved in outdoor sports. Although she is the only physically challenged athlete in her friend group, she is included wherever possible. However, she wants to move from being included in the activity to actively participating in the full ski touring experience. See figure 23.

The second persona, Benji, is an adaptive endurance sport athlete who is triggered by the outdoors and finds joy in being challenged. He is not about to let his physical capabilities dictate where he can and cannot go.

Although he is able to sit-ski, he rarely does so. He finds more meaning in endurance sports, where the challenge is not only in the environment, but also in pushing his own physical and mental limits. Para-triathlons used to be a big part of his life, and he has managed to compete at an international level.

He is now looking for a new challenge. Something that allows him to explore the mountains in a different way and push his boundaries beyond the sports he already knows.

He is highly motivated, physically capable, and used to training with a clear goal. For him, sit-ski touring is not only about reaching the top of a mountain, but about proving that physically challenged athletes can take on demanding outdoor challenges through their own power. See figure 24.

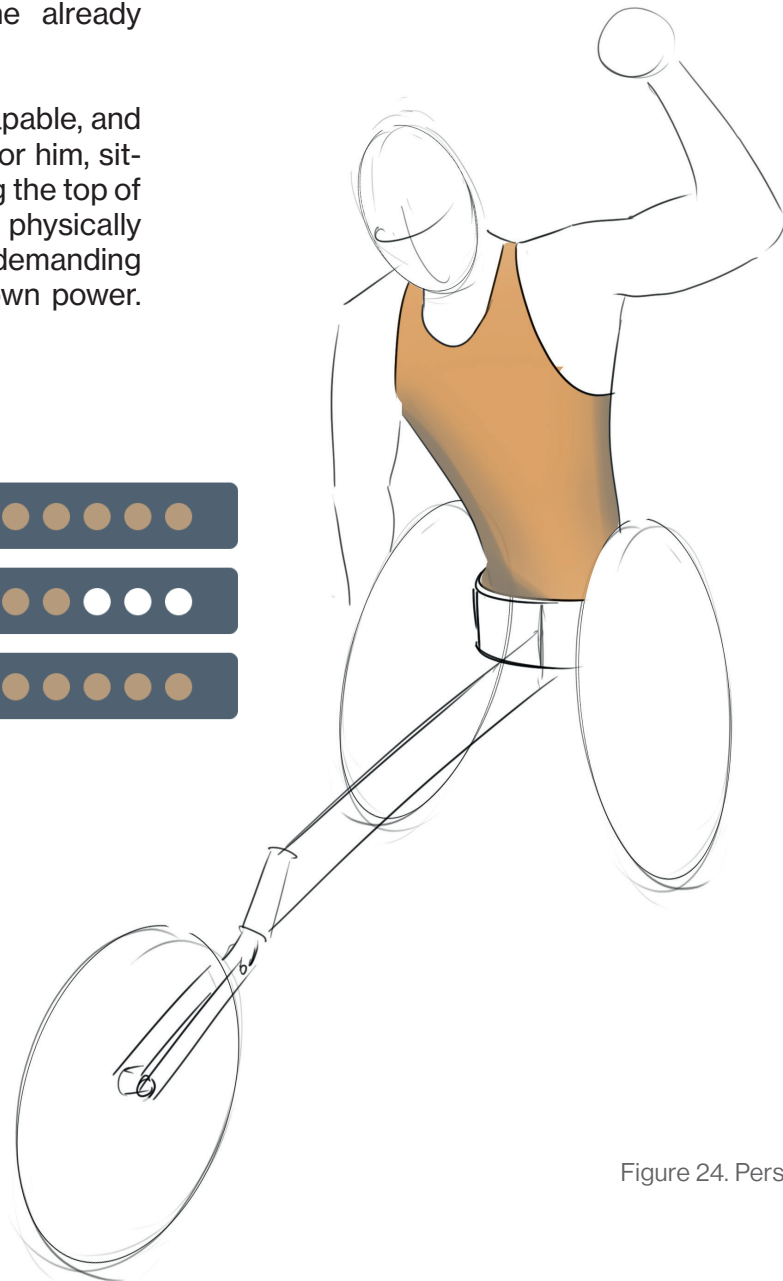
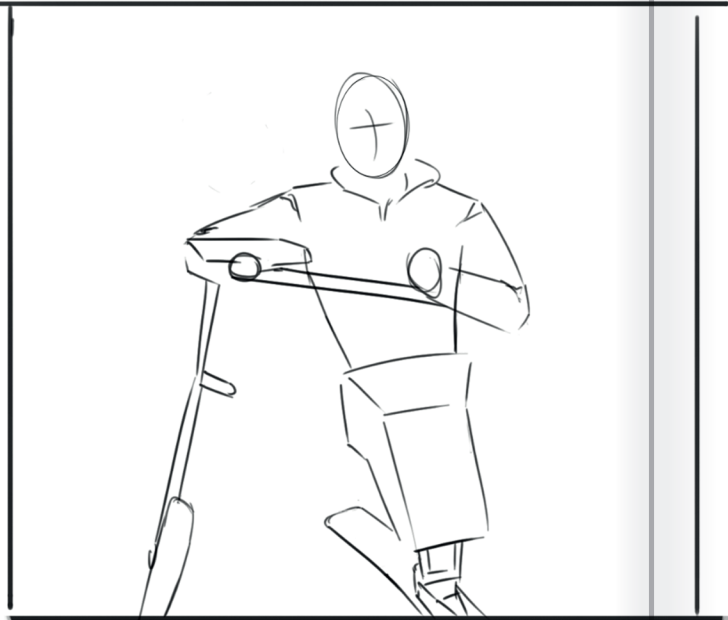
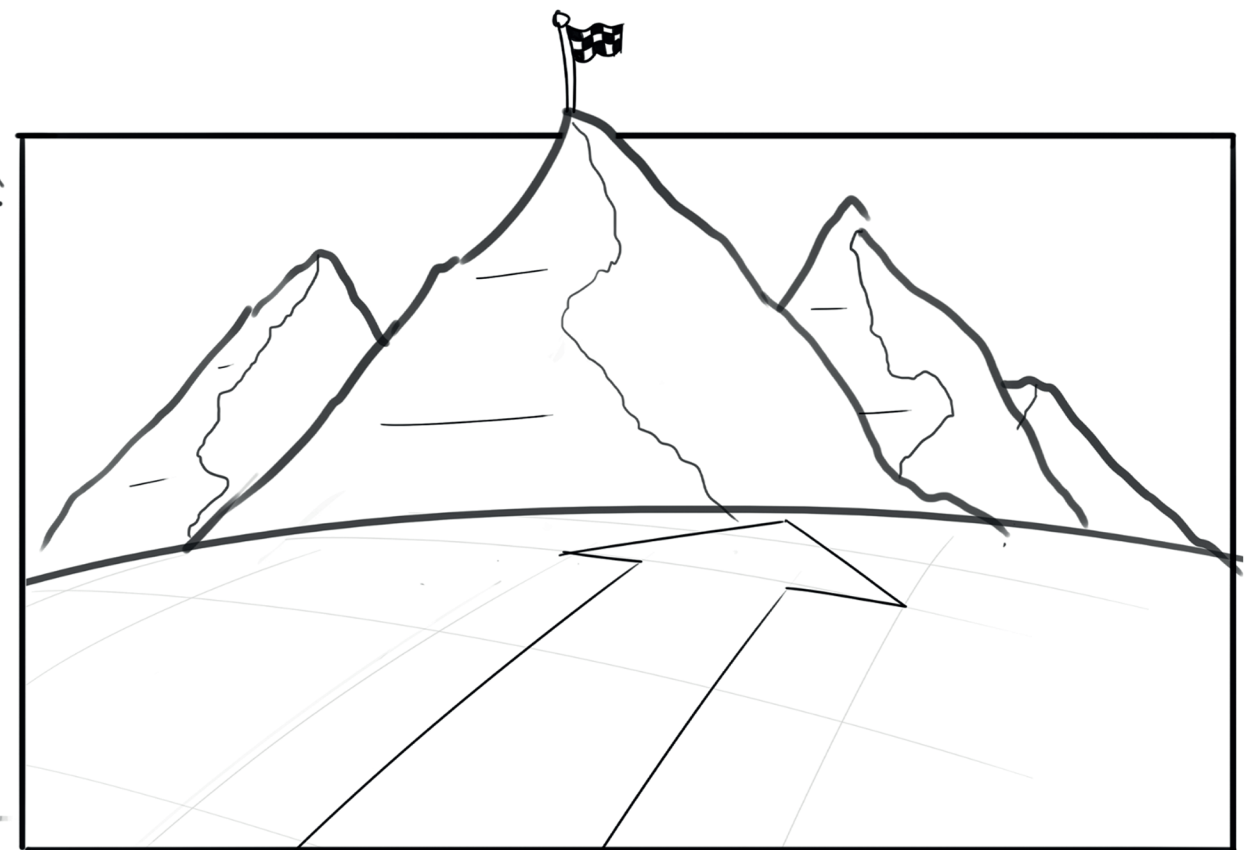


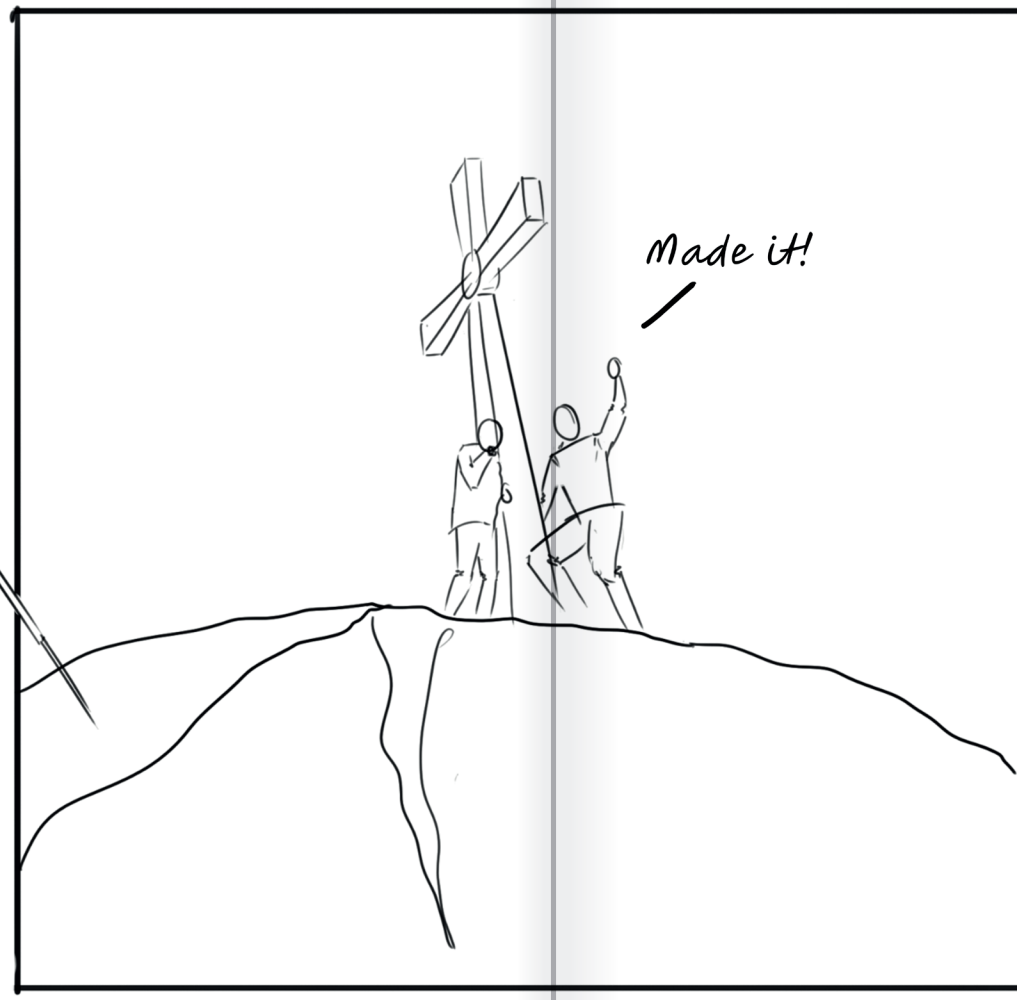
Figure 24. Persona Benji

Let's go on an adventure

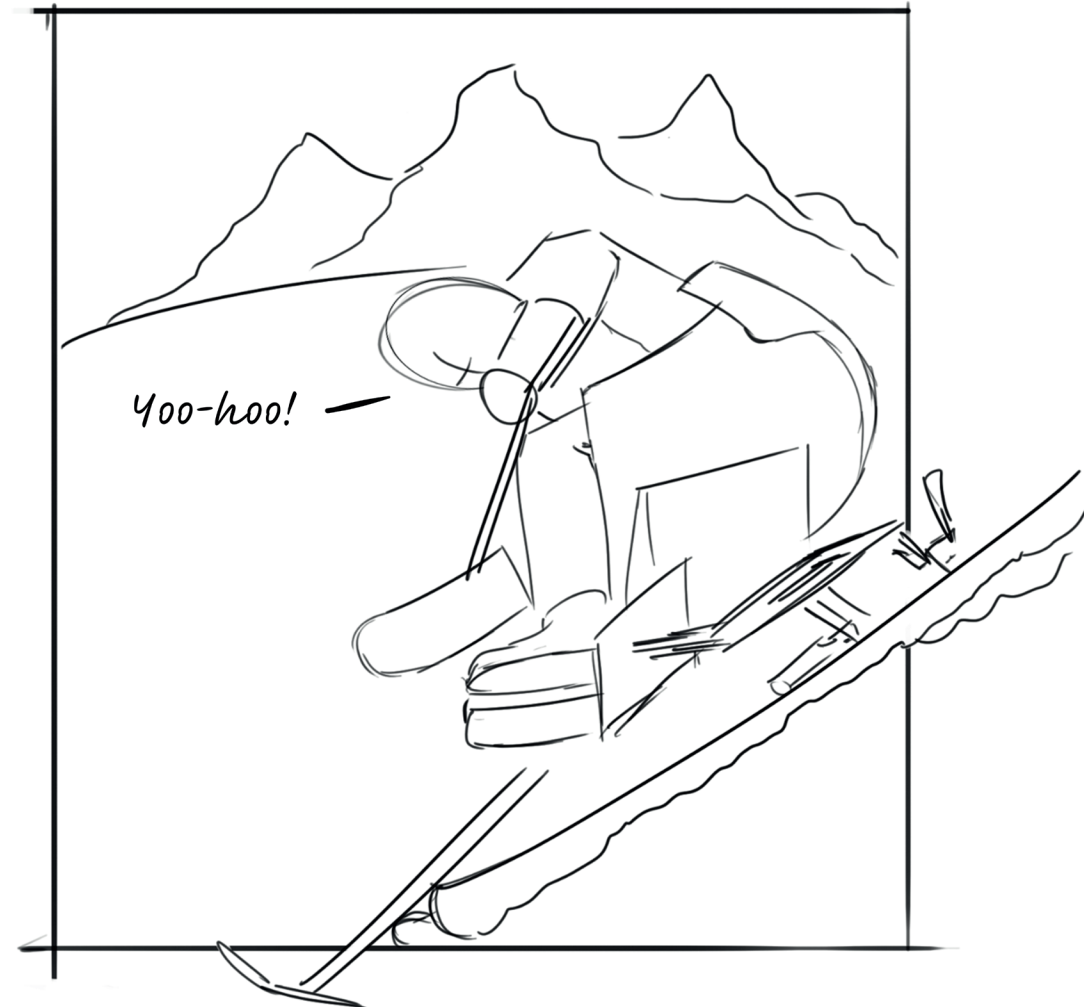
First get to the trail and into my sitski



'This is pretty steep,
let's traverse'



Made it!



Yoo-hoo!

7.4 Scenario

Figure 25. Scenario for a day skitouring

Iterative Development

Create - prototype - evaluate

Iterative Development comprises the last three phases of the UCD-approach, which were performed in multiple cycles to further iterate on the investigated opportunities brought forward in the *Synthesis* chapter. In this way, further research was performed through the act of designing (RtD). Cycles of creating, prototyping and evaluating, while maintaining close user involvement throughout the process, helped translate opportunities into concepts and a proposed design.

For documentation purposes, this section of the thesis is divided into two chapters. *Concept creation* describes the first iteration cycle, in which the initial translation from research insights towards concepts is made. *Concept development* describes the cycles of prototyping and evaluating, in which the most essential parts of the chosen concept are evaluated to validate solutions, eventually leading to a validated concept for a sit-skitouring setup.

8 Concept creation

In the creation phase an initial translation from the research insights towards a concept is made. Free ideation, targeting solution direction and standalone features, were explored along with new ways to approach movement to propel from a seating position.

Sketching was used as a tool to translate research into ideation. More over, a co-creation session was used to include user input into the ideation process. Figure 26 gives an overview of how research and user input eventually lead to concepts.

Ideas are generated based on subfunctions abstracted from the technical analysis (Appendix C). The result is used to complete a morphological chart, which helped to identify 4 core concepts.

8.1 Create

As part of the user-centred design approach, a two-hour co-creation session was organised at the TU Delft Faculty of Industrial Design Engineering. The goal was to involve users early in the ideation process and to generate input for targeted design solutions. A sit-ski athlete and her adventure partner were

invited to participate. The session started with simple warm-up tasks before gradually moving toward project-specific functions. For each function, participants were asked to quickly sketch ideas or write keywords on post-its within a two-minute brainstorming round. Each round was followed by a short discussion and a joint clustering of the generated ideas. The outcomes of the co-creation session were used to further develop and complete the morphological chart, in which possible solutions were structured per function (see figure 27).

Within the boundaries of the morphological chart, sketches were used to explore and develop possible design solutions. Methods such as brainsketching and design drawing supported the generation of multiple solution directions and helped translate abstract functions into concrete product ideas. In Appendix C you can find all sketches created during the ideation.

The morphological chart was used as a tool to structure the solution space by listing possible solutions for each key function (see Appendix D). By combining different sub-solutions, the results from ideation converged into four promising concept directions.

