Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

Balder Habberstad Borgen

Design of Helmet for Surfing

Master's thesis in Industrial Design
Supervisor: Jon Herman Rismoen
Co-supervisor: Gunnar Eidsvik Tvedt
June 2023

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Preface

I would like to start by thanking my supervisor Jon Herman Rismoen and my co-supervisor Gunnar Eidsvik Tvedt, for engaging discussions, valuable feedback, and their continuous commitment throughout the entire project.

Secondly, a big thank you to Terje Brandsø and Rolf Steinsheim for always providing assistance and a good atmosphere in the workshop.

Finally, I want to express my gratitude to my dear friends, family, and my girlfriend for their love and support throughout my five years of study.


NTNU
Fakultet for arkitektur og design
Institutt for design

Masteroppgave for student Balder Habberstad Borgen

Design av hjelm for bølgesurfing
Design of Helmet for Surfing

Bølgesurfing er en voksende sport på verdensbasis. I motsetning til mange andre ekstremsporter, hvor bruk av beskyttelse har blitt en norm, er ikke dette vanlig i surfing i dag. Man ser imidlertid en endring hvor hodeskader har fått et større fokus i sporten, og flere profesjonelle utøvere og hobby-surfere velger å bruke hjelm.

Markedet for surfehjelmer består av få aktører og har lenge vært dominert av én produsent. Gath Sports lanserte sin første hjelm i 1989, og den har ikke blitt videreutviklet nevneverdig siden lanseringen. Allikevel er dette den foretrukne hjelmen for mange profesjonelle utøvere innen bølgesurfing. Det har imidlertid vært en stor utvikling i sporten siden 1989. Større og farligere bølger blir surfet, i tillegg til at økningen av surfere utgjør en større risiko i seg selv gjennom at sjansen for kollisjoner med andre øker og det skaper en mer kaotisk situasjon i vannet.

Målet med oppgaven er å designe en hjelm for bølgesurfing, med fokus på estetiske og funksjonelle kvaliteter og som er tilpasset dagens marked og bruksmønster. I tillegg skal en ny hjelm redusere skaderisikoen for surferen.

Oppgaven vil blant annet inneholde
- Analyse av eksisterende hjelmer til bølgesurfing og lignende formål
- Teori om hodeskader
- Kartlegging av behov basert på brukerinnsikt og andre relevante kilder
- Konseptutvikling
- Utforskning av relevante materialer og deres egenskaper
- Fysisk prototyping og testing
- Presentasjon av ny hjelm

Oppgaven utføres etter "Retningslinjer for masteroppgaver i Industriell design".

Hovedveileder: Jon Herman Rismoen

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NTNU, Trondheim, 9. januar 2023

Jon Herman Rismoen
Veileder

Sara Brinch
Instituttleder

About the Assignment

Good helmets are complex technological products, which require extensive testing and meeting rigorous safety standards. Therefore, as a designer in this project, the goal has been to conceptualize a new helmet that meets the specific functional aspects of use and has an appealing appearance. The "new helmet" will therefore not be a fully market-ready product, but rather a well-defined concept that encapsulates the key functional and aesthetic features. This prototype is intended to provide a solid foundation for further refinement and development towards a final, market-ready product.

Abstract

Background
Surfing has taken the world by storm in recent years and the estimated number of participants has nearly tripled from 13 to 37 million in less than ten years. Like all sports, surfing also carries a risk of injury, with the majority of these being head injuries. Furthermore, research has shown that more crowded surfing beaches result in a higher risk of injuries. Despite this, it is not common to wear a helmet for surfing, which is reflected in the few manufacturers and limited selection on the current market. However, this appears to be changing; competitions and multiple sources report a recent increase in helmet usage.

Objective
The primary aim of the master's project is to design a new helmet for surfing that meets safety requirements while satisfying surfers' functional and aesthetic needs. To succeed in this, I have chosen to particularly focus on achieving functional and aesthetic qualities in the product. The work will lay the foundation for possible further development and realization of the product.

Process
The process initially involved literature searches and research on injuries in surfing, head injuries in sports in general, and the effectiveness of helmets. Analyses of helmets on the market have been central to understanding important principles and material use. Surveys and interviews provided valuable user insights about attitudes and key focus areas. Furthermore, product testing and physical prototyping were essential for acquiring new knowledge and testing concepts. The collection of inspiration sources, sketching on paper and digital drawing tools, as well as 3D modelling, have been crucial in concept development and detailing.

Result
The project has resulted in a helmet design where optimal user experience and performance are at the forefront. The appearance is characterized by formal measures that contribute to and highlight the helmet's functional qualities. The helmet paves the way for a new category of helmets, where the snug fit of soft helmets is combined with the protection of a hard shell. With the innovative shock-absorbing material, the necessary flexibility is achieved, making the helmet feel like a part of the body while having optimal shock absorption in strong impacts as well as less forceful ones. In addition, the design of the core is crucial for performance and user experience; the design minimizes weight, maximizes drainage and ventilation, and ensures that the helmet reduces rotational forces on the head. Combined, this makes the helmet the most advanced in its segment.

Sammendrag

Bakgrunn
Surfing har tatt verden med storm de siste årene og det estimerte antallet deltakere har nesten tredoblet seg fra 13 til 37 millioner på under ti år. Som i alle idretter medfører også surfing en risiko for skader, og hovedandelen av disse hodeskader. I tillegg har forskning vist at mer folksomme surfestrender resulterer i høyere risiko for skader. På tross av dette er det ikke normalt å bruke hjelm til surfing, noe som reflekteres i at det er få produsenter og lite utvalg i dagens marked. Dette ser imidlertid ut til å være i endring; konkurranser og flere kilder rapporterer om en nylig økning i bruken av hjelm.

Mål
Hovedmålet med masterprosjektet er å designe en ny hjelm til surfing, som imøtekommer de sikkerhetsmessige kravene, samtidig som det tilfredsstiller surfernes funksjonelle og utseendemessige behov. For å lykkes med dette har jeg valgt å spesielt fokusere på å oppnå funksjonelle og estetiske kvaliteter i produktet. Arbeidet vil danne grunnlag for mulig videreføring og realisering av produktet.

Process
Prosessen har innledningsvis vært preget av litteratursøk og research om skader i surfing, hodeskader i sport generelt og hjelmers effektivitet. Analyser av hjelmer på markedet har stått sentralt for å forstå viktige prinsipper og materialbruk. Spørreundersøkelse og intervjuer har gitt verdifull brukerinnsikt om holdninger og sentrale fokusområder. Videre har produkttesting og fysisk prototyping essensielle for å tilegne ny kunnskap og teste konsepter. Samling av inspirasjonskilder, skissing på papir og digitale tegneverktøy, samt 3D modellering har stått sentralt i konseptutvikling og detaljering.

Resultat
Prosjektet har resultert i et hjelmdesign hvor optimal brukeropplevelse og ytelse er satt i sentrum. Utseende er preget av formmessige grep som bidrar til og fremhever hjelmens funksjonelle kvaliteter. Hjelmen baner vei for en ny kategori av hjelmer, der den tettsittende passformen til myke hjelmer forenes med beskyttelsen et hardt skall gir. Med det innovative støtdempende materialet oppnås den nødvendige fleksibiliteten som gjør at hjelmen føles som en del av kroppen samtidig som hjelmen har optimal støtabsorbsjon i kraftige støt så vel som mindre kraftige støt. I tillegg er utformingen av kjernen avgjørende for ytelsen og brukeropplevelsen; designet minimerer vekt, maksimerer drenering og ventilering, og gjør at hjelmen reduserer rotasjonskrefter på hodet. Kombinert gjør dette hjelmen til den mest avanserte i sitt segment.

Motivation

My motivation for designing a surf helmet stems from personal experiences, a recognized need within the market, and the recent increase in the use of surf helmets. It was also an opportunity to combine two of my passions, surfing and design. As an avid surfer with over 10 years of experience, I have witnessed the importance of protective gear first-hand and have encountered situations where a reliable surf helmet would have greatly enhanced safety.

Moreover, there has been a notable rise in surfers opting to use helmets for added protection in recent times. Surprisingly, the current market offers limited options, with existing helmets being underdeveloped and not meeting the specific requirements of surfers. This gap in the market, coupled with the growing demand for surf helmets, further motivates me to design a surf helmet that addresses these shortcomings, providing surfers with a high-quality, purpose-built protective headgear.

Content

1 Introduction

1.1 A Brief Introduction to Surfing

The history of surfing spans over thousands of years. It is believed to have originated in ancient Polynesia and prior to Western influence, it was a culturally significant and popular recreational activity that both chiefs and commoners in Hawaii participated in. During the late 19th century, religious missionaries discouraged the sport, and it nearly disappeared. The Hawaiian Olympic champion swimmer, Duke Kahanamoku, is widely credited with reintroducing the sport to California and Australia in the early 1920s, which sparked a resurgence in popularity (A. Nathanson et al., 2002). In the 1990s, the commercialisation of surfing apparel further contributed to the popularity of surfing and the surfing lifestyle.

Today, surfing is a thriving global activity with an estimated 37 million surfers globally (McArthur et al., 2020). Both leisure and competitive surfing have grown rapidly in the last decades, with the total number of participants almost tripling since 2002 (Furness et al., 2015). Surfing was included in the Olympic Games for the first time in the Tokyo 2020 Olympics, showing the recognition of surfing as a legitimate sport and exposing it to an even broader audience on the world stage. Additionally, the advent of commercial wave pools has revolutionised the surfing landscape, providing controlled environments where perfect waves can be generated. These wave pools have not only enhanced accessibility to surfing, but have also spurred the growth of new surfing communities and fostered the development of new talent.

PLATE 2

This old-time Hawaiian surfer, photographed some time in the late 19th century, is holding an *alaia* surfboard at Waikiki beach, Oahu. (Courtesty B.P. Bishop Museum.)

Types of Surfing

As surfing has evolved, it has given rise to various styles and disciplines, each offering unique challenges and thrills. Some popular approaches to riding waves include short-boarding, longboarding, bodyboarding, stand-up paddleboarding (SUP), foil surfing. The origins of shortboarding trace back to the 60´s in Australia, and it has since become the most popular form of surfing, both for recreational enjoyment and competitive endeavors. Shortboarding entails riding a lightweight, highly manoeuvrable surfboard typically measuring between 5 to 7 feet. It allows for quick turns, tube rides, and aerial manoeuvres. In contrast, longboarding pays homage to the ancient roots of surfing, embodying the laid-back essence commonly associated with the sport. Utilising longer, heavier boards (typically 9 feet and longer), longboarders relish in a more relaxed ride, often embracing smaller, mellower waves. Meanwhile, bodyboarding involves riding smaller foam boards while lying on the stomach and SUP involves using large buoyant boards and a paddle, enabling riders to navigate the waves while standing. Riding bigger waves is a natural part of the evolution for individual surfers as they get better, but has also been part of the sports evolution with big wave "Paddle-in" surfing and "Tow-in" surfing (getting pulled into a wave by jetski). For the purpose of this thesis, the focus will be on stand-up surfing as the defined form of the sport.

Typology of Surf Breaks

Surf breaks vary greatly in terms of the type of waves they offer and by nature the type of surfing it attracts. The types of breaks can generally be divided into four categories: beach breaks, point breaks, reef breaks and artificial waves. Beach breaks have waves that break over a sandy ocean floor, point breaks on the other hand break along a more fixed point (rocky point or headland) and in reef breaks the waves break over a coral or rock reef. Moreover there are currently 19 commercially open wave pools, specifically designed for making perfect waves for surfing. Within these types of breaks, there is a great variation of waves. Every type of break can offer large powerful waves, shallow breaking tubular waves or soft waves for beginners. It all depends on the bathymetry of each spot and the size and direction of the swell and the wind. However, in general, beach breaks are a safer option for beginners, as there are no hard or sharp objects to collide with. Reef breaks on the other hand tend to offer more brutal waves than beach breaks and point breaks, and can have sharp rocks or corrals.

Photo: World Surf League.
A surfer enjoying a reef break tube, the ultimate feeling and goal to surfers

Surfer Equipment

Depending on type of waves, skills, preferences and environment, surfers use a variation of different equipment. To get a sense of the different clothing that is used, these are some typical choices depending on temperature.

Tropical (24-30 degrees): Boardshorts/bikini with optional additional sun and rash protection through t-shirts or rashguards, caps and hats.

Temperate (20-24 degrees): Steamer (short wetsuit)/2 mm wetsuit

Cool (16-20 degrees): 3/2 wetsuit

Cold (12-14 degrees): 4/3 wetsuit with boots and gloves

Freezing (Sub 12 degrees): 6/5 mm wetsuit with hood, boots and gloves.