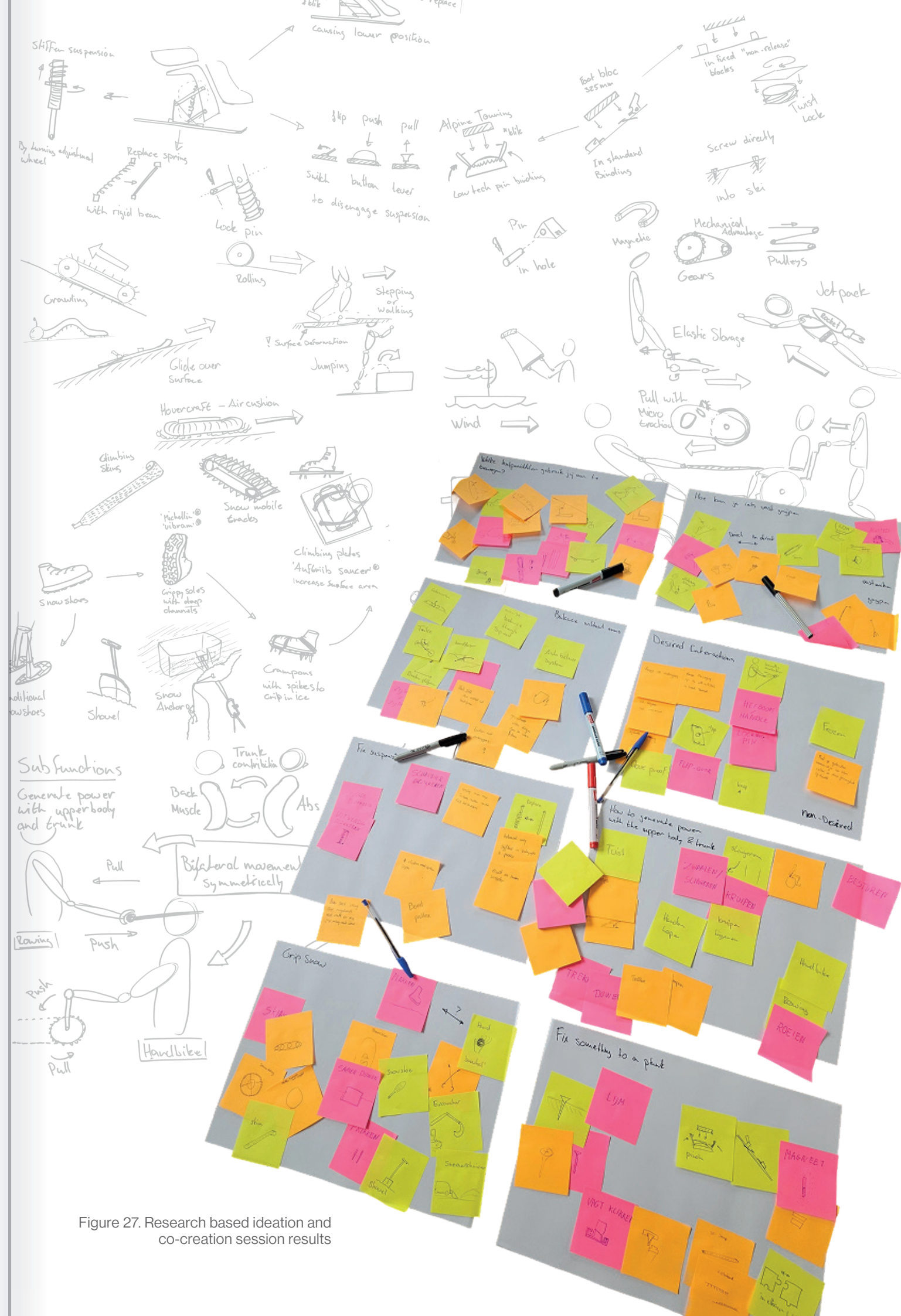
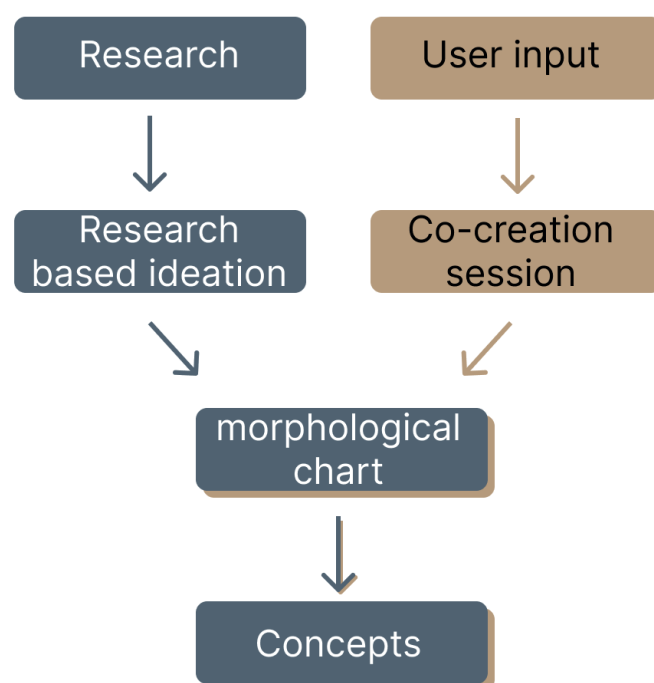


Figure 26. Relation of research and user input into concept creation

Figure 27. Research based ideation and co-creation session results

8.2 Digital prototype

In a later stage, design drawings were used to visualize promising combinations from the morphological chart. This made it possible to compare different concept directions and select the most relevant solutions for further development.

Digital three dimensional models were build using blender, as prototypes to explore the concepts in three dimensions. Images from these models are used to present four concepts. In the next chapters, four presented each based on an unque movement strategy to generate propulsion. These strategies define the identity of the concepts. To help identity and differentiate these movement strategy, each concept received a concept-identifier.

Concept Rower is based on a synchronous pulling movement strategy. Power is generated through pulling two levers simultaneously, see figure 28.

Concept Walker is based on an asynchronous pulling movement strategy, where power is generated through pulling two levers alternatingly see figure 29.

Concept Double poler is based on an synchronous pushing movement strategy. Power is generated through pushing two poles simultaneously against the surface, see figure 30.

Concept cycler is based on an synchronous rotary movement strategy, where pulling and pushing follow each other with each rotation. Power is generated through rotating a crank, see figure 31.

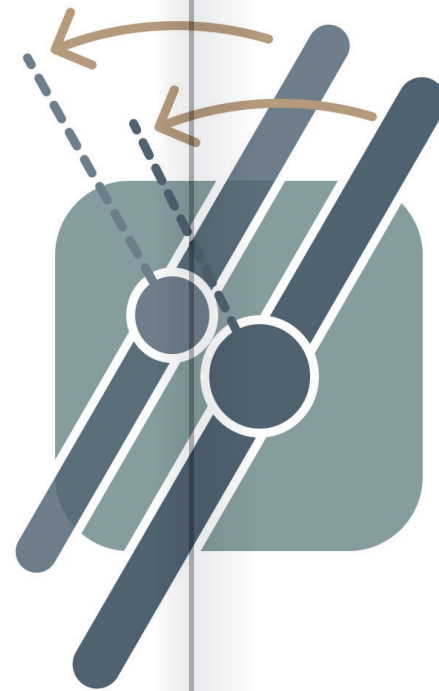


Figure 28. Concept identifier
Rower

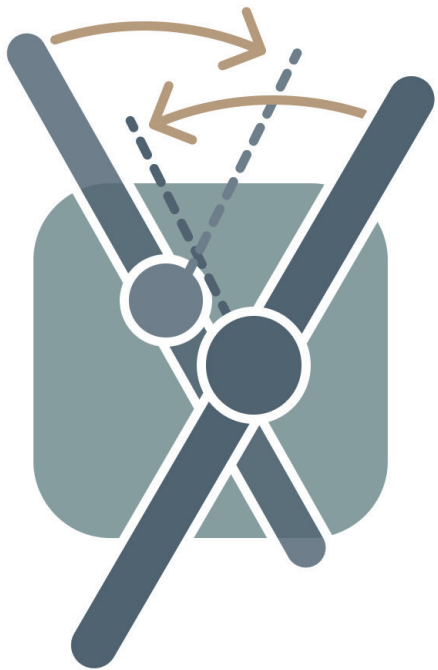


Figure 29. Concept identifier
Walker

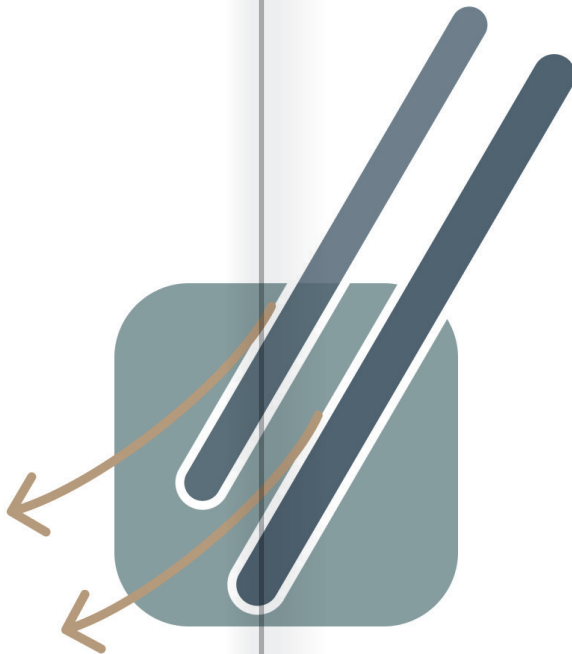


Figure 30. Concept identifier
Double poler

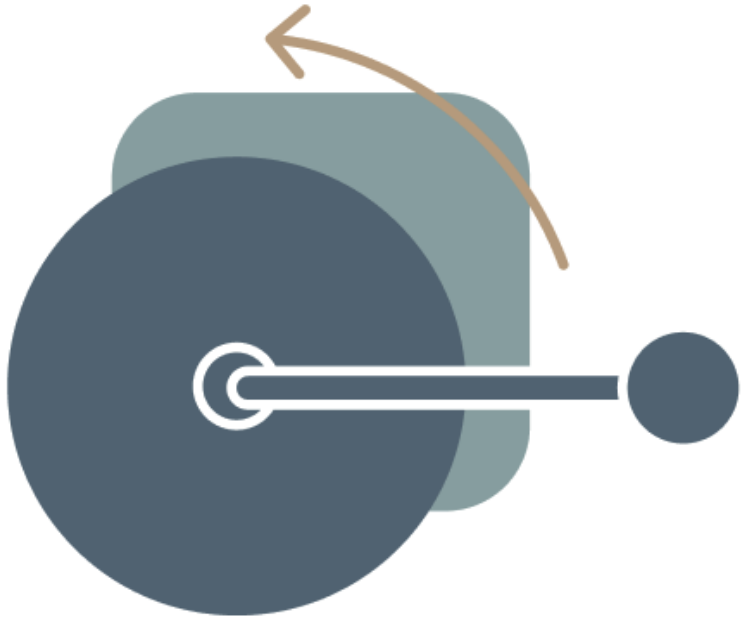


Figure 31. Concept identifier
Cyclier

8.3 Concept Rower

Propulsions movement strategy: Rowing

Concept Rower enables a rowing motion as propulsion, according to research using muscles in the upper-body most efficiently. It remains close the downhill setup and used products used in able-bodied skitouring. The oars used to row yourself up serve a double function as ski outriggers on the downhill. The user can row backwards to engage larger muscle groups on easier longer parts, or row forwards for more technical sections where navigation is key. The user will have to stay balanced over the ski and optionally correct its using the outriggers.

The outriggers can be attached to the sit-ski via an adapter that is situated underneath the seat. This allows concept Rower to be retrofitted on existing models. Using climbing skins and crampons as a backwards slip prevention system, means sit-skiers can benefit from the wide range of available existing mountaineering products.

USP:

- Both pushing and pulling propulsion
- Retrofittable on existing models
- Uses existing mountaineering products

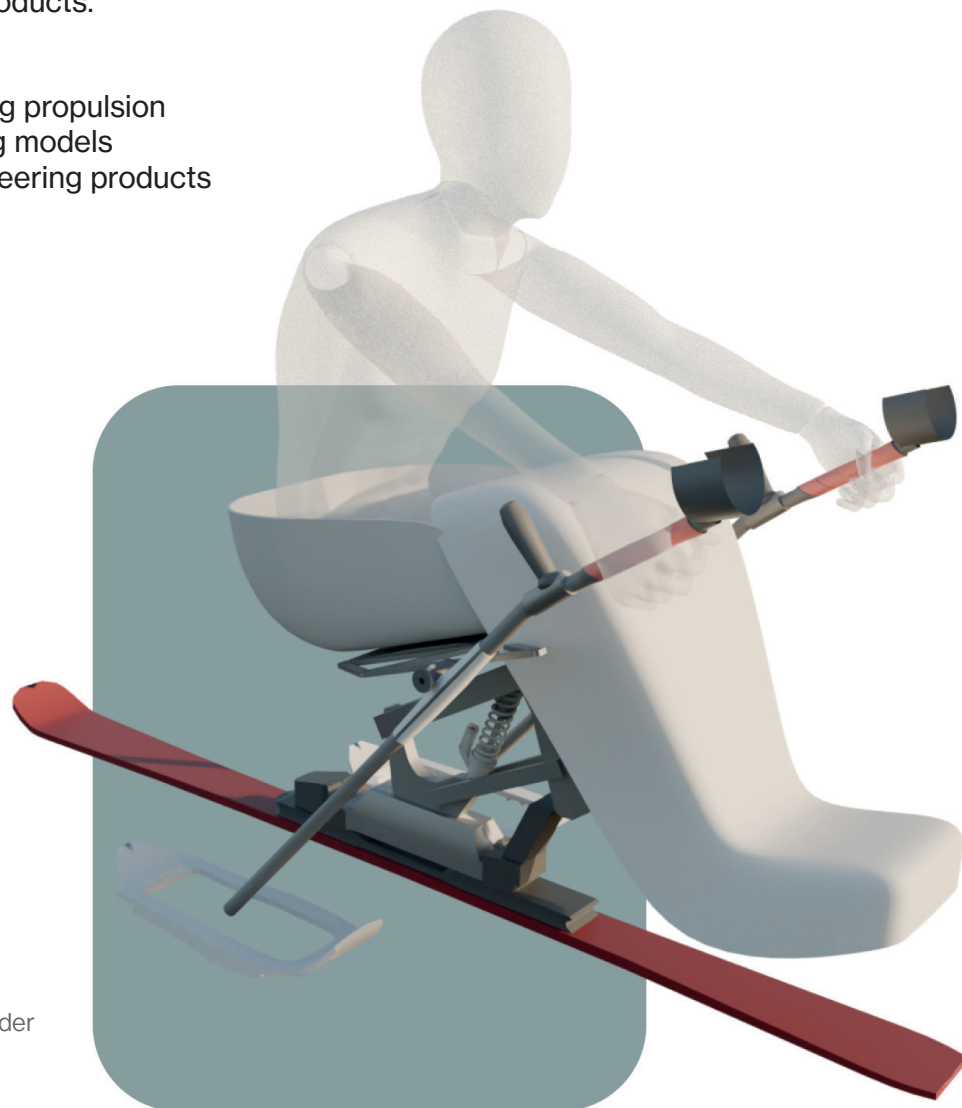


Figure 32. Concept Rower render



8.4 Concept Walker

Propulsions movement strategy: Alternating onesided Rowing

Concept Walker best resembles the motion one makes on a cross-trainer in the gym, and accordingly making steps forward. It resembles a rowing motion, but alternates between left and right making the motion more fluid.

The outriggers can be attached to the sit-ski via an adapter that is situated underneath the seat. This allows concept Walker, just like concept Rower, to be retrofitted on existing models.

The user will be optionally be aided to stay balanced by using side-skis. Using climbing skins and crampons as a backwards slip prevention system, means sitskiers can benefit from the wide range of available existing mountaineering products.

USP:

- Semi continues motion.
- Retrofittable on existing models
- Uses existing mountaineering products



Figure 33. Concept Walker render

8.5 Concept Double Poler

Propulsions movement strategy:
Double poling

Concept Poler uses a technique used in adaptive cross country skiing, where athletes push themselves forward using long poles.

The concept heavily relies on a extremely lightweight setup and minimal to no sliding friction. A different position allowing for longer strokes means, alternative bindings will need to be used as an interface between the frame and the ski.

The user will have to stay balanced over the ski and correct using the poles if necessary.

USP:

- Familiar technique for cross country athletes
- Lightweight
- Little additional parts

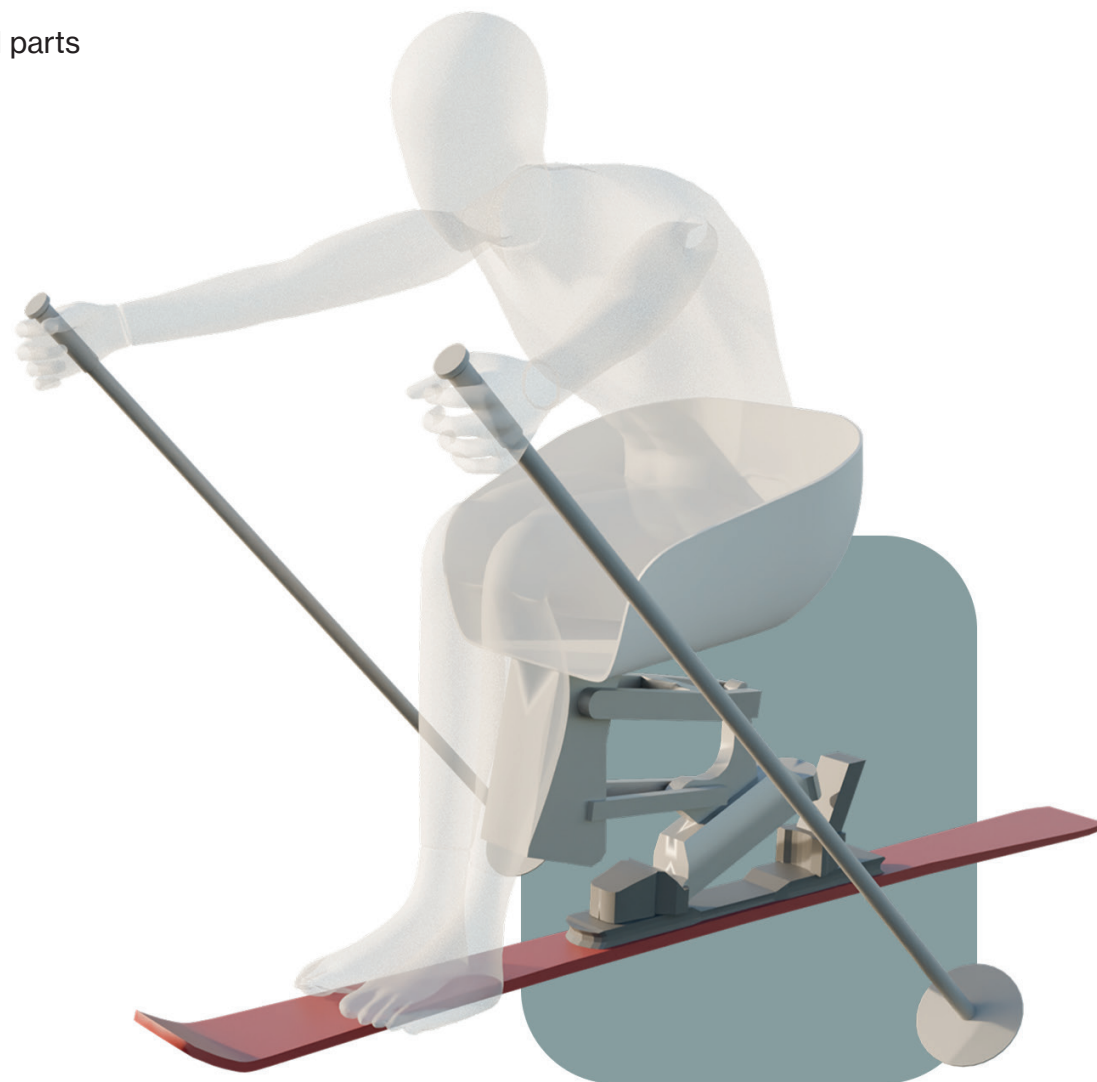


Figure 34. Concept Double poler render

8.6 Concept Cyclcr

Propulsions movement strategy:
Handcycling

Concept Cyclcr resembles the idea on a handbike, by generating propulsion through driving hand cranks in a circular motion. This is a proven method for propelling a human-powered vehicle, using the upper-body only. Concept cyclcr uses gearing to keep the required user force input consistent. This allows even steeper sections to be covered with ease.

The user is balanced by the tricycle shape that is consist of the ski in the middle and two tracks, one on each side. Instead of wheels, concept Cyclcr uses tracks made from mohair or specialised plastic to gain traction on the surface.

USP:

- Gearing allowing for control over the effort
- Option for electric assistance

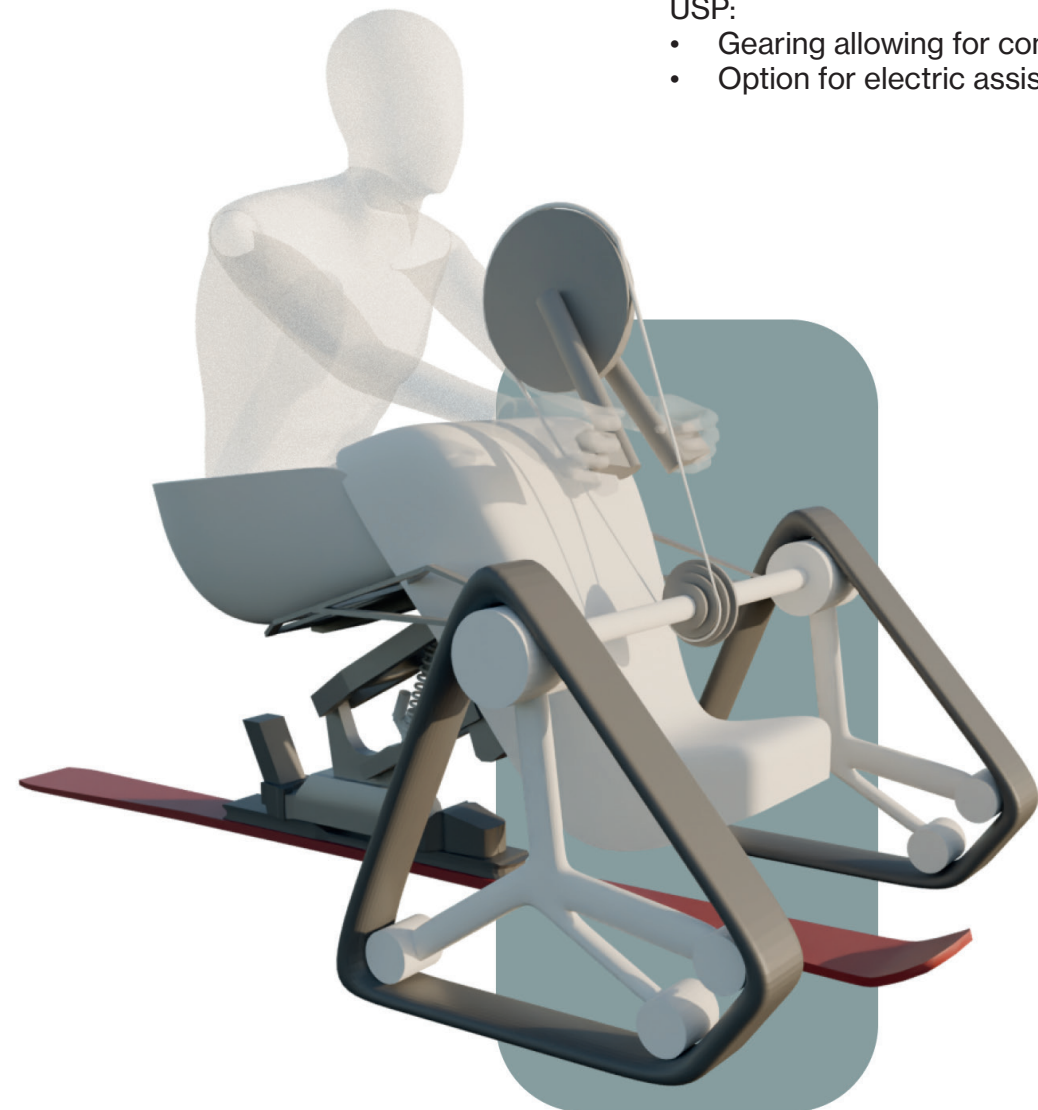


Figure 35. Concept Cyclcr render

8.7 Evaluate

Concept creation output was evaluated through multiple user validations.

Initial concept drawings were reviewed with sitski users, who raised no issues and showed interest in further development. Digital 3D models and animations helped visualize user-product interaction, aiding communication. Feedback highlighted concept Rower as the most popular. A field test with an able-bodied skier using two poles to push uphill, mimicking double poling, proved extremely difficult and unsustainable beyond 10 minutes. Thus, the Double Poler concept was quickly discarded as unfeasible.

To differentiate the concepts in question further, they will be judged against a set of criteria using the weighted criteria method. This will converge the concepts into one sit-skitouring concept, which will be further investigated during next iteration, in chapter *Concept development*. Find Appendix J for an elaboration on this evaluation method.

Evaluation criteria

- 1. Minimal added parts to the setup
- 2. Biggest amount of muscles jointly used in one motion
- 3. Energy efficient motion
- 4. Ability to generate & sustain power
- 5. Ability to recover after fall over
- 6. Ability to maintain balance
- 7. Necessary parts are useful uphill and downhill
- 8. Short change over time
- 9. Independent scenario

In figure 36 a comparative overview between the total weighted criteria scores (WCE) of the concepts is shown. See the full weighted criteria concept evaluation in Appendix J.

Multiplying the received score by the attributed weight generates a final criterion valuation. Adding up the final valuations per concept reveals the total concept score. This indicates which concepts to move forward with. In addition to the overall score for all concepts, it also shows a concept's strengths and weaknesses, indicating potential opportunities. However, it

should be noted that a decision on a concept should not be based solely on the numerical outcomes of a method such as this, as there are more nuances within the concepts, such as improvement opportunities and qualities beyond the criteria. Reviewing the overall scores, it was interesting to find that the final values were very close together, except for concept Rower, which was significantly higher.

Concept Rower has scored significantly higher on the weighted criteria evaluation compared to the other concepts. This was taken into consideration as factor for the concept choice. Concept Rower adds less parts to a downhill setup compared to concept Cyclor making it more likely to be a desirable outcome. That insight together with the results of the weighted criteria evaluation, led to the choosing of concept Rower to investigate further through *Concept development*.

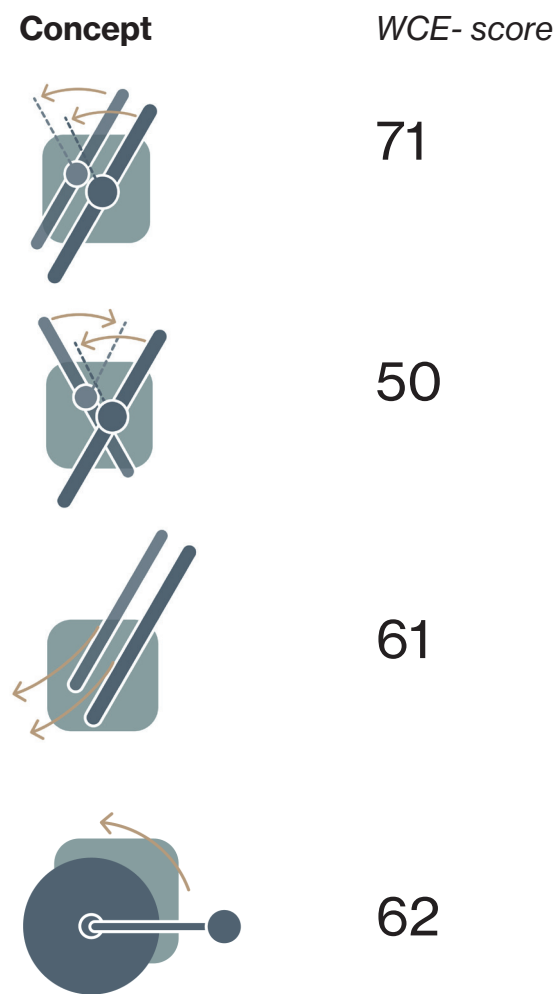


Figure 36. WCE score comparative overview

9 Concept development

Concept development describes the cycles of prototyping and evaluating, in which the most essential parts of the chosen concept are evaluated to validate solutions, eventually leading to a validated concept for a sit-skitouring setup.

This process consisted of multiple cycles, each characterized by a research question, a prototype and an evaluation to find answers on the research question. Each cycle resulted in generated knowledge about several aspects of the concept. The learnings from the evaluation shaped the next cycle and aided the further development of the concept. Figure 37 describes the second diamond from the design process as presented in figure 4.

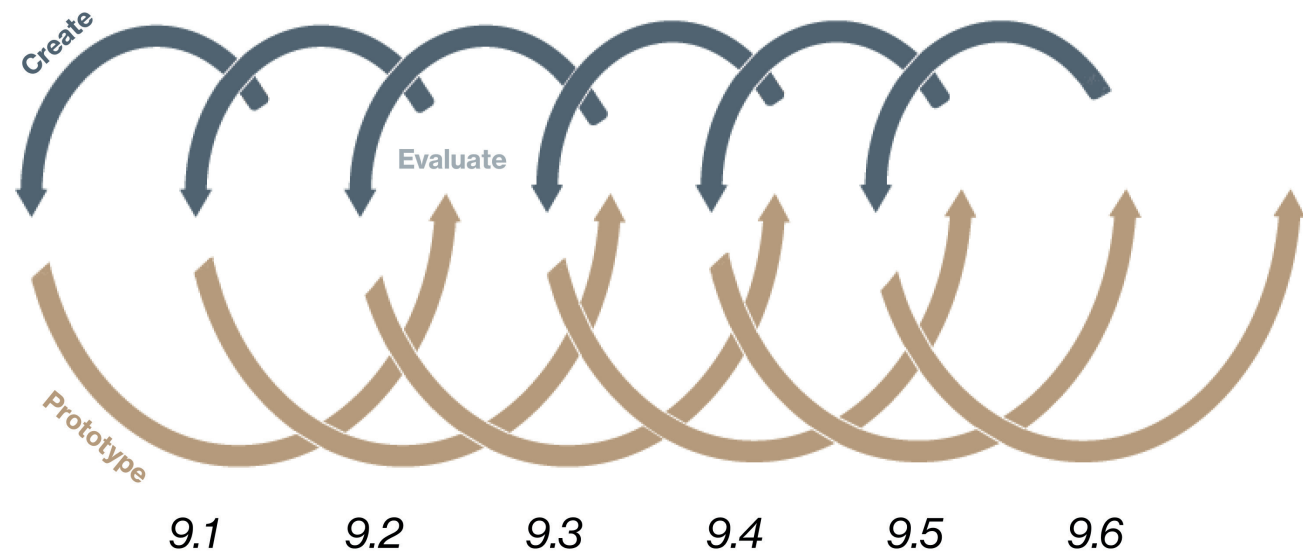


Figure 37. Elaborated concept development process

9.1 Rowing on hard surfaces

Research question

What implications does rowing on hard surfaces have?

Method

A model was created that could be used in combination with an office chair. This allowed different positions to be tested. The model consisted of three wooden sheets of multiplex, which were screwed together. Two wooden poles with shoes for traction were used as oars. See figure 38.



Figure 39. Participant evaluating usability



Figure 38. Model with office chair

Evaluation

The test was performed by a fellow student, who was given the opportunity to have a seat and try rowing in the chair.

Results and implications for the next iteration

The rowing motion seemed to work on hard surfaces. Interestingly, the oars rotated parallel to the sagittal plane to prevent them from slipping away too much on the floor. The test participant experienced soreness in the shoulder muscles, because she had to constantly push the oars downward to keep pressure on the floor. The oars moved up and down through the holes during each stroke, indicating a need for a system that allows for vertical travel.

Therefore, a different method is needed to attach the oars to the sitski, in order to prevent the user from spilling his energy into pushing the ends of the oars into the snow. This should increase traction.

9.2 Transfer user force

Research question

How can the oars be attached to the sitski while still providing enough degrees of freedom to perform a rowing motion?

Method

In addition to the previous model, a part was created resembling a pin-hook connection. By connecting the oars this way, maximum degrees of freedom are preserved supporting the forces generated by the users close to the oar. Four versions of the part were created with increasing complexity, ranging from cardboard models to functional metal parts. See figure 42 and find more images and technical drawings Appendix K.

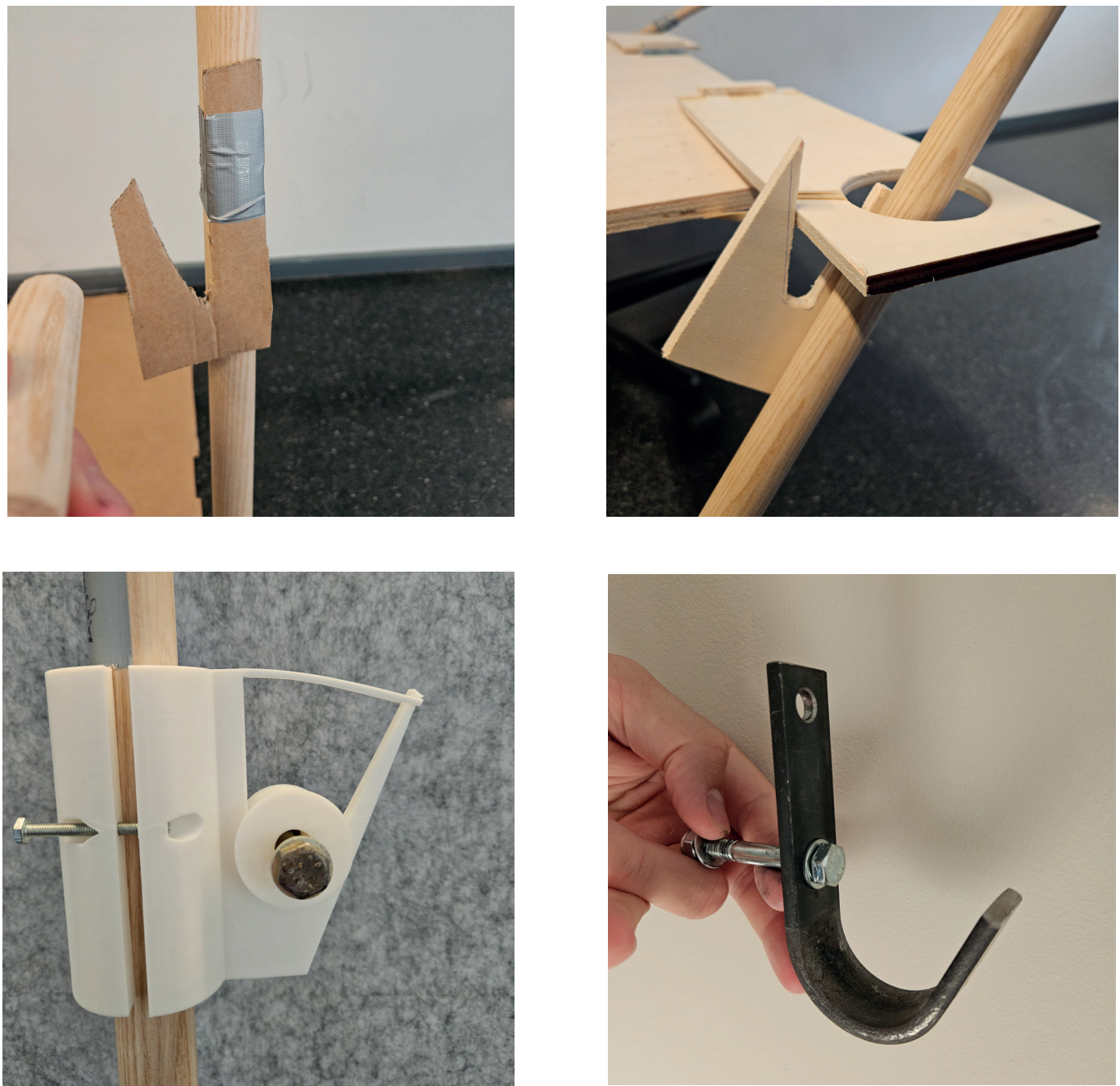


Figure 42. Evolution of prototypes

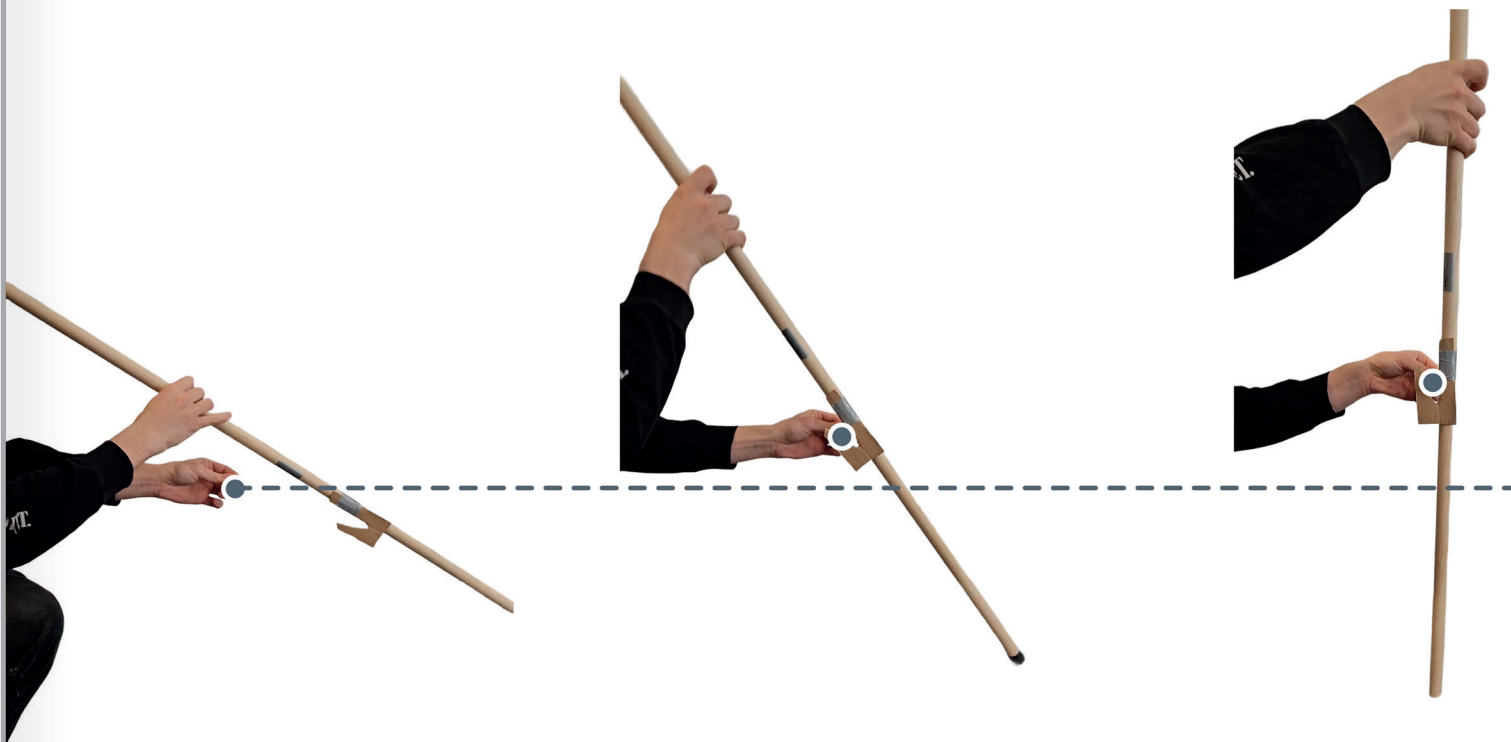


Figure 41. Attach the oars through a hook pin connection, usability test

Evaluation

The test was performed by the designer, who used the model from 9.1 and added this hook to test.