The most typical form of surfboards are short boards with three fins. The board is made of a foam core (EPS or PU) and fibreglass/carbon composite. The fins are usually also made of similar composite constructions. The leash connects the surfer to the surfboard, hindering accidents from loose boards and connecting the surfers to a source of floatation in emergency.

1.2 The use of Helmets in Surfing

Even though surf helmets have been around since the late 80s, their usage has not become a standard among surfers as it is in many other action sports. Existing research on the use of protective gear in surfing is sparse, with only a few studies reporting occasional helmet use of 1% in Norway (Ulkestad & Drogset, 2016) and regular use of 1.9% with an occasional usage of 10.2% in Australia (Taylor et al., 2005). However, recently, there's been a noticeable increase in helmet use, largely associated with the notorious surfing spots - Banzai Pipeline in Oahu, Hawaii, and Teahupoo in Tahiti. Both locations are renowned for their massive, perfect barreling waves that are as deadly as they are beautiful. Multiple fatalities and serious brain injuries have occurred, leading to increased helmet use at these spots. The New York Times has reported on this surge (Rogers & Hobro, 2021), with local sources like the Pick Up Podcast echoing the trend, noting, "Gaths are back in a big way," and, "This Hawaiian winter we have seen more helmets than ever before" (The Pick Pp, 2021). Furthermore, the World Surf League has started providing optional helmets for the athletes competing at Pipeline as well as implementing their own concussion protocol, signalling a shift in professional surfing towards safety. Though helmet use in surfing remains minimal globally, the growing acceptance in key surf communities like Hawaii could potentially inspire a broader uptake of surf helmets in other areas.

Sally Firzgibbons, currently ranked number 12 on the World Tour, commented the differences between the helmet acceptance in Hawaii and Australia;

"It's actually not as supported really wearing helmets back in Oz, I feel like there's still a bit of that reluctant cool factor," "But over here (in Hawaii) in particular, all the layers from the young kids to the women to even the top, top guys and the Jamie O'Briens (Pipeline masters winner and surfing legend) of the world, it's really supported" (Greenwood, 2023).

Photo: Brent Bielmann/World Surf League

1.3 Previous experience using a surf helmet

In the autumn before officially starting the master thesis, I bought a Gath Neo surf helmet, which is known as the original surf helmet and still one of the most popular in the market. I tested the helmet on multiple occasions, first on the west coast of Norway and then in Portugal, with the goal of learning as much as possible from the experiences (in terms of product functionality).

The helmet was tested on the bare head, with a 3 mm wetsuit hood and with a 6 mm wetsuit hood. The helmet in size XL is stated to fit heads with circumference of 59-60 cm, my head being 59 cm. Lacking adjustability, the helmet was a bit loose on my bare head, snug fitting with a 3 mm hood and uncomfortably tight with a 6 mm hood. Consequently, the different configurations and resulting fit scenarios came with quite different user experiences which is described in the next paragraphs.

Bare head
For the most part the helmet feels good, however I experienced the uncomfortable bucket effect a couple of times. This can be explained as the moving turbulent water from a wave flowing in between the head and the helmet, resulting in a pulling force to the head. The lack of soft material between the ear and plastic parts in the ear section of the helmet made it slightly painful to wear the helmet over time.

3 mm Hood
This was the sweetspot in terms of fit for me personally. It felt like the helmet was moving less in the water and I did not experience bucketing. Overall more comfortable.

6 mm Hood
This configuration made the helmet fit uncomfortably tight. It resulted in feeling more encapsulated through the pressure to the head and the significant loss of hearing. The combination of the thick hood and the pressuring fit also resulted in making my head uncomfortably warm.

Other experiences
The helmet provided a strong sense of protection, especially in situations that occur quite frequently where surfers on a wave end up getting close to my head (e.g. ducking under a wave while someone surfs over you). In fact, I even experienced getting hit by another surfer’s board while duck-diving under a wave. The impact didn’t feel too hard, but it served as a solid confirmation that wearing a helmet can be a wise decision.

Photo of me testing the Gath Neo in Supertubos, Portugal

1.4 Description of the Process

Through the project, a variety of design and research methods have been used. By studying scientific literature, I have gained a solid theoretical foundation. In the beginning of the project I focused on understanding the extent and nature of surfing injuries as well as research about helmets and their role in head injury prevention. Later in the project it has been used as a tool to dig deeper into specific helmet technologies and materials that could potentially reduce the risk of injuries in surfing.

To gain firsthand insights into surfers' perspectives on helmets, I initiated a survey exploring their attitudes towards helmet usage, experiences, key considerations, and areas for improvement. The survey responses offered valuable data that informed my design process. Complementing this, I conducted semi-structured interviews with several surfers to delve deeper into similar themes and uncover more nuanced perspectives. Additionally, an enlightening interview was carried out with a specialist from an independent helmet testing facility. This conversation provided invaluable insights into the variances in helmet types and their performance, crucially shaping my understanding and approach towards helmet design in surfing.

To get familiar with the nuances of helmet design, I conducted a market research. Through analysing a range of helmets through physical examination and desk research, I got a better understanding of key aspects, such as fit, materials, ventilation, and emerging technologies and identified potential design opportunities

Product testing and physical prototyping played a key role in investigating functional aspects and establishing the main direction for the concept. There was a focused effort to save time and resources by utilising existing products for testing and prototyping, and adopting an appropriate fidelity level to not get fixated towards an idea too early.

Sketching was used as a tool to manifest ideas that emerged during the project and to actively generate ideas through visual thinking with the pen. In other words, it was actively used throughout the project. 3D modelling became essential during the detailing work. A technique that was frequently used during concept development involved drawing changes onto images of the 3D model using the digital drawing tool Procreate on an iPad. This approach made it easier and faster to explore alternative directions.

2 Theory

2.1 Injuries in Surfing

All sports come with some risk for injury, and surfing is no exception (McArthur et al., 2020). There are many ways of reducing risks, however sports protection gear, including helmets, continue to serve as the most effective active protection. Sports helmets are designed to meet the safety requirements and the user needs related to different activities. In order to get a better understanding of the specific hazards in surfing, I studied scientific literature on the topic of surfing injuries and the mechanics behind.