Results and implications for the next iteration

The hook seems to work in connecting the oar to the sitski and transfer user forces better. No downward direct force by the user was needed to apply sufficient grip on the surface. However the pin-hook connection prevented the oars from displacing vertically freely. This meant the user was lifting his own weight during every stroke. This underscores a need for a system that allows for vertical displacement while still applying sufficient pressure on the surface.

9.3 Sustain surface pressure

Research question

How to sustain pressure on surface during stroke and prevent complete lift of user?

Method

Two theories were evaluated through building a prototype. The first theory being that a vertically displacing connection point in a constructions resembling a the wing of a bird would be the best option. The second one being that a fixed connection point with a suspending oar would be the best option. It was hypothesized that the energy input required to compress the springs would be stored temporarily and released near the end of each stroke. As a result, the additional effort required at the beginning of the stroke is expected to be compensated by the assistance provided at the end of the stroke.

To evaluate these theories, models were created and their functionality was assessed. See figure 43 and 44 and find more images and technical drawings Appendix K for

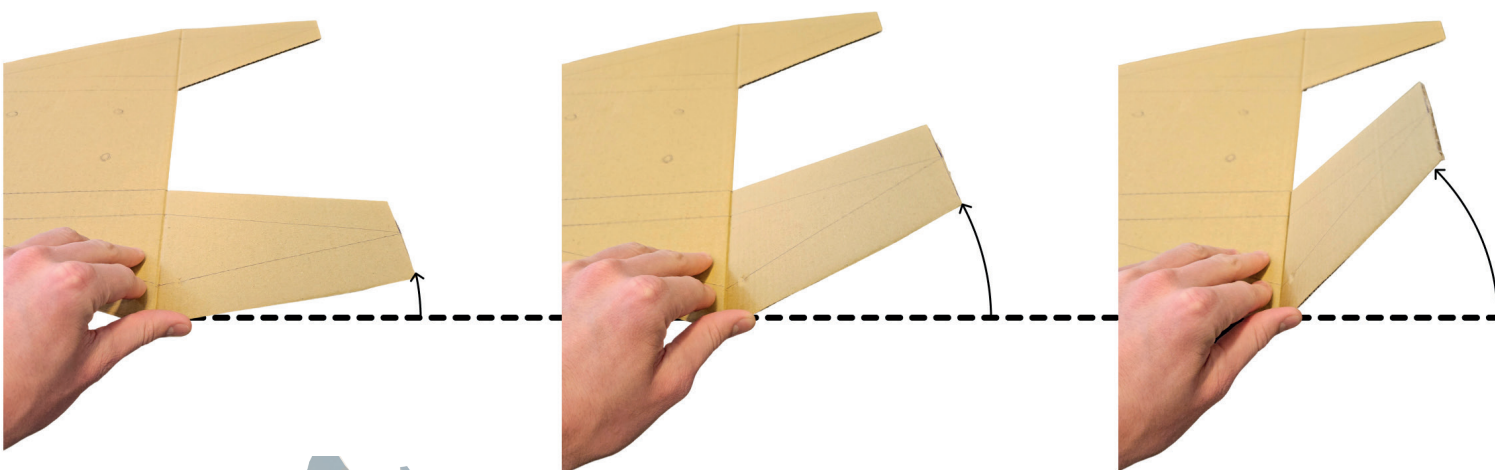


Figure 43. Digital and physical models to assess wing theory.

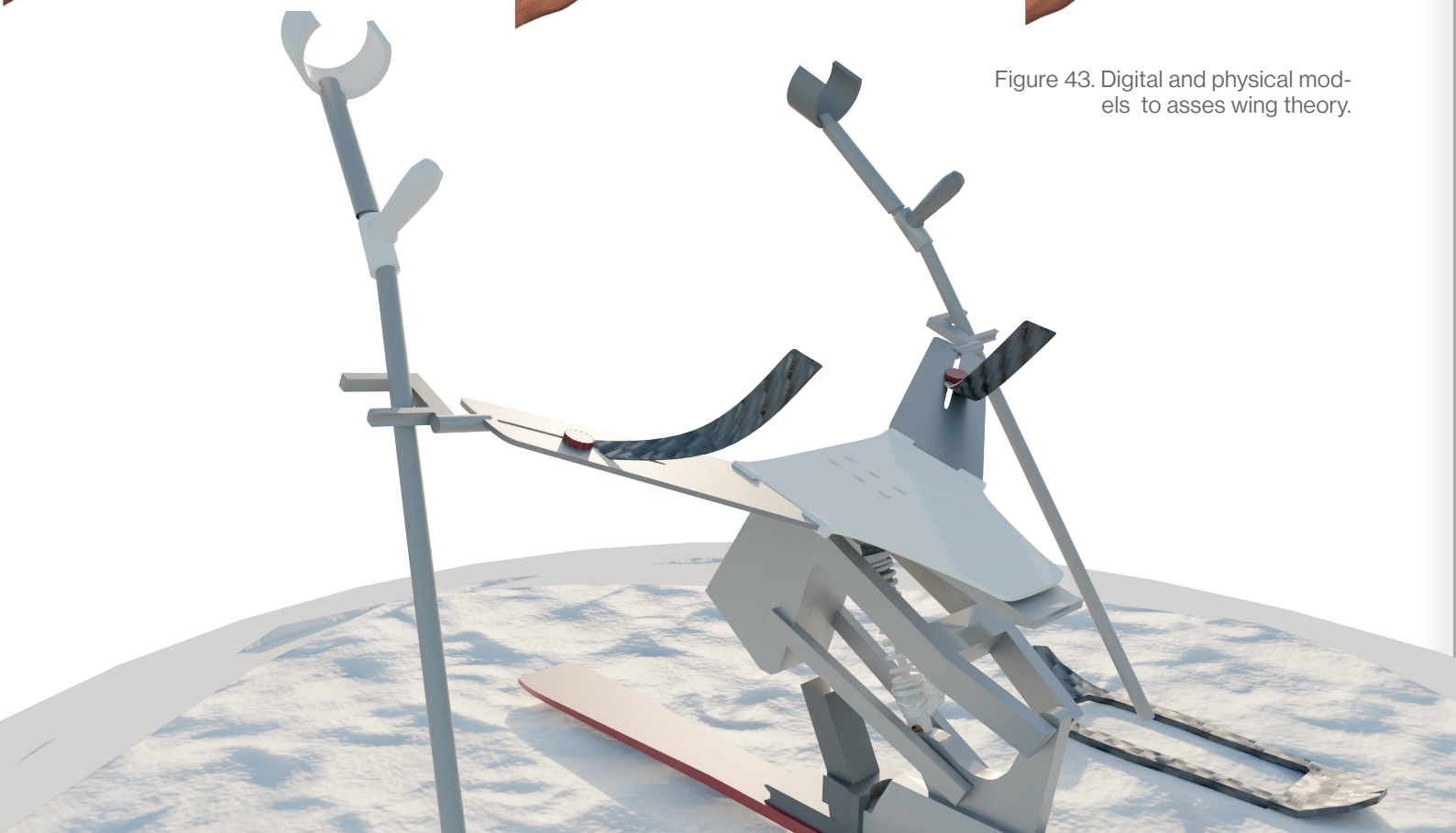


Figure 44. Models to assess suspending oar theory



Evaluation

The functionality tests were performed by the designer.

Results and implications for the next iteration

The **wing theory** was debunked because the vertical displacement of 14cm required for one stroke to move the user forward by 70cm, meant that the radius of the circular path followed by the wing had to be at least equally large. As a result, the oars were positioned far to the sides of the user at the start and end of the stroke, while moving close to the body in the middle of the stroke. This movement pattern falls outside the ergonomic range of motion of the shoulder joints.

The **suspending oar theory** was tested and proved useful in scale models. In the functional model, however, it produced some noise due to metal-on-metal friction. This should be solved by implementing plain bearings. Based on the test results, the suspending oar theory was adopted and continued with.

While the suspending oars provide constant pressure on the surface, a method of focusing that pressure in different ways to provide grip on hard-packed and soft snow is needed to pair with the suspending oars.

9.4 Grip snow

Research question
How can different types of snow be gripped by an oar?

Method
Snowshoes have been used for thousands of years in many shapes and forms. Today, a wider range of models from different manufacturers is available, each designed for specific scenarios and snow conditions.

Instead of designing a completely new snowshoe-like component, an adapter was conceptualized to connect the oars to existing commercially available snowshoes. Models were created to evaluate the compatibility of this approach. Snowshoe parts that were essential to make the development of the adapters possible were provided by *Tubbs Snowshoes*. The adapter designed in this chapter should fit on any snowshoe provided by *Tubbs Snowshoes*.

See figure 45 and 46 and find more images and technical drawings Appendix K for



Figure 45. Evolution from a cardboard model to Sheet-metal and CNC-machining optimised CAD-models



Figure 46. Assembling the oar before on-snow testing

Evaluation
The design was evaluated in consultation with engineering experts at Metaltechnik Schöpf in Längenfeld. The functionality tests were performed by the designer.

Results and implications for the next iteration
The adapter functioned as expected. High safety margins have been used to account for the uncertainties and ensure durability during field testing. Later iterations could involve making the part leaner to save weight in the overall system.

9.5 Interaction of parts

Research question

Will all parts interact with a sitski, the snow and a user as hypothesized in concept Rower?

Method

A Prashberger Mono sitski has been modified with parts described in 9.1, 9.2, 9.3 and 9.4. The use of the modified sitski has been evaluated on snow, at the Rettenbach Glacier at 2.675m. See figure 47 and 48 and find more images in Appendix L.



Figure 47. Prashberger Mono modified with sitskitour parts, me standing proudly in front of it.



Figure 48. Prototype during on snow usability testing

Evaluation

The design was evaluated on two separate occasions. On 01.05.2026, the full system was assembled and different settings, dimensions and configurations to understand how the mechanism behaved were tested. The prototype's performance was also compared with the conventional method of pushing through the snow using standard sitski outriggers. This comparison helped evaluate whether the prototype offered a meaningful improvement over the existing sit-ski touring movement strategy.

This included testing with and without skins, moving forwards and backwards, and testing on flat terrain, a slight uphill slope of approximately 3 degrees, and a steeper slope of approximately 10 degrees. (Appendix L)

Different propulsion techniques were explored, including using only the arms, only the trunk, a combination of arms and trunk, short fast strokes, longer strokes, reloading the stroke by pushing the handles inward, and pushing off at the end of the pull.

On 02.05.2026, the prototype was tested with a participant. The participant was first allowed to explore how he expected the system to be used. Afterwards, different configurations were tested, including with and without suspension, forward and backward movement, short fast strokes and longer strokes. The test ended with a concluding conversation to discuss pain points and usability issues.



Traveling distance



Direction of travel

Figure 49. On snow usability testing with participant



Figure 50. Struggles reloading for a new stroke



Figure 51. Me pulling as hard as I could , to overcome resistance

Results and implications for the next iteration

Qualitative data was collected through observation, video recordings and a post-test interview to identify performance issues and development opportunities.

The prototype test showed that the rowing-based propulsion concept did not work as efficiently as expected. The test resulted in the following key learnings:

1. The pulling force required was too high to create forward movement in the current setup.
2. The snowshoe lost grip when the handle moved past the vertical position, reducing the effectiveness of the propulsion stroke and debunking the hypothesis of assistance provided by the stored potential energy.
3. The climbing skin prevented downhill sliding, but created excessive friction during forward movement, increasing the required pulling force.
4. Reloading the oars for each new stroke was a hassle and took too much time, resulting in a slow and non-continuous movement pattern.

These findings suggest that sliding skin-based propulsion has major limitations and that a rolling or rotating propulsion system may be more promising. The next iteration should therefore focus on alternative backward-slip prevention, faster stroke reloading, gearing options to reduce input force, and further development of the downhill function of the touring outriggers.

9.6 Rolling propulsion system

Research question

What could a rolling propulsion system mean for a sitskitouring setup?

Method

Design drawing for development has been used to explore the research question. A track based system propelled by two levers was conceptualized. Digital model models been created to build a digital three dimensional representation and explore the interaction between the new concept, sitski and user.

A cardboard model has been created asses the proportions and placement of the track compared to the sitski. For this comparison, a Tessier Scarver was used. Tessier has provided this sitski for testing and research purposes. See figure 52 and 53.

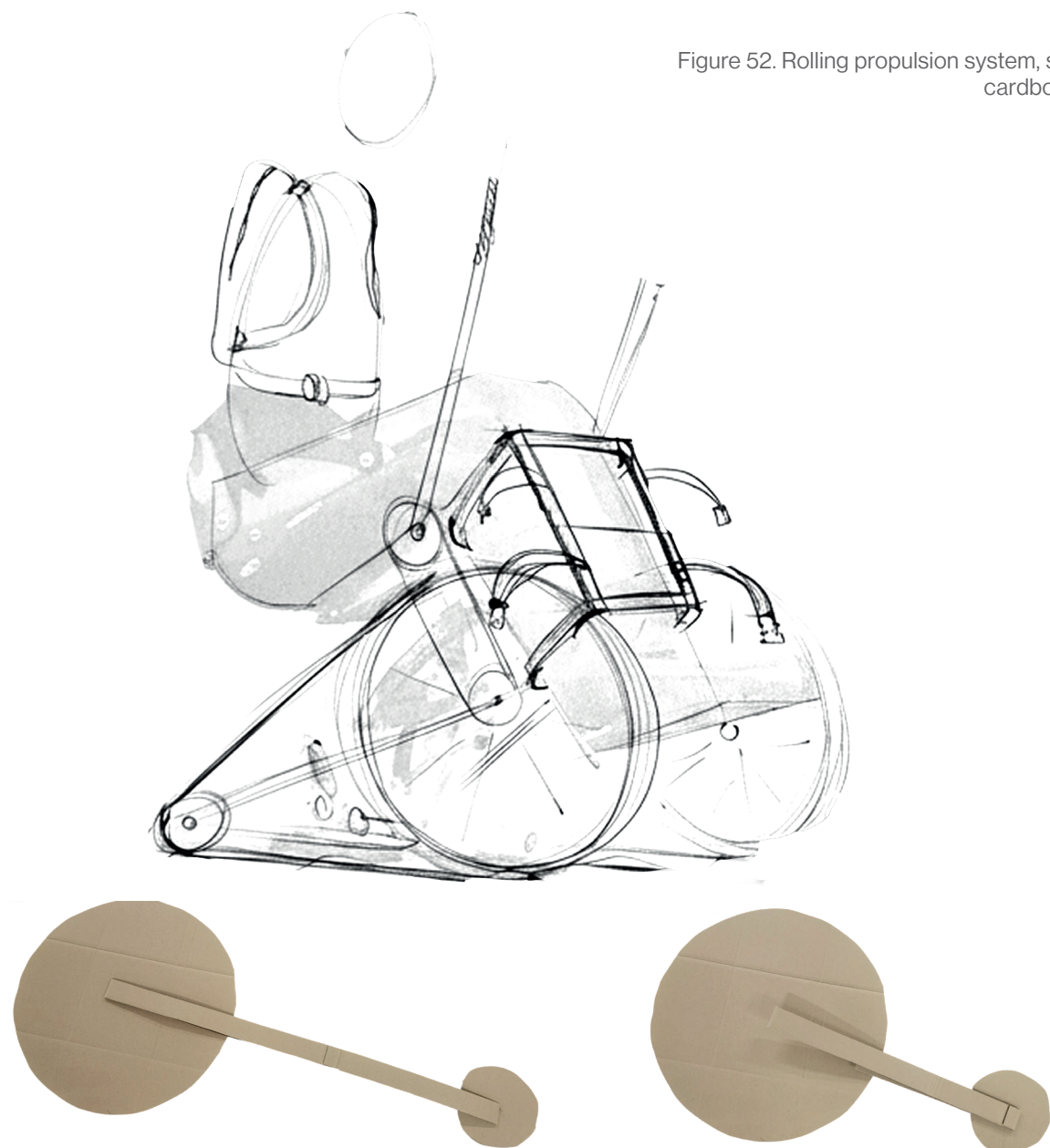


Figure 52. Rolling propulsion system, sketch and cardboard model

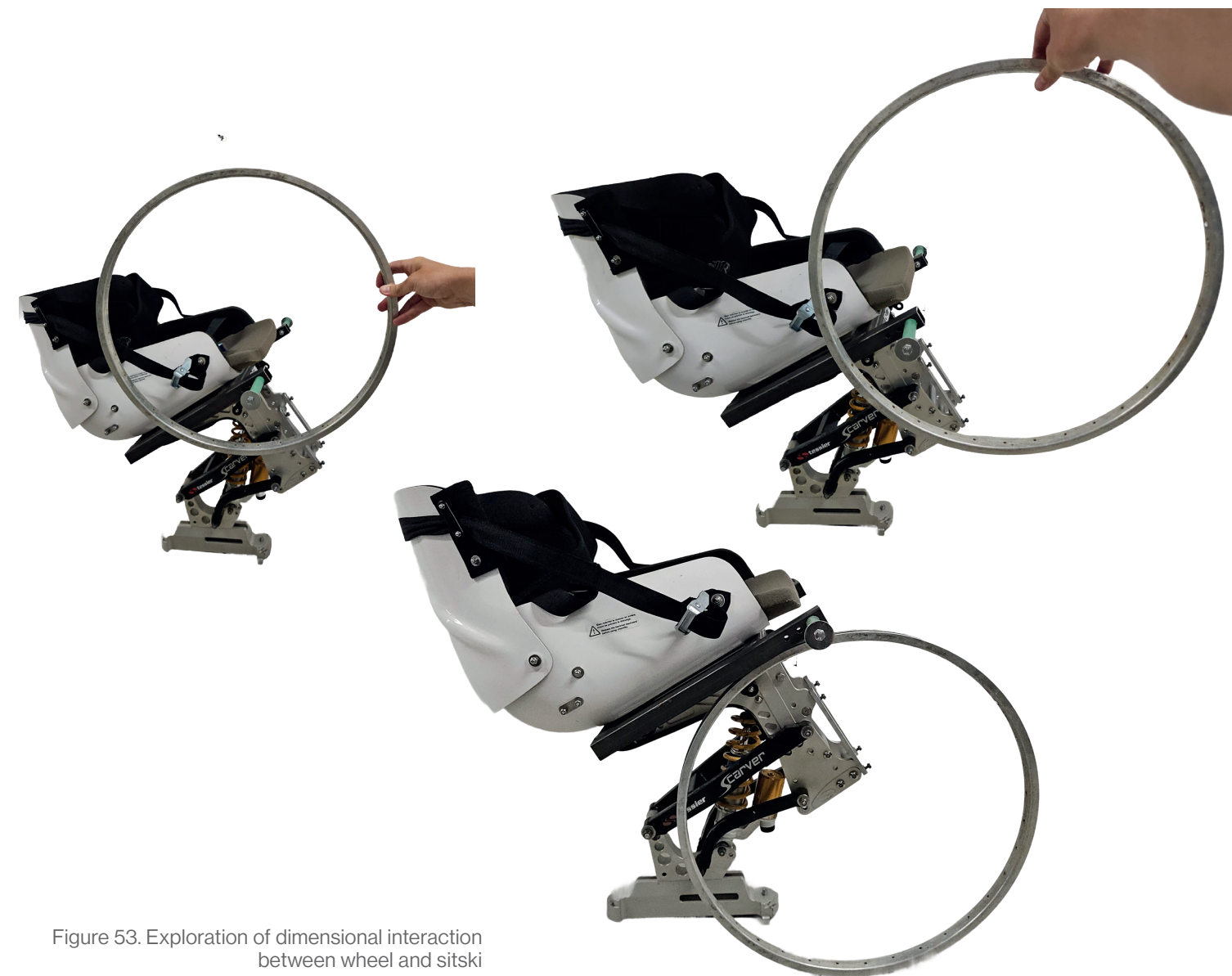


Figure 53. Exploration of dimensional interaction between wheel and sitski

Evaluation

The concept was evaluated by the designer. The assessment focused on the extent to which the issues identified in the previous iteration, described in section 9.5, had been resolved, while also incorporating insights from earlier iterations.

Results and implications for the next iteration

Digital and physical models both confirm that the proportions match. This means that parts of the disassembled track can fit onto the sit-ski, allowing the user to ski down again. The following aspects are improved by this design:

1. The required force input is manageable by shifting gears, allowing the system to adapt to varying inclines.
2. No energy is lost through spring compression. Instead, the power input is translated into propulsion through a drivetrain with a high expected energy efficiency.
3. The full stroke length can be used, effectively doubling the usable stroke length compared to iteration 9.5, where the oar lost grip once it moved beyond 90° relative to the surface
4. Friction caused by the climbing skin underneath the ski has been eliminated, as the track prevents backward slip and therefore removes the need for a skin underneath the ski.
5. Reloading the levers for each new stroke has been made easier by allowing the user to simply push and pull the handle backward and forward.

New iterations should focus on validating the modular track system in terms of weight, energy efficiency, provided traction, durability and usability. This is an essential part of this concept.

Design presentation

Capra Ibex 

This section transitions from process and development to the outcome of this project. It presents the final concept design, serving as a response to the identified user desires and needs, and capabilities of the human body.

The concept has been designed to be an integrated and coherent system, where experience and function are interrelated, serving the overarching mission of the concept. The design that will be presented is the result of a 100 working days individual project. Recommendations for further development can be found in the *Discussion*.

10 Design Presentation

Capra Ibex

Introducing Capra Ibex, a proposal for a sitskitouring setup, enabling physically challenged athletes to explore the mountains autonomously under their own power. Capra Ibex consists of a modular track system, propelled by moving two levers backwards and forwards. The tracks and the levers are connected through a range of gears, allowing the athlete to shift into an easier gear for steeper sections or a faster gear for flatter sections. The propulsion system can be packed together and stored away onto the cargo rack, which serves a double function of protecting the athletes legs. Capra Ibex can be fully transitioned from inside the sitski by the athlete contributing to the athletes independence.

Capra can be retrofitted on any available sitski on the market through an adapter situated between the suspension frame and the bucket.

The propulsion concept uses a large leading wheel to drive a compact track system. A larger wheel radius reduces the chance of the system digging into loose snow, while the track increases the contact surface with the snow. By using only two wheels, the track remains simple and lightweight. The position of the smaller rear wheel defines the length of the contact surface and can be adjusted to regulate track tension or disassembled for storage. The tracks can consist of climbing skins for soft snow, rubber tracks for all-round use, or spiked rubber tracks for hard-packed snow and ice.

Figure 54. Capra Ibex in context.



On snow



Figure 55. Capra Ibex on snow in skitour

Off snow



Figure 56. Capra Ibex on dirt road

On & off snow

The wheel-based modular tracks allow athletes to turn their sitski into an off-road wheelchair. The ski is replaced by a small tail wheel attached to the binding. Athletes can make their way to and from the start of the trail when the snow starts higher up the mountain.

On multi-day routes, athletes can use their wheelchair-adapted sitski to manoeuvre around mountain huts.

Movement

The athlete can generate movement by moving the levers backward and forward, creating a fluent, rhythmic motion. By pulling the levers, the large wheel rolls over the track, causing the sitski to move forward.

Athletes can opt for an electrically assisted version, which supports propulsion by taking over part of the required power output. This allows physically challenged athletes to explore the backcountry for longer and travel further.

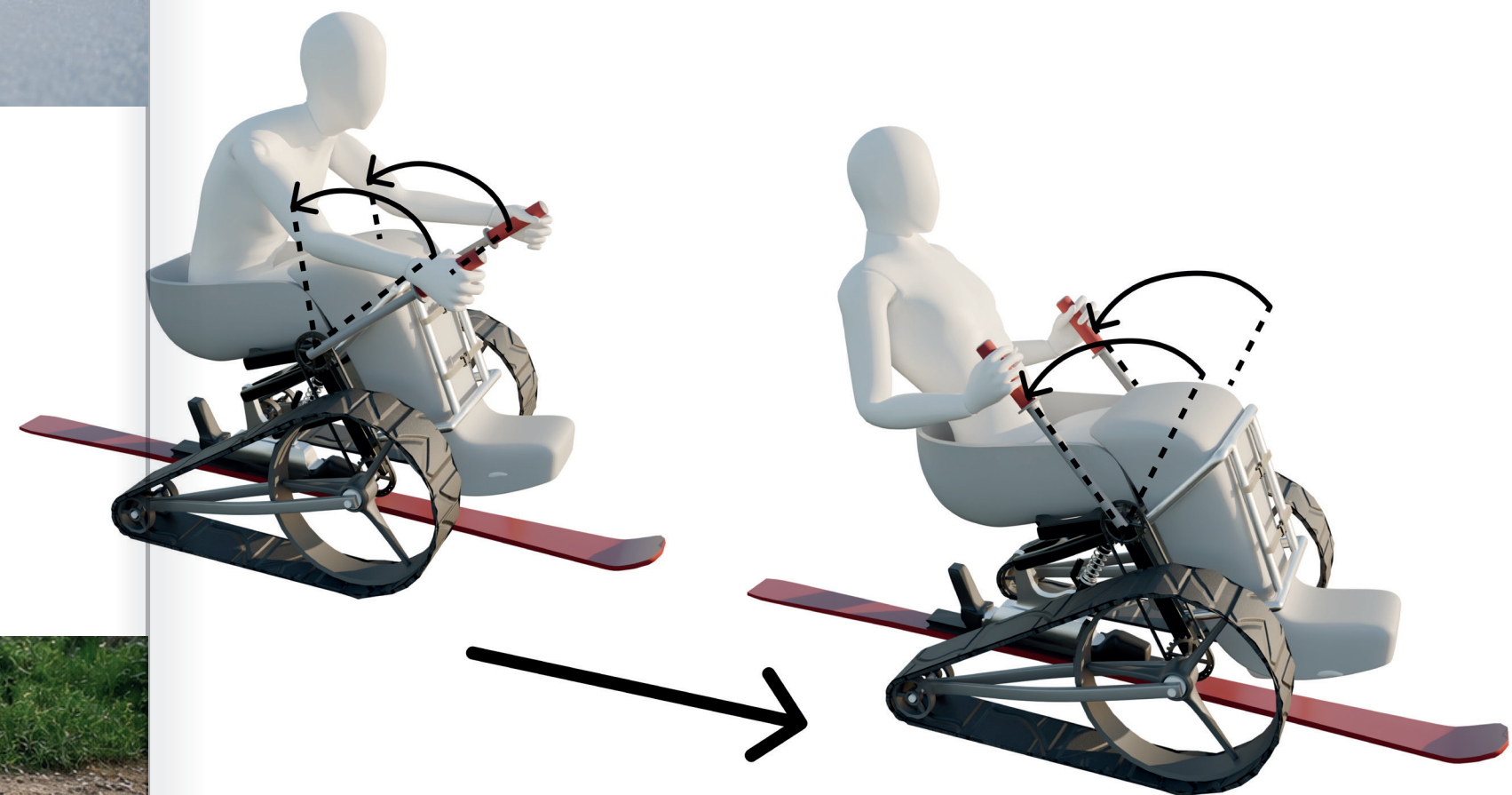
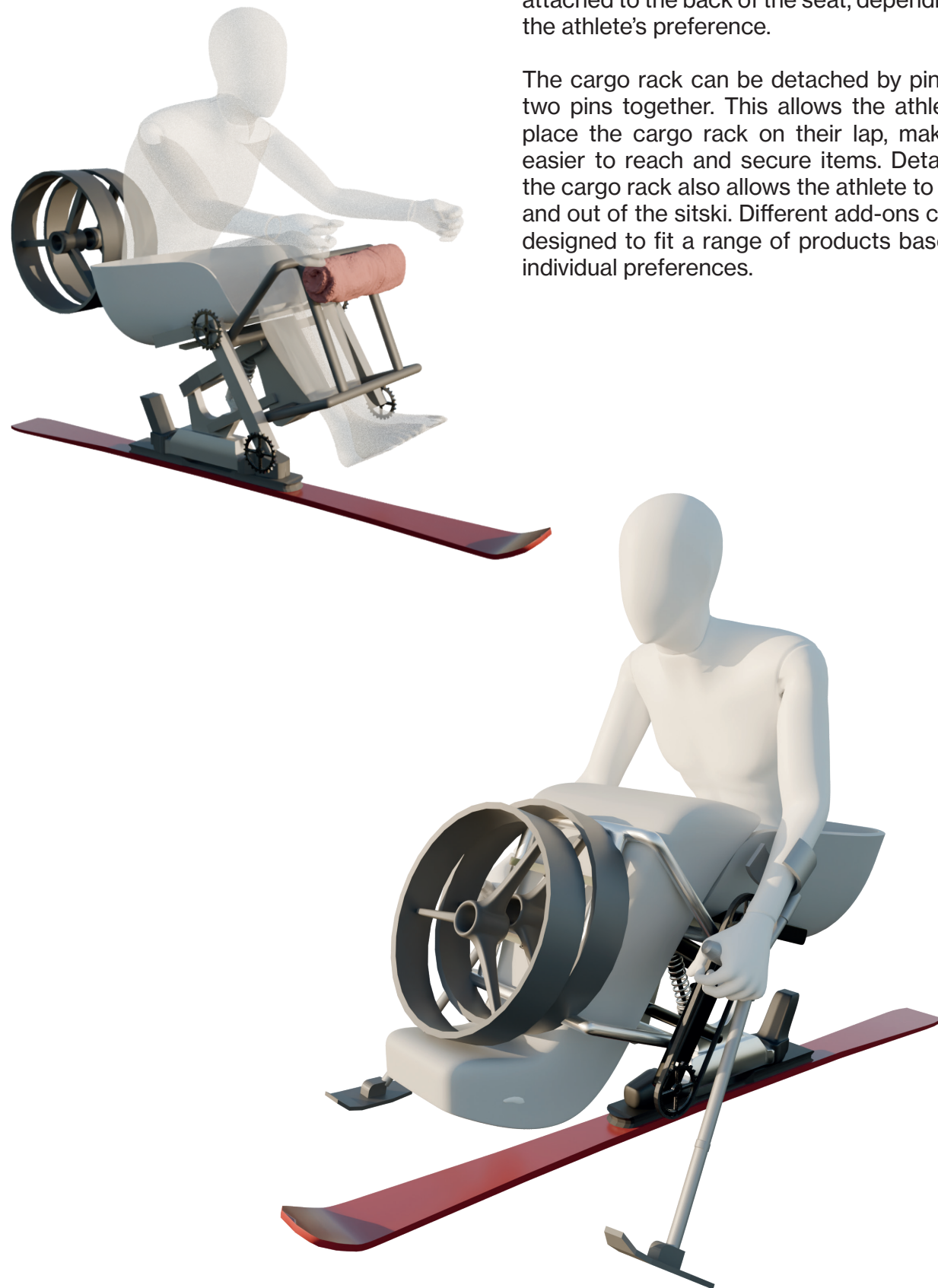


Figure 2. Capra Ibex In motion



The packed propulsion system can either be stored in front of the legs on the cargo rack or attached to the back of the seat, depending on the athlete's preference.

The cargo rack can be detached by pinching two pins together. This allows the athlete to place the cargo rack on their lap, making it easier to reach and secure items. Detaching the cargo rack also allows the athlete to get in and out of the sitski. Different add-ons can be designed to fit a range of products based on individual preferences.

11 Conclusion

This chapter concludes the graduation project and gives answers to the main research question (MRQ): *'How can a sit-ski touring setup be designed to support autonomous participation of physically challenged athletes with lower-body impairments in mountain adventures?'*

This project started with a curiosity: would it be possible for a sit-skier to climb a mountain, reach terrain that is not accessible by lift, and do so under their own power? This curiosity developed into the present project, in which opportunities for sitskitouring are investigated.

Sit-ski athletes and adaptive endurance sport athletes have expressed a need for equipment that supports autonomous participation in mountain adventures. Currently, no product is available that addresses this need. At the same time, trained physically challenged athletes with lower body impairments are able to generate sufficient power to perform a ski tour under their own power. The missing link is equipment that enables athletes to convert this power into propulsion, allowing them to ascend snow-covered mountain terrain and perform a ski tour in a sitski.

Capra Ibex is proposed as this missing link. The design consists of a propulsion system that can be operated from a sitski. It can be retrofitted onto existing sitskis through an adapter mounted between the frame and the seat. Since sitski configurations are highly user-specific, the design allows athletes to continue using the equipment they are already familiar with.

The design translates the athlete's generated power into forward propulsion with minimal expected efficiency loss. However, the efficiency of the complete system, including the sit-ski itself, can be further improved by reducing weight. This would decrease the amount of energy required to ascend. Because the design is retrofittable, it also allows manufacturers to further optimise sitskis for weight reduction. In the future, users should be able to configure their own setup according to their specific needs, for example by selecting lighter components or adding electric assistance.

The modular track-based propulsion system uses tracks to generate propulsion on snow. The system can be disassembled and mounted onto designated positions on the sit-ski, where they are not hindering the descent. In addition, the track-based propulsion system can be converted into a wheel-based propulsion system, turning the sit-ski into a wheelchair-like setup. This enables the user to move across non-snow surfaces, such as inside a mountain hut or during approaches where the snow starts higher up the mountain. The complete changeover from ascending mode to descending mode can be performed by the sit-skier without leaving the seat, contributing to the autonomy of the athlete.

Further development of Capra Ibex is needed to validate its functionality on snow with users, before it can be used on mountain adventures.

This thesis shows that skitouring in sitski has strong potential. The project followed a User-centred design approach leading to the design outcome which has been evaluated along the way, through in-context testing. Although further development of Capra Ibex is needed before it can be used in mountain adventures, the proposed design answers the main research question. By enabling autonomous participation in sit-ski touring, it supports physically challenged athletes with lower-body impairments to experience autonomy in exploring the mountains on their own terms. They can be the engine of their own adventure.

Figure 57. Capra Ibex In skimode, two different configurations

12 Discussion

The final design outcome should not be seen as a finished product, but as a first working step towards a new type of sit-ski touring equipment. The concept is still in an early development phase and requires further iterative loops before it can become reliable, refined and ready for mountain use.

The in-field evaluation prototype validated the main principle behind the design. Using a rowing-like pulling motion to generate power from a seated position in a sit-ski is feasible and comfortable for users. The biomechanical research supported the theoretical feasibility of this direction, while the prototype test showed that this principle can be translated into uphill movement on snow. Due to the scope and timeframe of the project, several parts of the design had to be simplified to reach a testable prototype. These simplifications included the connection between the touring outriggers and the sit-ski, the suspension behavior, suspension control and the reloading of a new stroke. Although these choices made testing possible, they also influenced the performance of the prototype in chapter 9.5.

The project showed that sit-ski touring through upper-body propulsion is theoretically and practically promising, but not yet fully proven in a real use context. The biomechanical exploration indicated that trained athletes can generate enough upper-body power to make this direction plausible. The prototype then demonstrated that this power can be transferred to the snow surface and result in uphill propulsion. However, a functional prototype of the proposed design still needs to be tested before **feasibility** can be confirmed with certainty.

The **viability** of the concept is strongly connected to the existing sit-ski market. Sit-skiing equipment is expensive, long-lasting and highly personalised to the user. Therefore, it is unlikely that many users would immediately buy a second complete sit-ski setup only for touring. This influenced the decision to design Capra Ibex as an add-on system that can be mounted onto existing sit-skis. This lowers the threshold for users to try sit-ski touring while continuing to use equipment they already know and trust. In the long

term, a touring-specific sit-ski or a rental and demo service could further improve viability.

The **desirability** of the concept became clear throughout the project. Potential users, professionals, manufacturers and pioneers in adaptive outdoor sports responded with strong enthusiasm. More importantly, several people invested their time, resources and network to help move the project forward. This shows that the community desires a solution that supports autonomy, adventure, inclusion and participation in mountain environments.

With further development, Capra Ibex could become a valid option for enabling sit-ski athletes to perform a ski tour using their own power.

Recommendations

Development of Capra Ibex

Issues to be addresses are:

- Coping with traverses and kick-turns.
- Development of the modular track system
- Finite Element Analysis to assess durability and make decisions to save weight.
- Addition of optional electric assistance

User evaluation

More in-field tests are needed to determine pain points and usability issues. A list of participants who expressed to be willing to join next test rounds has been made for the winter of 2026/2027. Over the duration of project, a functional prototype of the Capra Ibex has not been made or tested on snow. These user evaluations include setting out to try and perform a skitour with the proposed design. Gathering user insight on the design is essential to potentially increase user-product satisfaction significantly.

Lightweight sitski

Lightweight parts to customize current sitskis will have to be developed for weight saving purposes. This will allow athletes to save energy and go further, higher or longer.

Reflection on research and design process

Looking back, I believe that the research and exploration phase provided a solid foundation for the design process. The project required knowledge from multiple fields, including sit-skiing, ski touring, adaptive sports, biomechanics, existing equipment, user needs, and mountain conditions. Bringing these areas together was essential, as the design challenge could not be fully understood from a single perspective.

A key strength of this phase was the active involvement of people from the adaptive sports industry. Rather than relying solely on literature and online research, I reached out to users, manufacturers, and experts. These conversations made the project more grounded in real user needs and helped to define the design direction. One aspect that could have been strengthened was the biomechanical exploration. This part helped me understand the “engine” I was designing for: the human body. However, involving a biomechanics expert, preferably with experience in adaptive sports, could have added more depth and accuracy to this part of the project.

At the same time, design is not a linear process. Researching, exploring, building, testing, and learning continuously influence one another. During this project, I had to prevent myself from remaining in the research phase for too long. There was always another question to explore or another technical detail to understand, but progressing in the project required me to stop researching and start building. In that sense, I gradually adopted a research-through-design approach.