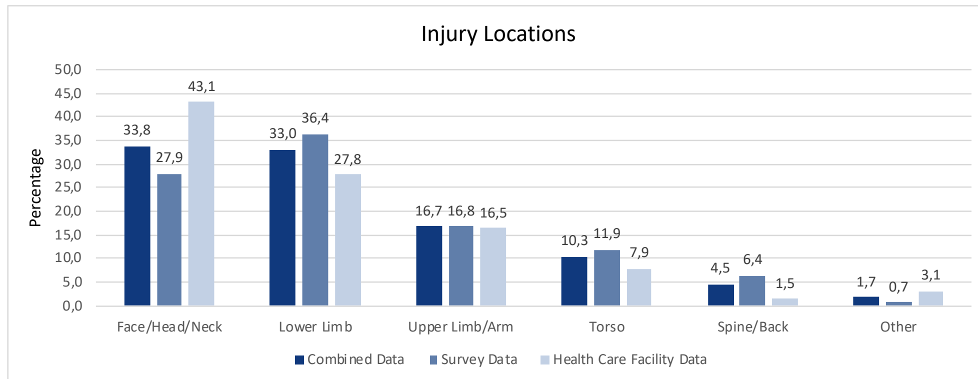
Rate of acute injuries

In a literature review McArthur et al. reviewed 19 surf injury studies, where nine studies were found reporting incidence rates between 0,74 to 13 injuries per 1000 hours of surfing (McArthur et al., 2020). Studies grouping both competitive and recreational surfers had similar incidence rates, ranging from 0.74 to 1.79 injuries per 1000 hours of surfing. These studies were retrospective, using data from either questionnaires or online surveys. For professional surfing, a greater variation was found with incidence rates varying from 0.3 to 13 per 1000 hours. A. Nathanson et al. collected injuries that were recorded by medical personnel at 32 professional and amateur competitions between 1999 and 2005 (A. Nathanson et al., 2007). They found incidence rate to be 13 per 1000 hours of surfing, and 6.6 significant injuries per 1000 hours, where significant injuries were defined as requiring medical care or forced break from surfing. In a post-hoc analysis of the same data Nathanson found a statistically higher injury rate at the four competitions held at Oahu´s Pipeline, with 32 injuries per 1000 hours (A. Nathanson, 2020). In a survey with 1348 Australian surfers, Furness et al. discovered that there were 1.8 “major” injuries (defined as injuries leading to missed days from surfing or work, or injuries requiring medical attention) for every 1,000 hours of surfing (Furness et al., 2015). Additionally, they found that within the preceding year, 38% of the surveyed surfers had sustained a major injury (35% for recreational and 42% for competitive). While some of the studies found low incidence rates, the studies show that the risk of surfing varies greatly, depending on factors such as skill and surf spots.

Nathanson found evidence on the correlation between wave size and injury, with 56% of acute injuries occurring in waves higher than head-high (the typical height of a man) (A. Nathanson et al., 2002). Self rated experts and surfers more than 40 years old were almost twice as likely to get injured severely. The risk of significant injury was also more than doubled (2.4) when surfing head-high or larger waves and waves breaking on reefs and rocks (2.6) (A. Nathanson et al., 2007). These findings indicate that experienced surfers are at a higher risk of severe injuries and prove that the risk varies greatly depending on type and size of wave.

Types and location of acute injuries

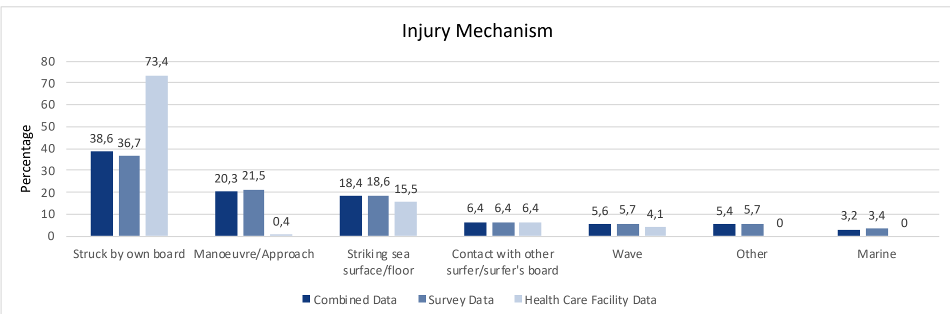
McArthur et al. combined injury data from 19 previous studies (McArthur et al., 2020). They found skin injuries to account for 46%, soft tissue 22,6%, bone 9,6, joint 6,9, concussion 2,3. The body region to be most commonly injured was face, head and neck, accounting for 33.8%, closely followed by lower limb which accounted for 33%. 16.7% were injuries to upper limbs, 10.3% were injuries to the torso, 4.5% to the spine and 1.7% were defined as other. When looking at data from health care facilities, injuries to the head accounted for 43.1% while injuries to the lower limbs accounted for 27.8%. The difference might point towards head injuries either being more serious or being perceived as more serious than lower limb injuries.



Mechanisms of acute injuries

McArthur found being struck by their own board as the most normal mechanism of injury with 38.7% (McArthur et al., 2020). Manoeuvres caused 20.3%, striking the sea surface or sea floor 18.4% and contact with other surfers or their surfboard caused 6.4% of the injuries.The percentage varied greatly between survey data and health care facility (HCF) data for some of the categories; struck by own board caused 36.7% and 73.4% respectively while manoeuvre caused 21.5% and 0.4% respectively. These results indicate that the severity of the injuries caused by being struck by their own board were more serious or acute than the injuries caused by manoeuvres. Introduction of surfboard leashes have been reported as contributing to surfers being struck more by their own board (Dimmick et al., 2013), however it also reduces the likelihood of getting struck by someone else's board as well as providing access to floatation.

A. Nathanson et al. studied the reasons causing the accident, in greater detail (A. Nathanson et al., 2007). One specifically interesting finding was that 16% of all injuries were associated with unsuccessful tube riding. Getting tubed (surfing inside a tubular wave) is described as the ultimate feeling by most experienced surfers. Because these types of waves only happen with certain conditions (wave size, wind direction, bathymetry) most surfers don't surf barrels often. This finding indicates the increased risk of surfing barreling waves, while it is not possible to quantify.