During testing, some ideas did not work as intended. Looking back, it is tempting to view these moments as mistakes that could have been avoided. However, that judgement is made with knowledge that only became available through testing. Therefore, these tests were not only moments of validation, but also essential steps in the learning process.

One of the biggest practical challenges was the lack of direct access to a suitable sit-ski. I was designing a product that had to fit onto an existing product, while only having limited dimensional information available. This made parts of the design process time-consuming and partly based on assumptions. During testing, some measurements and proportions turned out differently than expected, which influenced the geometry and performance of the prototype. To reduce this risk, I incorporated several adjustment options into the prototype. This flexibility proved valuable during testing, but it also added complexity to the design. With direct access to a sit-ski from the beginning, some of these issues could likely have been avoided.

Still, within the financial, time, and collaboration limitations of the project, I made use of the opportunities that were available. Setbacks forced me to adapt quickly, but they also led to valuable connections and, eventually, to a working prototype that could be tested in real mountain conditions.

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Appendix A. List of requirements

1. Functional Requirements

- 1.1 The equipment must allow independent uphill propulsion using the upper body and trunk muscles.
- 1.2 The setup must allow the athlete to switch between uphill (ascent) and downhill (descent) mode (without external help). (It should take less than minutes, ideally without removing the athlete from the seat.)
- 1.3 The propulsion interface must enable forward motion without backward sliding.
- 1.4 The system must be compatible with existing skis and bindings where possible. (to ensure serviceability and replaceability)
- 1.5 The frame must support modular configuration, allowing different seat types and backrests to be interchanged depending on user preference and ability level.
- 1.6 The design must enable easy entry and exit by the user, even in mountain environments with deep snow.

2. Performance Requirements

- 2.1 The system must allow propulsion while staying below an average power output of 170 W. (corresponding to the sustainable output of trained para-athletes)
- 2.2 The total system weight should be as low as possible, without compromising safety. (ideally below 15–18 kg including skis).
- 2.3 The design must transfer power efficiently from upper body motion to the skis, minimizing frictional and inertial losses.
- 2.4 The setup must ensure structural integrity under dynamic loads equivalent to freeriding impacts (based on current Tessier Scarver durability standards).
- 2.5 The equipment must operate reliably across temperature ranges from -20 °C to +5 °C and in varying snow conditions in alpine environments. (powder, packed snow, wet snow).

3. Ergonomic Requirements

- 3.1 The equipment must enable ergonomically aligned joint positions for propulsion.
- 3.2 The posture should be adjustable to switch between climbing and descending configurations.
- 3.3 Backrest height and support level must be adaptable to match the athlete's classification (LW11–LW12) and trunk control.
- 3.4 Seat edges, harnesses, and contact zones must be designed to avoid pressure points, abrasions and circulation restrictions.
- 3.5 Controls (locks, straps, levers) must be operable with gloves and limited finger ability.

4. Safety Requirements

- 4.1 The structure must not fail under peak stresses from impacts or torsional loads typical of freeride conditions.
- 4.2 A quick-release system must allow the user to detach from the setup in emergencies like avalanches and treewells.
- 4.3 The equipment must maintain stability and enable recovery without external help in case of tipping over.

5. Usability and Maintenance Requirements

- 5.1 Basic maintenance operations must be possible with basic tools in remote conditions.
- 5.2 The propulsion mechanism should remain functional with minimal cleaning or snow clearing.

6. Aesthetic and Inclusive Design Requirements

- 6.1 The product should visually align with high-end freeride/touring equipment. (to avoid stigmatization and to promote inclusivity)
- 6.2 The design should appear lightweight, performance-oriented, and desirable (“something non-sitskiers would want to use.”)
- 6.3 The design should communicate user identity as an athlete, not as a patient.

7. Environmental and Contextual Requirements

- 7.1 Where possible, components should be recyclable or repairable (sustainable design principles)

8. User-centred and Psychological Requirements

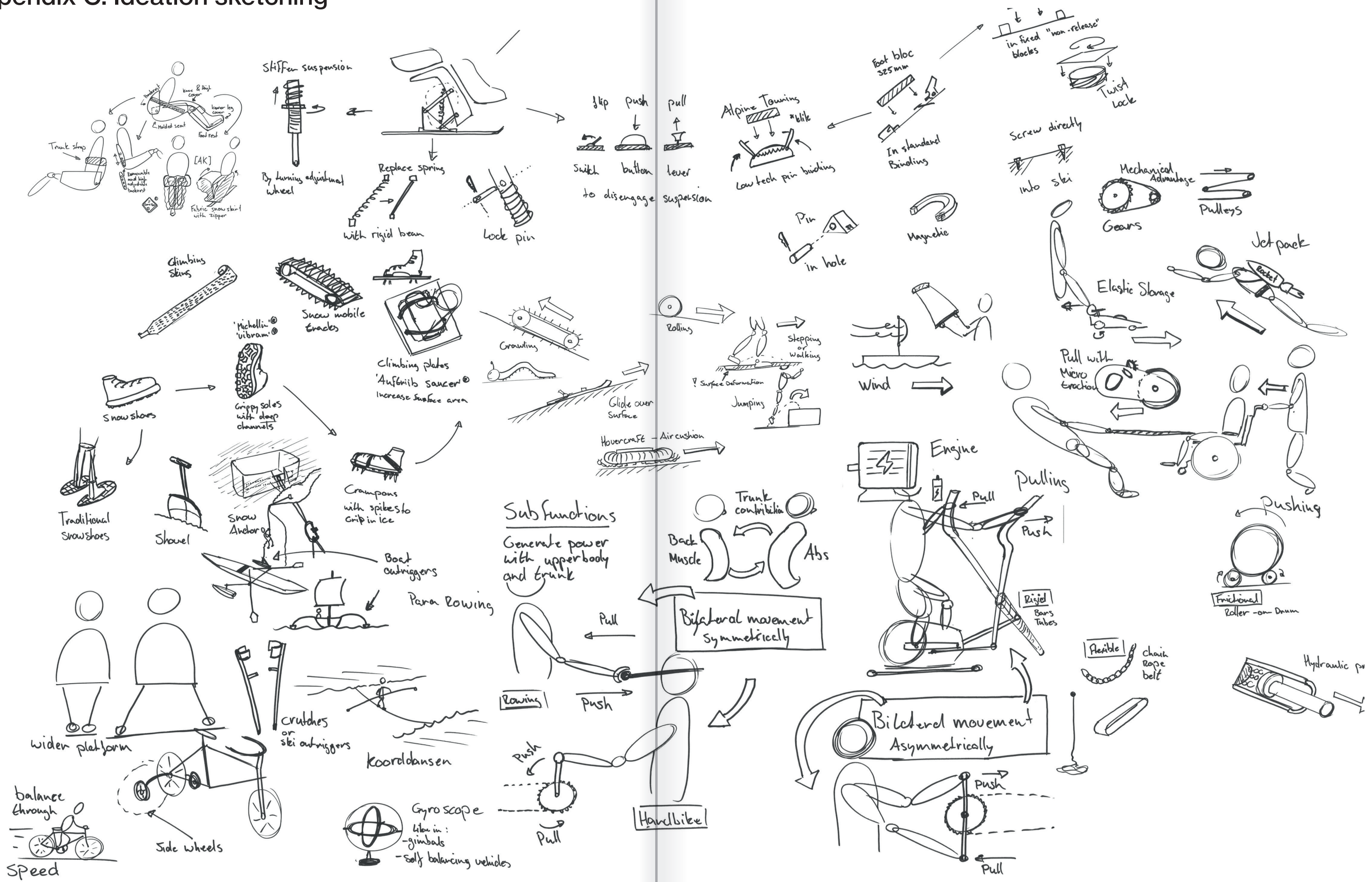
- 8.1 The product should strengthen the athlete's sense of autonomy.

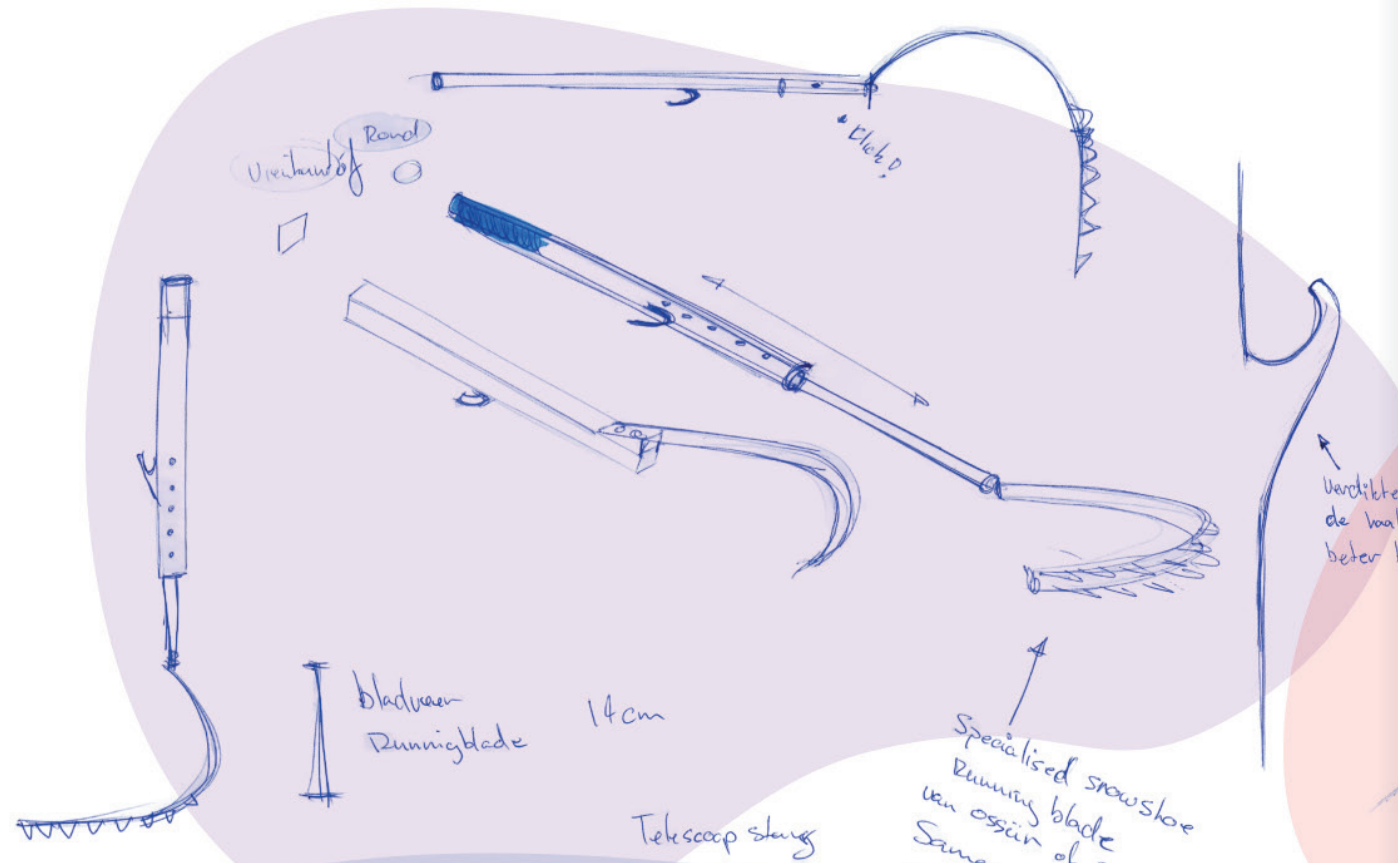
Appendix B. Technical analysis

Current stand up touring setup					
Subfunctions	Solutions				
Fix ski to boots					
Transfer forces from skier to ski					
Support skiers balance					
switch between walk and ski mode					
Prevent sliding backwards					

Sit tour ski					
Subfunctions	Solutions				
Fix ski to sitski interface Downhill					
Suspense shocks downhill	4 link system with (semi) vertical Spring/damper 	4 link system with (semi) horizontal Spring/damper 	Spring blade and separate damper 	No suspension at all 	
Transfer forces from skier to ski Downhill	Stiff frame 				
Support skiers body. Downhill	Fiberglass seat with carbon reinforcements. White gelcoat outer layer 	Fiberglass seat with carbon reinforcements + carbon outer layer. 			
Support skiers balance. Downhill	 With cord to pull up the mini ski for more grip in snow	 Without cord to pull up the ski, but with screws on skitip			
Enable lift access					

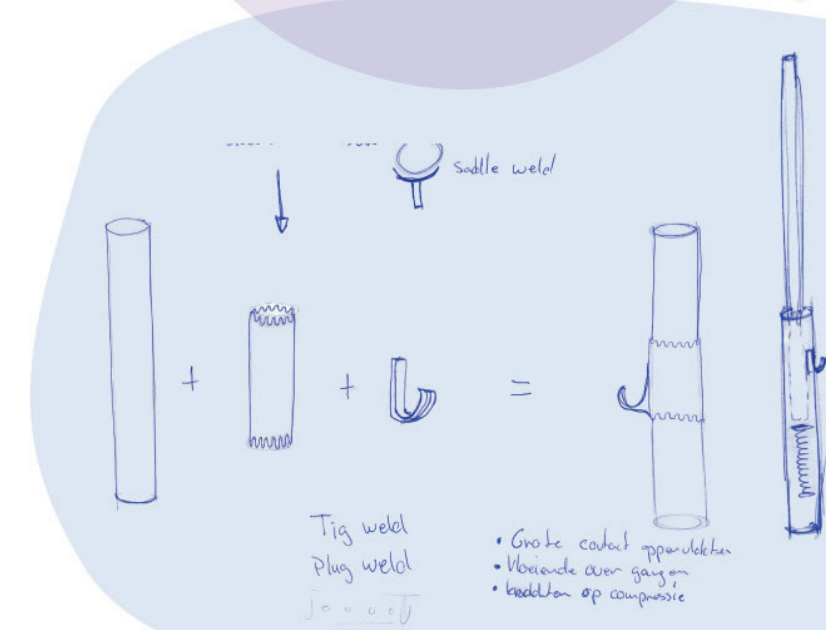
Appendix C. Ideation sketching



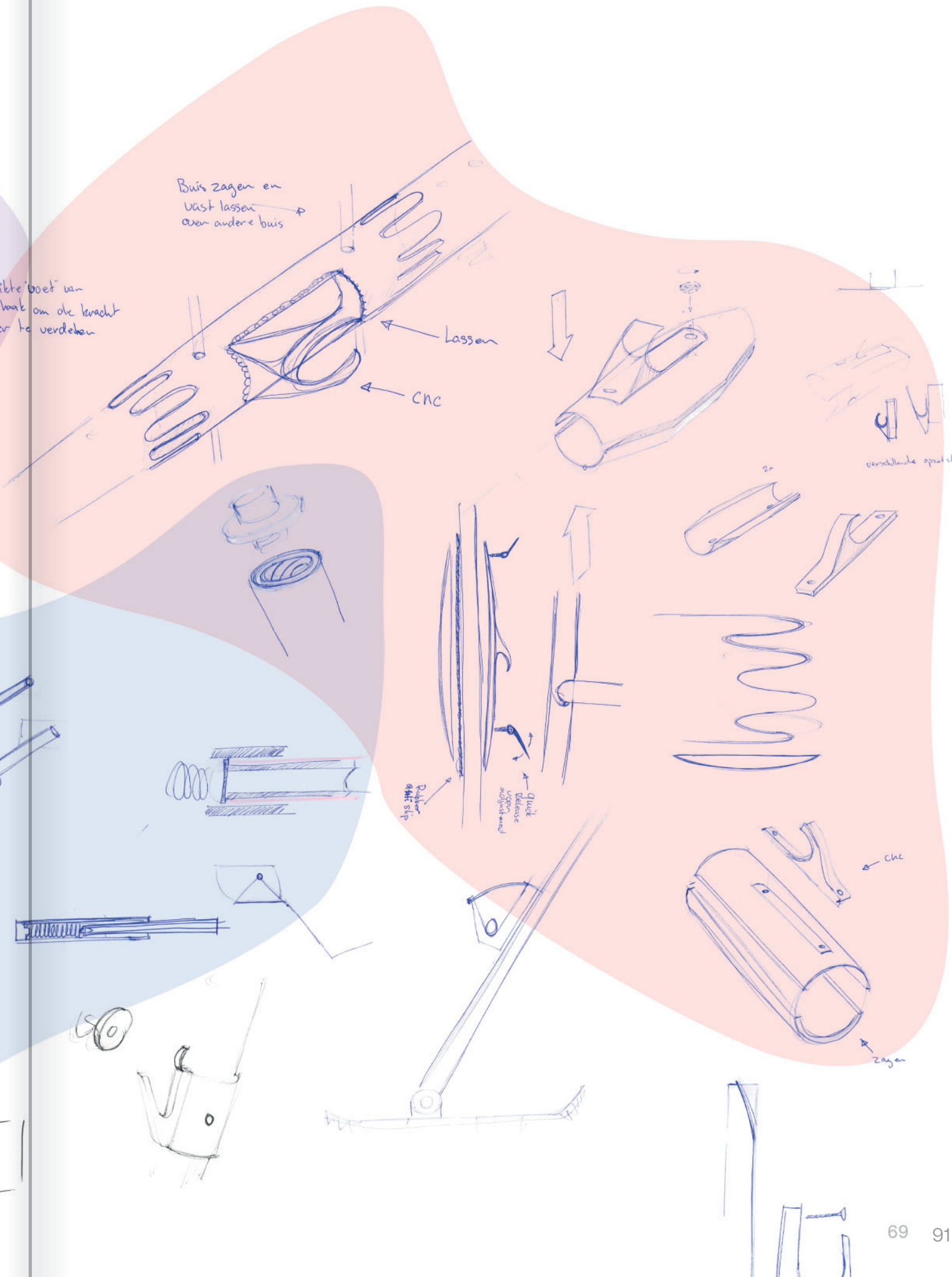
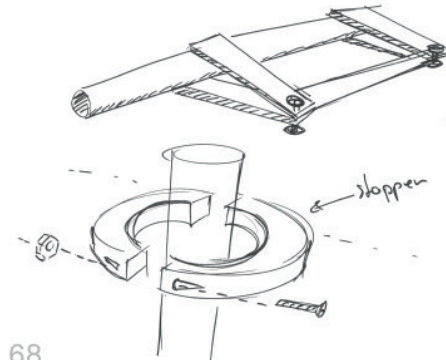


Verdikte 'boet' van de haak om de kracht beter te verdelen

Specialised saw shoe
Running blade
van ossen of?
Samen werking zaden



Kop:
- Dollen



Appendix D. Morphological chart

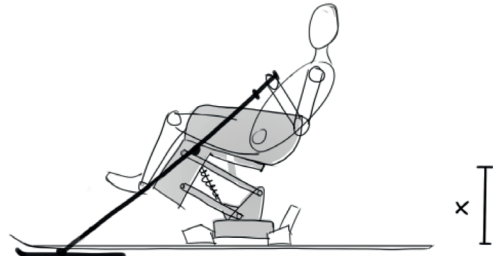
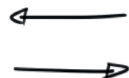
Subfunctions	Solutions														
Fix ski to sitski interface Downhill															
Suspense shocks downhill	 4 link system with (semi) vertical Spring/damper	 4 link system with (semi) horizontal Spring/damper	 Spring blade and separate damper	 No suspension at all											
Transfer forces from skier to ski Downhill	 Stiff frame														
Support skiers body. Downhill	 Fiberglass seat with carbon reinforcements. White gelcoat outer layer	 Fiberglass seat with carbon reinforcements + carbon outer layer													
Support skiers balance. Downhill	 With cord to pull up the mini ski for more grip in snow	 Without cord to pull up the ski, but with screws on skitip													
Enable lift access															
Grip snow	 Climbing skins X Un-suitable for downhill	 Climbing skins X Require lifting in order to move forward	 Crampons with spikes to cut ice	 Snow shoes	 X Not suitable for ice and hardpack	 X Takes too long	 X Snow sticking to bottom results in losing grip								
Fix ski to sitski interface uphill	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski
Fix suspension	 Stiffen suspension	 Replace spring with rigid beam	 Lock pin	 Up push pull	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski	 Screw directly into ski
Transfer forces from skier snow uphill	 Mechanical roller-snow Drive	 Rigid Bars tubes	 Hydraulic pressure												
Support skiers body uphill	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat	 Track seat
Support skiers balance uphill	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed	 Balance through speed
Generate power with upperbody and trunk	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles	 Trunk muscles
Move sitski interface over snow - Move something over a surface	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins	 Climbing skins
Propulsion Assistance	 Wind	 Engine	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys	 Pulleys
Desired interaction	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.	 Hoe zou je willen dat je je veering kan vastzetten. Welke handling.