External auditory exostoses (EAE), also known as Surfer's ear, are hyperostotic bone outgrowths in the external auditory ear canal (House & Wilkinson, 2008). The condition is typical for surfers, with prevalence rates ranging from 70-80% (House & Wilkinson, 2008) and the condition worsen with more time in the ocean (Chaplin & Stewart, 1998). Cold water is widely accepted as an important factor, as cold water surfers have been reported to be six times more exposed than surfers in warmer waters (Kroon et al., 2002). However, in a study from the Gold Coast in Australia, where water temperature stays above 19 degrees, a prevalence rate of 70.8% was found, indicating that incidents of surfers' ears in warmer climates might be more typical than earlier thought (Simas et al., 2021). Moreover, wind exposure seems to influence the development and progression of EAE, as it increases the evaporative cooling effect (Fabiani et al., 2010; Wegener et al., 2022). Fabiani et al. found the highest prevalence of EAE among sailors when comparing different water sports and Wegener et al. found the condition to develop quicker among kiters and windsurfers compared to surfers, both indicating the increased effect from the wind. This has further been indicated as studies report unilateral condition, which has been explained as a likely effect of prevailing winds hitting mainly one of the ears as surfers look to the horizon waiting for waves (Hurst et al., 2004; King et al., 2010; Umeda et al., 1989).

Surfer´s ear can be asymptomatic in its early stages, however with sufficient obstruction it can cause water trapping in the ear and recurring ear infections (Surfer's Ear | UCI Health, n.d.). Eventually if left untreated, severe EAE can cause a complete blockage of the ear canal, resulting in significant loss of hearing (more than 90% blocking) (UCI Health) or tinnitus (Common Surfer's Ear Questions | SurfEars, 2019) (Surfears.com). If conservative treatment is not satisfactory, the only real treatment is to surgically remove the outgrowths (Surfer's Ear | UCI Health, n.d.). However it has been reported that the exostosis seems to grow back quicker than when the condition was first developed (Chaplin & Stewart, 1998).

Because there is a lack of treatment options and due to the returning of the condition, early detection and prevention of progression are critical (Landefeld et al., 2023). Other than reducing exposure, this includes wearing earplugs and/or wetsuit hoods to reduce the exposure of the auditory canal (Landefeld et al., 2023; Ulkestad & Drogset, 2016). These preventive measures also provide protection from more acute ear injuries, such as tympanic membrane rupture. While there has not been found any literature on the effect of other types of ear protection, such as helmets covering the ears, it seems likely that headgear covering the ears can help to prevent EAE by reducing the cooling effects of the wind.

2.2 Do Surfers Need Helmets?

The literature studying injury rates in surfing have found rates varying greatly. While many The literature studying injury rates in surfing have found rates varying greatly. While many studies report that surfing generally is safe due to low incident rates, others have recommended the use of head protection due to the large portion of head injuries (Minasian & Hope, 2022; A. Nathanson et al., 2002, 2007; Ulkestad & Drogset, 2016). It is also noteworthy that the most severe injuries reported in several studies were head and spine injuries (Lowdon et al., 1983; A. Nathanson et al., 2002; A. T. Nathanson, 2013; Steinman et al., 2000; Taylor et al., 2004; Ulkestad & Drogset, 2016). Even though traumatic brain injuries are rare in surfing, milder head injuries that can cause loss of consciousness are especially dangerous because of the obvious added threat of drowning (Ulkestad & Drogset, 2016). Moreover, the large variations in reported rates have made researchers question how riskful surfing really is (McArthur et al., 2020).

When comparing the rate of recreational surf incidents to other sports, surfing can be conceived as relatively safe. Kitesurfing has been reported to have a risk of 7-10.5 injuries per 1000 hours (Nickel et al., 2004; C. J. van Bergen et al., 2020). Whitewater kayaking 3.6-5.9 per 1000 days (Fiore, 2003). Winter sports like skiing and snowboarding have been reported to have injury rates of 1.2 and 4 injuries per skier days respectively (Rønning et al., 2000). We can see that the reported incidence rates for recreational surfing places surfing risk of injury in the lower end. However, for professionals and more experienced surfers, the injury rate is in the same range as kiting and potentially much higher in tubular shallow waves over reefs specifically (Pipeline IR = 32/1000 hours). These conditions have been highlighted as the most critical and helmet use is generally recommended (A. T. Nathanson, 2013).

While skiing also started as a sport without protective equipment, the proportion of skiers in recent years have been reported to be more than 80% and widespread use of helmets has led to a decrease in head injuries (Davey et al., 2018). Most whitewater kayakers are also reported to use helmets (Spittler et al., 2020), and studies have found between 4-28% using helmets in kitesurfing (Nickel et al., 2004; C. J. van Bergen et al., 2020; C. J. A. van Bergen et al., 2016). Surfing differs from other water action sports in the sense that you spend more time submerged in highly turbulent waters. While wakeboarders and kiters glide on top of the water unless they fall, ducking waves and jumping off the surfboard is a natural part of surfing. In that sense, current helmets are likely less obstructive in other water sports than in surfing.

In conclusion, it is evident that helmets hold significant relevance in the realm of surfing. They are particularly crucial when surfing shallow, tubular waves, as tuberiding has been identified as causing a disproportionately high number of injuries.The associated risk of injury when surfing such waves has also been found to be considerably higher, further emphasising the importance of helmet usage.

2.3 The Role of Helmets in Preventing Head Injuries

While there is no current research that has studied the effect of helmets for surfing, While there is no current research that has studied the effect of helmets for surfing, evidence continues to confirm the significant role of helmets in protecting against lethal brain injuries, severe traumatic brain injuries (TBI), skull fractures, and traumatic intracranial haemorrhage (Sone et al., 2017). However, helmet effectiveness against concussions, a less severe form of TBI, may be more limited. These injuries typically result from more low-energy impacts and rotational accelerations that cause more diffuse impact loading across the brain, damaging the brain's microscopic structures. They are also less understood and more difficult to diagnose. In contrast, severe TBIs generally result from high-energy forces causing localised injuries, such as penetrating TBI and depressed skull fractures or from distributed impacts resulting in visible brain lesions and inflammation.

Even though concussions often are categorised as mild traumatic brain injuries (MTBI) because they are usually not life threatening, they can still have severe consequences that can last over time (What Is a Concussion?, 2023). Individuals who have previously sustained a concussion are also at a higher risk of enduring subsequent concussions. Furthermore, a persistent history of concussions leads to an increased risk of developing neurodegenerative disorders such as chronic traumatic encephalopathy (CTE) and dementia (Sone et al., 2017).

Simulation studies have shown that helmets reduce the chance of concussion (Fahlstedt et al., 2016) and impact studies have shown that helmets reduce linear and rotational accelerations, both linked to concussions (Hoshizaki et al., 2014; McIntosh et al., 2013). There has also been found significant evidence that helmets can reduce the chance of losing consciousness, a symptom of more severe concussion (Greve et al., 2009; Thomas et al., 1994). Thomas et al. reported a reduction by as much as 86% (62% to 95%) of losing consciousness in children with bicycle helmets vs children without a helmet. In a study comparing two helmets in American Football, Rowson et al. found a significant difference in the number of concussions between the models, which indicates that protection can make a difference in reducing concussions (Rowson et al., 2014). However, the concussion incidence rate in sports, despite high rates of helmet use, does not reflect these results as there has been an increase in sports related concussions in recent times (Hoshizaki et al., 2014; Sone et al., 2017). Consequently, helmets and helmet standards have been deemed ineffective in protecting against concussions. However, the rise in awareness and better diagnostics has also been highlighted as a possible part of the reason for the increased incidents. As a response to the rising incidences of concussions, there have been multiple technological innovations aiming to increase effectiveness of helmets against concussions, specifically by decreasing rotational accelerations to the head and bettering impact attenuation of lower energy impacts (Abayazid et al., 2021).

2.4 Whitewater Helmet Standard

There is no helmet safety standard specific to surfing, although the European standard EN 1385:2012 specifies safety requirements for kayak and whitewater sports. Whitewater sports in this context is defined as “non-powered sporting activities carried out in and/or on moving water as defined by classes 1 to 4 (out of 6) in accordance with Clause 4” (EN 1385, n.d., p. 7). The classes explain different levels of rivers with increasing difficulty and risk and the specific injury mechanisms typical for kayaking, capsizing, and hitting head-on rock. It also highlights that the maximum recorded river flow speed is 18 km/and that the benchmark impact energy level is derived from this. Furthermore, it is stated that fatalities in whitewater sports are generally attributed to drowning following a head injury rather than as a direct result of traumatic brain injuries. Consequently, the whitewater helmet’s primary role is stated to be to mitigate the risk of concussion that can lead to loss of consciousness. The statement, “The levels of protection recognize that most fatalities in canoeing and white water sports result from drowning after concussion and not from brain damage” reflects this (EN 1385, n.d., p. 1). In this context, a helmet is defined as a piece of “headwear that is intended to protect the wearer’s head from concussion” (EN 1385, n.d., p. 5). Despite the focus on river kayaking and the difference between rivers and the ocean, most water sports helmets are certified according to this standard. Key focus areas and requirements are summarised below.

1. Field of vision
the helmet must not interfere with the field of vision

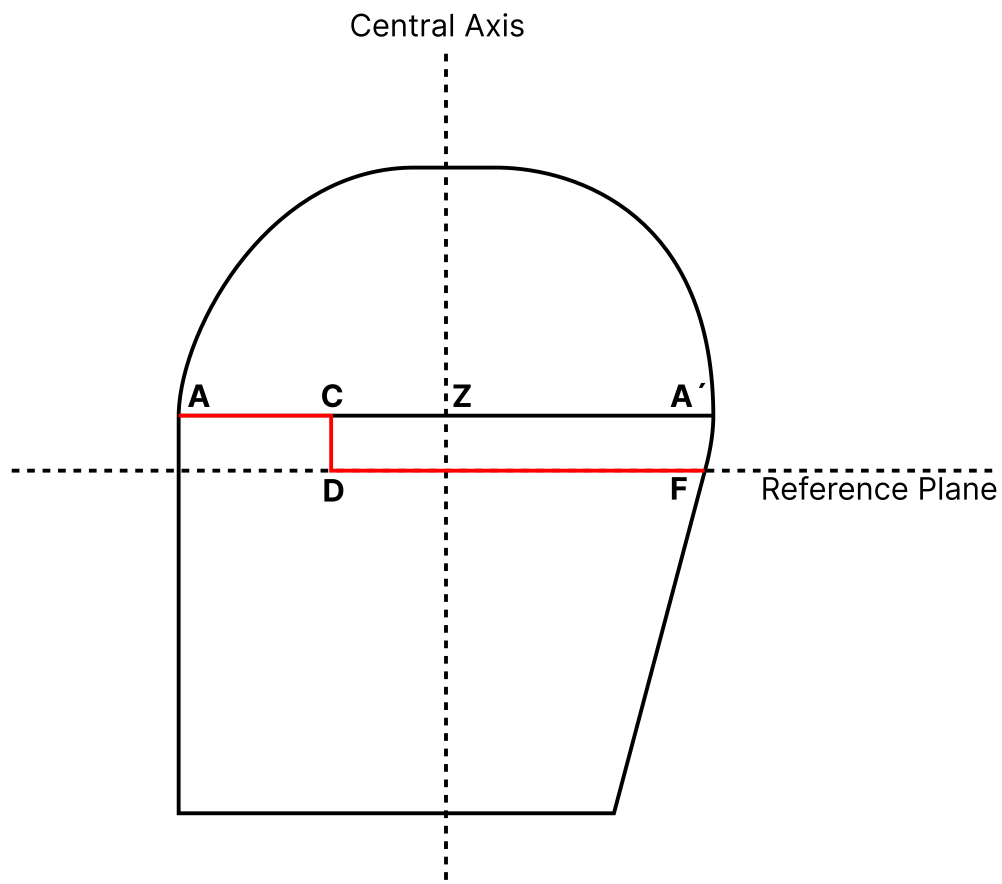
2. Extent of coverage
Necessary parts of the head must be covered (figure)

3. Shock absorption
The helmet is attached to a metal head of 4 kg and is dropped from a height that gives a speed of 2.5 m/s (15 J impact). Its tested foor the following conditions: high temperature (35°C), low temperature (0°C), after artificial aging and after the helmet has been submerged for 4 hours. Peak acceleration cannot exceed 250 g

4. Retention system performance
Checks whether the helmet is held in place.

4. Buoyancy
must float after being submerged in water for 4 hours.

6. Durability
The helmet must not show damage after the tests that could cause further damage to the user.



Should Surf helmets meet the 1385 standard?

Among the watersports helmets on the market, most are certified according to the standard. However when looking at surf helmets, only a couple of the helmets from Gath are certified, and both the Simba Sentinel or Soft Surf Helmet are not certified. The two models from Gath, the Gedi and the SFC, are the only one out of their line that are certified. While Gath writes that the SFC have risen in popularity among surfers, most surfers seem to choose the NEO or the EVA models. The Gedi however is rarely seen among surfers.