Appendix E. Concept sketches

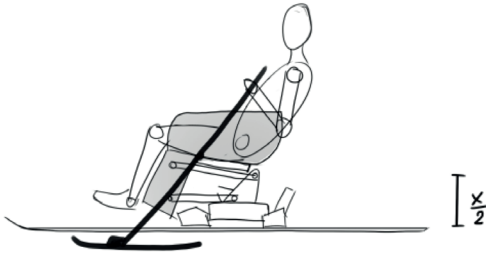
Downhill



Uphill

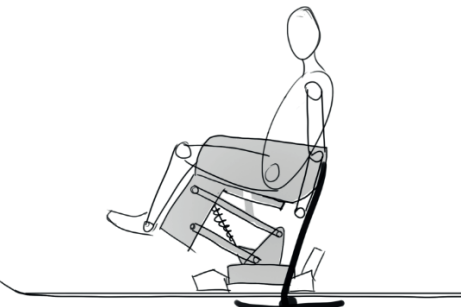


x

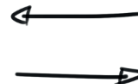


$\frac{x}{2}$

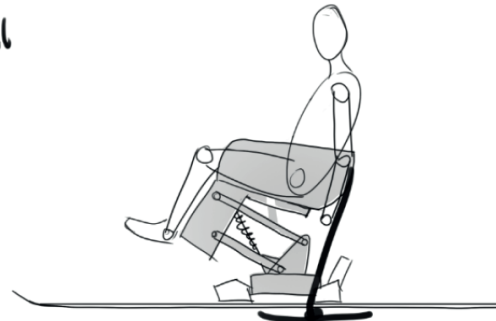
Downhill



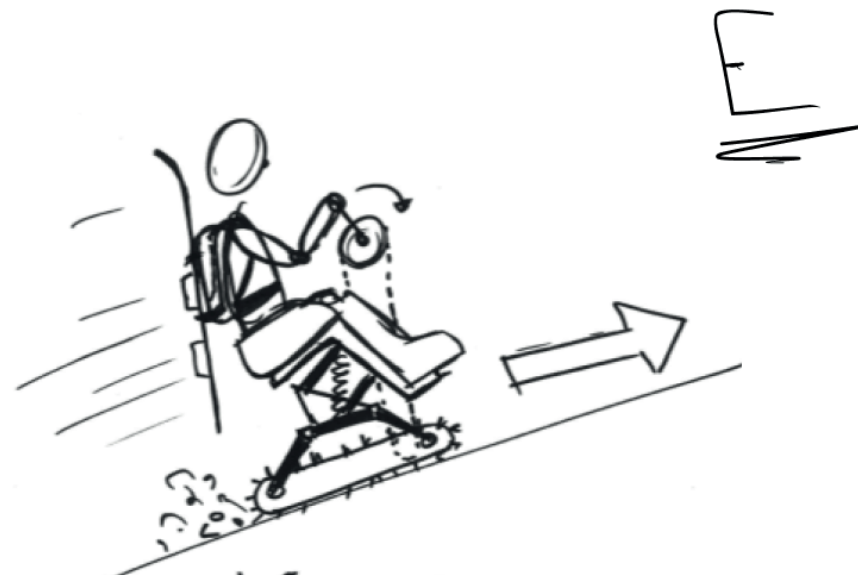
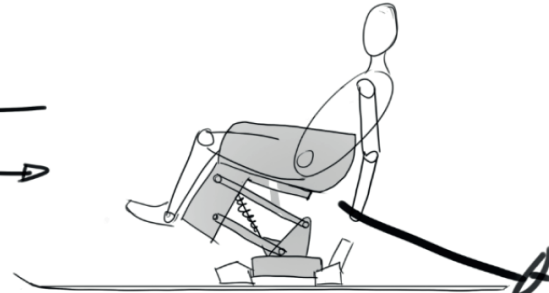
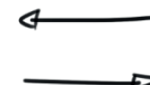
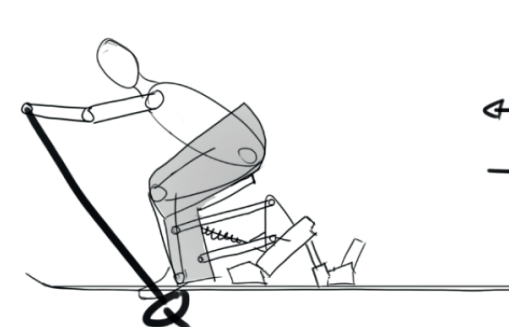
Uphill



Downhill



Uphill



Mount Frame onto a
Propulsion device
ski on backpack

Appendix F. Eligible impairments

The table below shows descriptions of the physical impairment types eligible to compete in Paralympic sport as describes by Connick et al. (2018)

Physical impairment type	Structure or function	Description	Examples of health conditions causing impairment
Strength	Function	Impairment to the force generated by the contraction of a muscle or muscle groups (World Health Organisation 2001)	Spinal cord Injury, spina bifida, muscular dystrophy
Range of movement	Function	Impaired Joint Mobility (IPC Athletics 2014)	Arthrogryposis, ankyloses, cerebral palsy
Hypertonia	Function	A form of motor overactivity which increases muscle tone in people with upper motor neuron lesions (Sheean and McGuire 2009)	Cerebral palsy, brain injury, multiple sclerosis
Ataxia	Function	A movement disorder that is associated with impairments of limb coordination (Topka et al. 1998; Morton and Bastian 2004)	Cerebral palsy, Friedreich's ataxia, brain injury, multiple sclerosis
Athetosis	Function	A movement disorder which is characterised by involuntary writhing, usually of the distal musculature (Neilson 1974; Hallett and Alvarez 1983)	Cerebral palsy, stroke, brain injury
Limb deficiency	Structure	Total or partial absence of the bones or joints of the shoulder region, upper extremities, pelvic region, or lower extremities (IPC Athletics 2014)	Amputation
Leg length difference	Structure	Aberrant dimensions of bones of right lower limb or left lower limb but not both (IPC Athletics 2014)	Congenital or traumatic causes of bone shortening in one leg
Short Stature	Structure	Aberrant dimensions of bones of upper and lower limbs or trunk which will reduce standing height (IPC Athletics 2014)	Achondroplasia

Appendix G. Skitouring power estimation model

```

> # Constants
g := 9.81 : # gravitational acceleration [m/s^2]

>
> #Variables
mequipment := 10 :
mrider := 80 :
mtotal := mrider + mequipment : # [kg]
Csliding := 0.223 :
# sliding friction coefficient of Contour basic easy skin on with air and snow temp. of -7 and -4 respectively
mu := 1.0 : # drivetrain efficiency (3% loss)
vkmh :=  $\frac{8.52}{2.75}$  :
v :=  $\frac{vkmh}{3.6}$  : # m/s

# grade is road gradient as a decimal
# To calculate a road's angle from a percentage grade, divide the percentage by
# 100 and then find the arctangent (or inverse tangent) of the result
grade :=  $0.01 \cdot \frac{8.52}{0.933}$  :
theta := arctan(grade) : # road angle [rad]

> #crazy variables
m_arm :=  $\frac{mrider \cdot 5.7}{100}$  :
# 5.7% of total bodyweight (source: https://exrx.net/Kinesiology/Segments)
m_leg :=  $\frac{mrider \cdot 16.68}{100}$  :
# 16.68% of total body weight (source: https://exrx.net/Kinesiology/Segments)

> # Power demand [W]:
#Fg := mtotal · g · sin(theta);
# Fsliding := Csliding · mtotal · g · cos(theta); # assumption: non existant in walking
#Faero := 0.5 · rho · Cda · v^2; # assumption: negligible
#Ftotal_walking := Fg + Fsliding;
#P =  $\frac{Ftotal\_walking \cdot v}{mu}$ ;
#Total equation in one line
#mass component in sliding friction excludes the mass of one arm since it's supported by a skipole
#and excludes half the body mass since the weight is shifted to the non sliding foot to provide
#grip and make sliding the ski forward easier.

Pdemand :=  $\frac{v \cdot \left( mtotal \cdot g \cdot \sin(\theta) + Csliding \cdot \left( \frac{mtotal}{2} - m\_arm \right) \cdot g \cdot \cos(\theta) \right)}{mu}$ 
Pdemand := 144.9192212
#Vermogen per kilo

```

(1)

Appendix H. Muscle function and corresponding sitski classification

Muscle group	Key muscles	Main innervation	Primary function	Effect of spinal cord lesion	Typical sitski class
Abdominal flexors	Rectus abdominis, external oblique, internal oblique, transversus abdominis	Thoracic nerves T7–T12 (and L1 for internal oblique & transversus)	Trunk flexion, rotation, and stabilization	T1–T6: absent control → no trunk flexion. T7–T9: partial upper fibers → limited flexion. T10–T12: near full → good trunk balance.	LW10-1: absent abdominals LW10-2: partial upper abdominals LW11: good abdominals LW12-1/2: full function
Back extensors (intrinsic)	Erector spinae group: iliocostalis, longissimus, spinalis	Dorsal rami of spinal nerves T1–L5	Trunk extension, postural control	T1–T6: absent → no active extension. T7–T9: upper extensors partly active → weak extension. T10–T12: full upper/mid extensors → good extension and posture. L1 and below: normal.	LW10-1: absent spinal extensors LW10-2: partial LW11: good control LW12-1/2: normal
Back (extrinsic)	Trapezius (CN XI, C3–C4), latissimus dorsi (C6–C8), rhomboids (C5), levator scapulae (C3–C5), serratus anterior (C5–C7), serratus posterior sup./inf. (T2–T12)	Various cranial and cervical roots; intercostal nerves for serratus post.	Scapular positioning, shoulder stability, assisted respiration	Generally intact in thoracic/lumbar SCI since most are innervated above lesion level	Intact across LW10–LW12
Back (extrinsic)	Trapezius (CN XI, C3–C4), latissimus dorsi (C6–C8), rhomboids (C5), levator scapulae (C3–C5), serratus anterior (C5–C7), serratus posterior sup./inf. (T2–T12)	Various cranial and cervical roots; intercostal nerves for serratus post.	Scapular positioning, shoulder stability, assisted respiration	Generally intact in thoracic/lumbar SCI since most are innervated above lesion level	Intact across LW10–LW12
Anterior thoracic muscles	Pectoralis major (C5–T1)	Medial & lateral pectoral nerves	Shoulder adduction, internal rotation, and trunk stabilization in sitting	Intact in lesions below T1; partial in T2–T4 lesions; contributes to forward propulsion and balance	Intact for LW10–LW12 (may be weak in high thoracic lesion LW10-1)
Combined trunk function	Abdominals + spinal extensors	T1–L5 segmental innervation	Dynamic balance, trunk control, postural adjustments	T1–T6: no flexion or extension; poor sitting balance. T7–T9: partial upper control; limited trunk movement. T10–T12: good flexion/extension; independent sitting balance. L1 and below: near-normal control.	LW10-1 → LW12-2 (progressive improvement with lower lesion level)

Table presents an overview of trunk muscle function in relation to spinal cord injury level and its implications for sitski classification. Adapted from Gray’s Anatomy for Students (5th ed.) StatPearls, Physio-Pedia, and FIS Para Alpine Skiing Classification Rules (2023).

Spinal cord lesion level	Expected back muscle function	Functional description	Likely sitski class
T1–T6	Only extrinsic muscles intact (trapezius, rhomboids, etc.); intrinsic extensors inactive	No active trunk extension; relies on arms and straps	LW10-1
T7–T9	Upper erector spinae partially active	Weak extension; limited trunk correction	LW10-2
T10–T12	Full upper & mid erector spinae active; partial lower	Good extension and balance	LW11
L1–L2	Nearly full erector spinae and paraspinals active	Strong extension, stable posture	LW12-1
L3 and below	Full intrinsic and extrinsic back muscles	Normal trunk extension; minimal impairment	LW12-2

Figure . Relationship between spinal lesion level and functional trunk control in sitski athletes, based on classification levels LW10–LW12

Appendix I. Kinematics of skitouring

A sitski suspension mechanism essentially acts as a set of mechanical legs when skiing downhill. Analysing how able-bodied athletes walk uphill with skis attached to their feet can help rethink how a sitski suspension mechanism could function differently, when keeping requirements for uphill capabilities in mind.

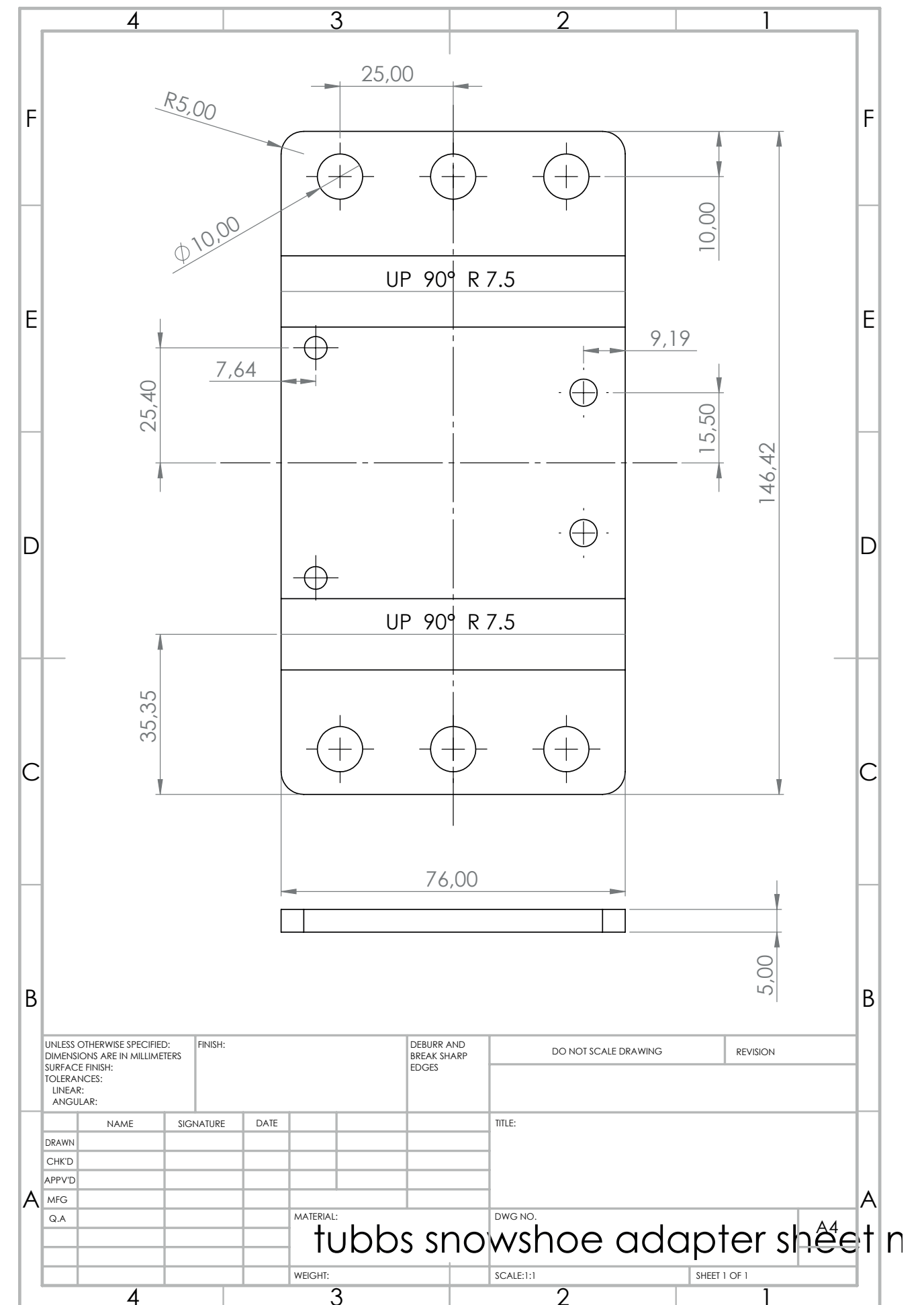
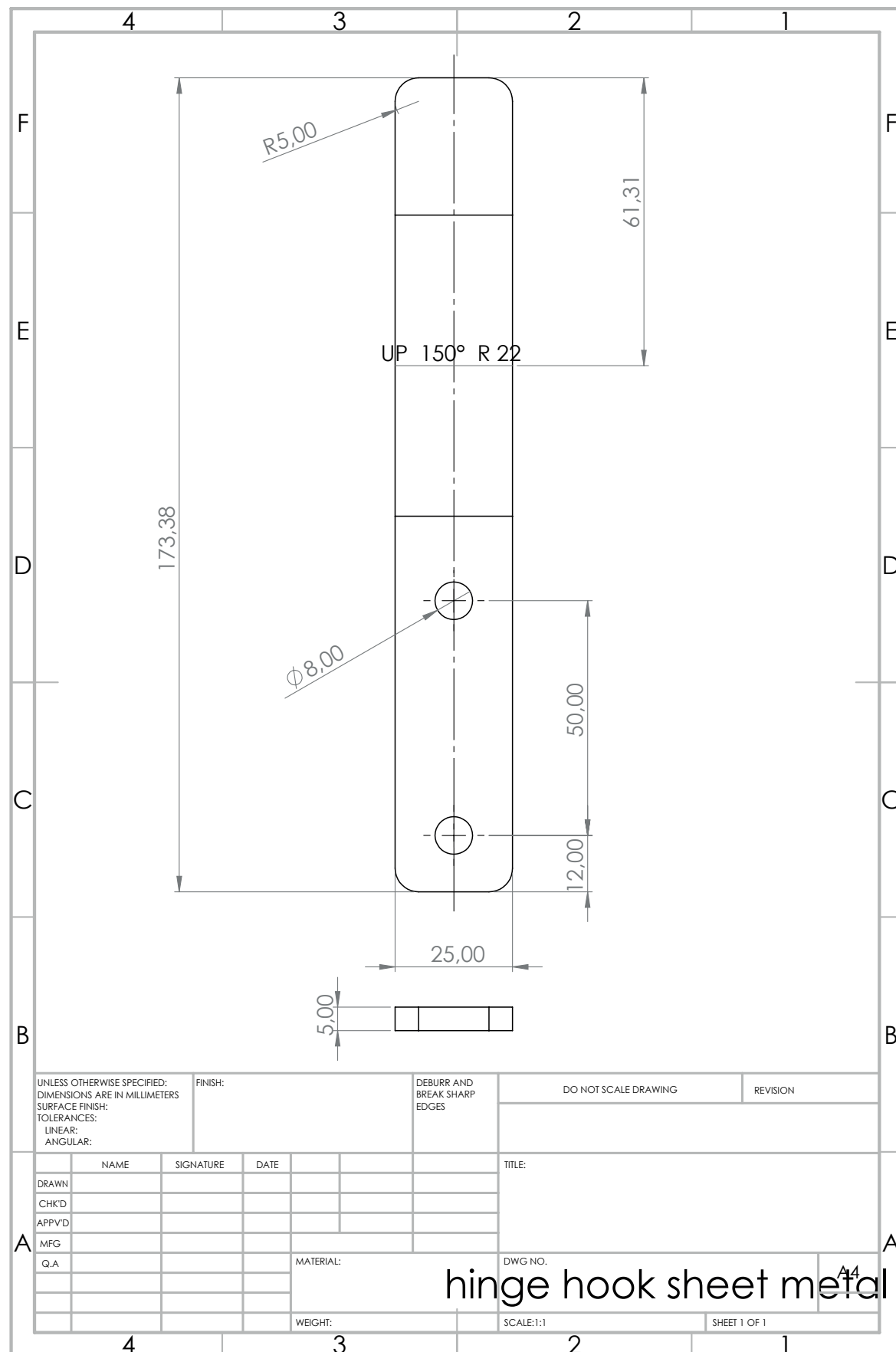
Recent biomechanical research by Donno et al. (2025) analyzed elite Skimo athletes performing uphill walking and running on a 9° incline. During ascent, the hip and knee joints work in synchrony to generate propulsion and absorb impact. Athletes begin each stride with the hip flexed (~50–60°) and the knee slightly bent (~35–40°), positioning the foot forward of the trunk for stability and energy absorption. The Rectus Femoris (front thigh muscle, part of the quadriceps) and Biceps Femoris (rear thigh muscle, part of the hamstrings) activate together to stabilize the knee. As the skier pushes off the snow, both the hip and knee extend almost simultaneously, powered mainly by the Rectus Femoris and assisted by the Gastrocnemius (calf muscle), which helps propel the body upward. At the same time, the Tibialis Anterior (shin muscle) stays active through most of the stride to keep the foot lifted inside the ski boot, countering the effect of the slope.