Because the standard is so closely designed for river kayaking it's not certain that its well formulated for other watersports, such as surfing. When compared to other action sports such as skiing and snowboarding, the EN:1385 has lower impact speeds (2.5 m/s compared to 5 m/s) and no requirement for protection against penetrating objects. If we compare to sports like rugby on the other hand, the impact levels are more similar (speed vs speed).

Meanwhile there currently is no existing scientific literature on the exact forces involved in surf accidents, we can only approximate. Breaking waves have the following relationship between wave speed and height; 16 km/h (1.4 m), 29 km/h (4.5 m), 56 km/h (18 m) (Sandwell, n.d.). Moreover the actual moving speed of the surfers have been measured with GPS watches, showing that they can reach velocities of almost 40 km/h on a shortboard and an estimated 80 km/h in big wave surfing (How Fast Do Surfers Go at Jaws?, 2018; Top Surfers Check Speed and Distance in a Wave, n.d.). From a different perspective if a surfer is going over the falls on a wave, the falling speed can be approximated (assuming free fall) to 23 km/h (2 m), 32 km/h (4 m), 39 km/t (6 m). Surfers generally use helmets in extreme situations, where waves are larger, speed is higher and water is shallower. These factors paint a picture that a helmet for surfers should at least comply with the Kayak and Whitewater sports standard, which is based on impact speeds generally under 18 km/h. This is reflected by the following statement from the EN:1385: "This European Standard is not intended to apply to helmets for use in extreme white water situations such as those where the jumping of high waterfalls is undertaken, because the need for impact absorption for such a helmet, and the area of the head to be protected, are greater than those for most canoeing and white water sports.". Similarly Gath Sports state "Paddle sports which may require a high level of impact protection should choose an EN 1385 accredited model." ('FAQ | Gath', n.d.).

Photo: Ella Boyd

3 Market and User Research

3.1 Analysis of Surf Helmets

There are a number of watersports helmets on the market, however, only a few that are designed specifically for surfing. To increase my understanding of surf helmets, an analysis of the helmets on the market was carried out. The collecting of relevant helmets was done through desk research and based on my previous experience.

The market has been dominated by one producer for many years, namely Gath Sports. Gath created their first surf helmet, the Gath Neo, in 1989. Since then, the producer has developed a wider portfolio of helmets, consisting of four helmets. However, the Neo continues to be the most popular. An example of the Gath Neo was acquired and studied physically, while other surf helmets were studied based solely on online material due to their unavailability in Norwegian shops.

Gath Neo

First impressions
The pulled back shell design and neoprene headband stands out, giving it a unique and characteristic silhouette. It also has a retro look, reminiscent of other older sports helmets (ski jumps etc). This can be due to the thin look in combination with the outline, as well as the lack of complexity in the surface that is often seen in more modern helmets (dated production).

Coverage
Hard shell covering most of the head, excluding the forehead, face and neck. Some coverage of the jaw.

Vents
10 small vents (not direct), Adjustable ear vents for hearing

Adjustability and sizes
No

Construction
2 mm hard shell with 6 mm soft mulit-impact closed cell foam

Ear pads
Rigid

Draining
Thicker band around edge keeps water away from face, ‘Gaps in the band in the neck and below ears lets water out

Gath EVA

First impressions
Almost same as NEO (slightly updated), but the EVA headband gives a more protective look

Coverage
Covering head and some jaw protection

Vents
10 small direct vents, adjustable ear vents for hearing

Adjustability and Sizes
Simple detachable soft foam fitstrip that is adhered with glue in a grove in liner

Construction
2 mm hard shell with 6 mm soft mulit-impact closed cell foam liner

Ear pads
Rigid

Draining
Less emphasis on draining than the original Gath NEO. Small channels from vents to the back, one small draining channel in the middle of the back. Fitstrip blocks the draining channel unless modified by the user.

GATH SFC

First impressions
Similar to the EVA, but with an updated shell outline and detachable ear covers. The silhouette is less precise in its shape than the NEO and EVA, bringing a surprisingly round form language.

Coverage
Hard shell covering head and some jaw protection

Vents
10 small direct vents, Adjustable ear vents for hearing

Adjustability and Sizes
Detachable fitstrips (comes with two sizes: mm?)

Construction
Hard shell with soft mulit-impact foam closed cell foam

Ear pads
Detachable, same adjustable hearing vents

Draining
Same internal foam shape as the EVA, with less emphasis on draining than the original Gath NEO. Small channels from vents to the back, one small draining channel in the middle of the back. Fitstrip blocks the draining channel unless modified by the user.

Simba

First impressions
The sentinel is a newcomer in the market, launched in 2020. It is inspired by Ancient Roman helmets, which distinguishes it from other sports helmets, but also gives cosplay accosiations. It has more extensive face coverage, with a low forehead edge and cheek and jaw protection. Looks thin and sharp on the edges close to the face, and jaw protector seems likely to grab the water.

Coverage
Hard shell covering head, jaw and cheeks.

Vents
6 slits offering direct ventilation

Adjustability and Sizes
Two piece (front and back) fitstrip system with foam strips in two sizes

Construction
ABS shell with EVA liner

Ear pads
Rigid, 3 slits for hearing

Draining
Channels on the inside guide water to the back

DMC Soft Surf Helmet

First impressions
Also a newcomer in the market. Looks like a rugby scrum cap, slightly modified with brim in the front and a neck sun protector. Looks comfortable to use and close fitting. Seemingly little thought to padding pattern gives it an unprofessional and cheap look.

Impact coverage
Soft Foam Pads distributed across the head and upper jaw.

Vents
Four openings at the top offer direct ventilation

Adjustability and Sizes
Comes in four sizes and with shoe lace adjustment in the back

Construction
NBR (Nitrile Butadiene Rubber) foam, encased in nylon elastane

Ear pads
Not detachable. Small holes from hearing.

Draining
No channels guiding water

3.2 Mapping of sports helmets on the market

To widen my understanding of current helmets further, I studied helmets designed for other purposes (other sports and military). This was especially important given that the competition in the surf helmet market is relatively low and as a result the products are under developed compared to other segments. By analysing products from more competitive segments, the chance of missing fruitful design opportunities was reduced.

This research was started by visiting a couple of sporting goods stores and analysing some of their helmets. I went to two different general sports goods stores, one snowboard store and two watersports specialists. The watersports stores had a range of different whitewater helmets, however they did not have any of the surf specific helmets. Studying the helmets physically allowed getting a closer look at details and mechanisms, the feel of different constructions and the tactility of the different materials. Additionally it made it possible to take measurements of the helmets and compare fit and comfort by trying on the helmets. Some initial findigs are highlighted in the follwing paragraphs.