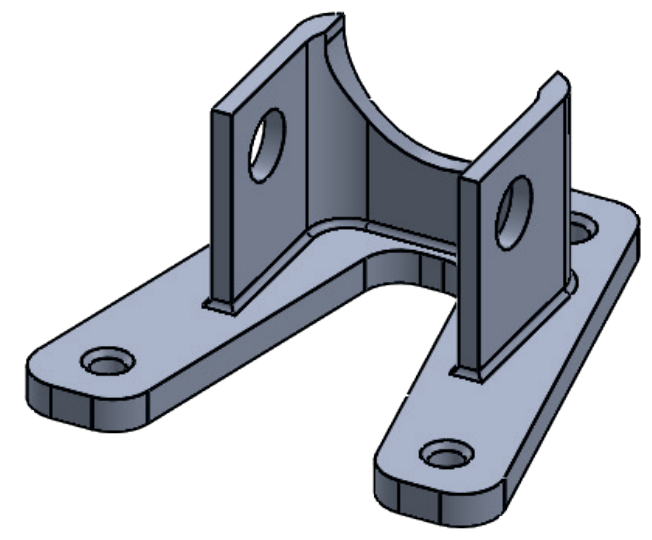
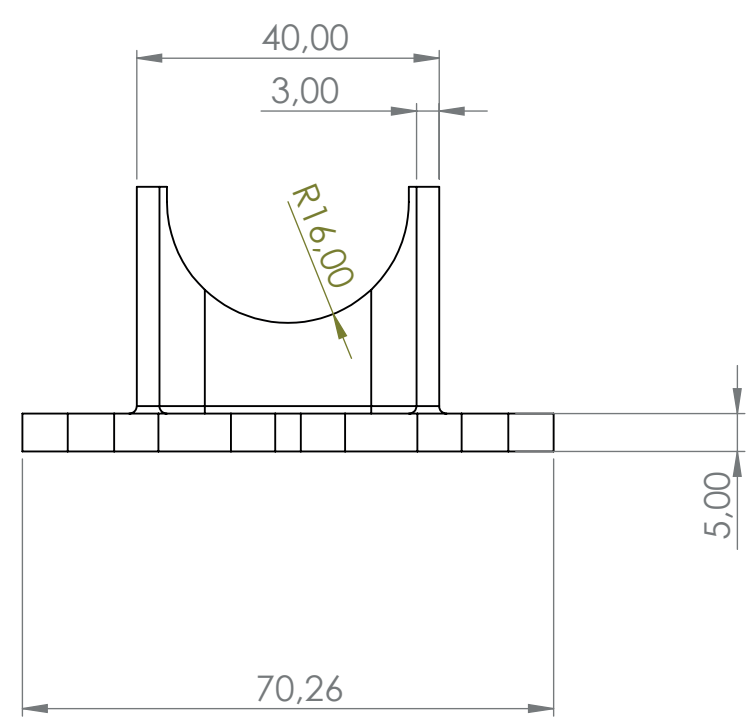
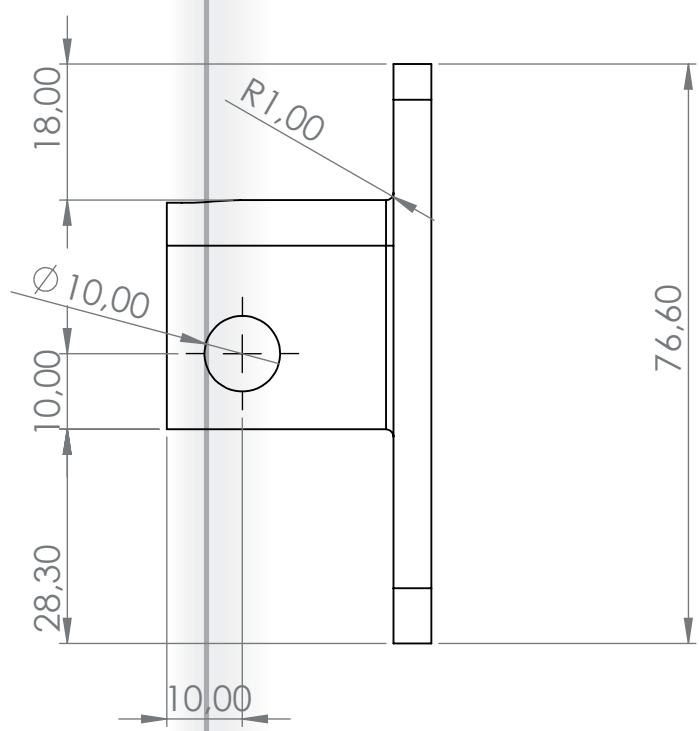
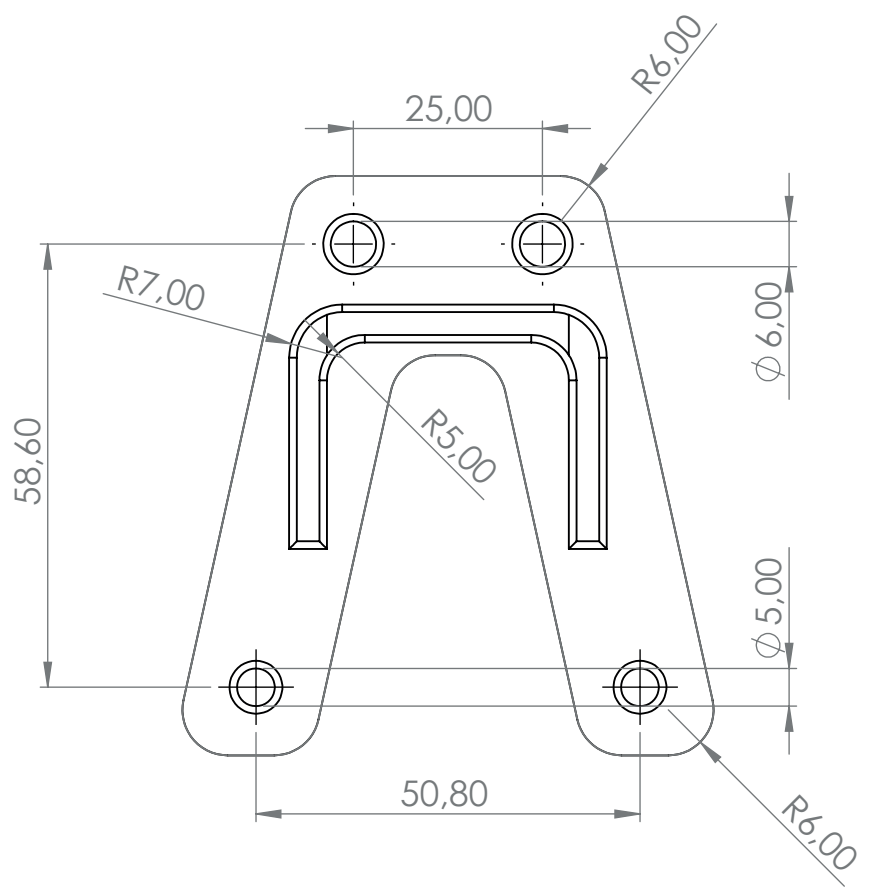
Trunk and pelvic control are equally important for efficient uphill motion. The Erector Spinae (deep back muscles) and Rectus Abdominis (the “six-pack” abdominal muscle) remain continuously active to stabilize the upper body and keep the pelvis tilted forward (about 25–27°). This coordination between the legs and trunk helps reduce unnecessary vertical movement of the body’s center of mass, which saves energy over long climbs. As the athlete increases speed (for example, from 7 to 8 km/h), joint movement becomes slightly smaller while muscle activation increases, suggesting shorter and faster strides are more efficient for maintaining power and rhythm (Donno et al., 2025).

Appendix J. Weighted criteria

Evaluation criteria	Rower		Walker		Polar		Cycler	
	Weight (1-3)	Score (1-5)	Final evaluation	Score (1-5)	Final evaluation	Score (1-5)	Final evaluation	
	• Minimal added parts to the setup / Potential of being adding minimal weight	4	12	4	12	5	15	
	• Biggest amount of muscles jointly used in one motion	3	4	12	1	3	5	15
	• Energy efficient motion	2	2	4	1	2	4	8
	• Ability to generate & sustain power	3	5	15	1	2	5	15
	• Ability to recover after fall over	1	3	3	1	3	1	1
	• Ability to maintain balance	1	2	2	1	1	5	5
	• Necessary parts are useful uphill and downhill	3	4	12	4	12	5	15
	• Short change over time	1	5	5	5	5	4	4
• Independent scenario	2	3	6	3	6	5	10	
		71		50		61		62

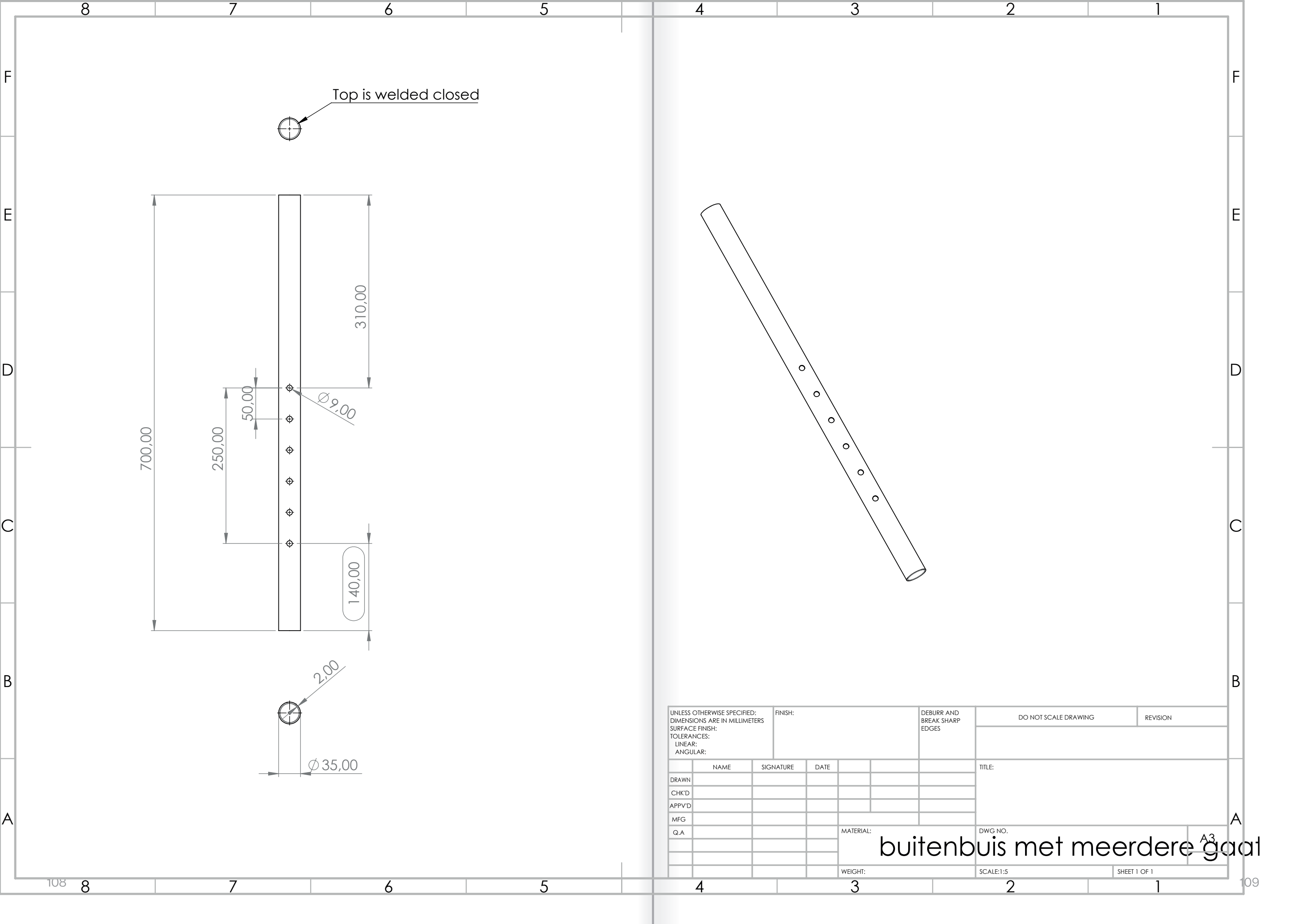
Appendix K. Technical drawings





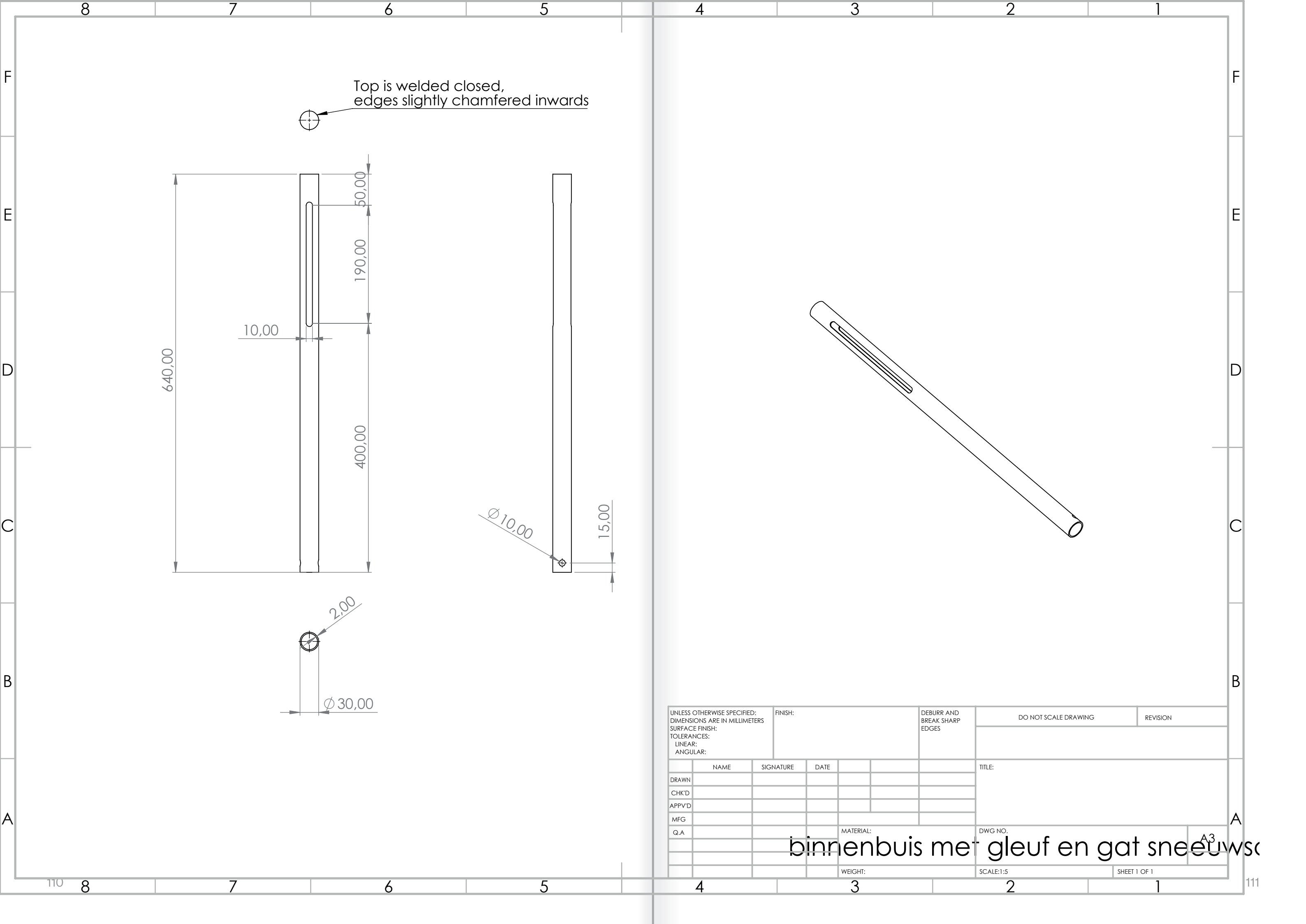
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sneeuwschoen stok adapter



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buitenbuis met meerdere gaatjes



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Appendix L. On-snow functionality evaluation



*I hoped you enjoyed reading 'The Ascent Reimagined:
Human-Powered Backcountry Access for Sit-Ski Athletes'*

*Thanks for joining me on this adventure.
Let this thesis be your reminder to get out there and have
fun.*

Mick Röer

Delft, June 2026