Fit
The inside shape, and consequently the fit of the helmets vary by brand. It shows that producers might choose specific head shapes to target users, or that some are better at producing well fitting helmets.

Adjustment
Both categories varied in terms of features included. Most skiing helmets came with a dial type adjustment system in the back, and possibility to change comfort liner. Some whitewater helmets also had dial adjustment but, but most did not. Only one whitewater helmet offered both an adjustment system and interchangeable comfort pads. One whitewater helmet differed a lot from the rest with a design where the whole helmet construction is adjustable.

Different construction and materials
Watersports helmets typically are made with different materials than skiing helmets. All the hard shell whitewater helmets I found, except Forward Wip, used EVA or similar foam in their helmets, while all skiing helmets used EPS, EPP or a combination. Skiing helmets offer premium composite shell models, while whitewater all have hard plastic and some even replicate carbon fibre with print. The thickness of the core material also differs between the categories. The skiing helmets were quite similar in liner thickness, most being between 2-3 cm at the front and back head, with slightly thinner sides and lower back. The whitewater helmet varied more in liner thickness. I measured helmets with 1 cm, 1.5 cm, 2.5 cm. Most whitewater helmets had unison liner thickness.

Surfacing
Surface details and complexity of bicycle helmets especially, but also skiing helmets are

more advanced than whitewater helmets. While skiing and bicycle helmets use form to distinguish themselves from competition, multiple brands produce whitewater helmets from the same shell design.

Ventilation
There were ski helmets with both fixed and adjustable ventilation. This was not observed in the whitewater helmets.

New technology
Ski helmets were observed to incorporate new technology more than the whitewater helmets. Most ski helmets had a MIPS system incorporated, each designed to fit the specific helmet. None of the whitewater helmets had this or any similar technology.

3.3 Helmet Materials and Technologies

During the market research, some typical constructions and materials were observed. In the following paragraphs, the materials that the shell and core are made of will be explained.

Shell Materials

The shell provides protection against sharp objects that could penetrate the head, in addition to distributing the impact over a larger area. By studying a wide range of helmets on the market, some materials stand out.

In hard shell helmets, ABS is the most popular shell material due to its strength and durability. More premium options have been found with more advanced materials, including resin and fibre based composites and fibre reinforced ABS. Of the resin based, carbon fibre and aramid fibres like Kevlar have been found used separately or in a sandwich construction. ABS have been found reinforced with carbon fibre. For in-mould helmets, polycarbonate is the most typical material used, and in some snow sports helmets, it is combined with an aramid fibre for better structural strength and penetration protection.

Shock Absorbing Materials

EPS (expanded polystyrene) is the most widespread shock-absorbing material in hard-shell and in-mould single-impact helmets. The material is lightweight and absorbs the forces through the cells in the structure being pressed together and crushed. Through this, the material slows down the acceleration of the head. Because the material shatters, helmets made from EPS are only designed to handle one heavy impact. This means that the helmet must be replaced if it has been through a significant impact, and also for safety's sake after normal use after a couple of years.

EPP (Expanded polypropylene) is another typically used material that is similar to EPS, however it has a more rubbery feeling. The material is typically used in helmets for multi-impact scenarios, such as for use cases where small bumps can be normal. An example is slalom helmets, where the skiers hit the gates with their head. These helmets usually have EPP in the front and back or EPP entirely in order to sustain these repeated blows without impairing the performance of the helmet.

A type of material that has shown great potential for increasing the performance of helmets is non-newtonian materials. These materials are unique in that they are soft at rest, but stiffen when impacted. This gives a great potential for creating great fit, as well as that the material can attenuate both low energy and high energy impacts, as the molecules react when impacted. There are currently a few helmets on the market

that use these kinds of materials as the shock absorbing liner, CCM (Ice Hockey) and Gamebreaker (Rugby) use D3O in their helmet liner, and Second skull (Flag Football) and Zenith (American Football) use their own developed non-newtonian materials. These materials are also typical in other types of protection gear, such as knee pads, back protectors and body armours for sports.

Rotation Mitigating Technologies

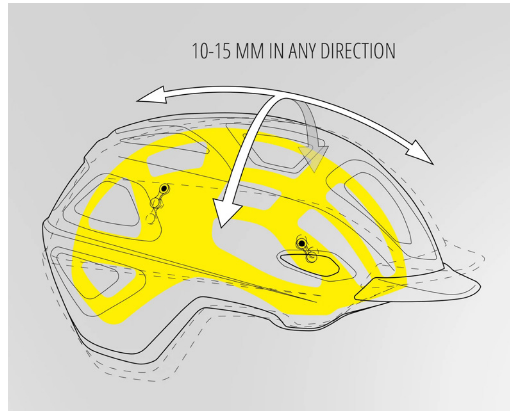
Several innovative technologies exist today that aim to mitigate the impact of rotational accelerations on the head during collisions or falls. These are designed in different ways, but all have the goal of letting the helmet rotate slightly independent of the head in an oblique impact. By studying a wide range of helmets, two main strategies have been found.

Slip Layer
One of the most prevalent rotation mitigation technologies is MIPS (Multi-directional Impact Protection System), which involves a thin, movable plastic layer inside the helmet that can slide in all directions on the smooth surface of the EPS or EPP core during an impact, reducing the rotational motion transferred to the brain. A competitor is Bontragers WaveCell technology, wavy cellular structure crushes and slides along the helmet core. While MIPS easily integrates in an unobtrusive way, WaveCell covers the entire inside of the helmet, making the helmet look less holistically designed.

Shearing Pads
Poc's SPIN (Shearing Pad INside) technology uses silicone pads that can "roll" or shear in any direction. These pads mimic regular comfort pads, and are therefore easily integrated.

Integrated in structure
A variety of modern helmets use the helmet structure itself to reduce rotational forces. Examples are Atomics AMID (Atomic Multi-directional Impact Deflector), Flexible structures seen in Xenith and Vicis helmets. By incorporating the technology

Each of these technologies showcases the progress being made in helmet design to protect against the harmful effects of rotational accelerations on the brain.



Mips

WaveCell

Atomic AMID

Schutt Helmet With Rheon Padding

3.4 Adjustment Mechanisms and Sizes

Sizes

There are many helmets equipped with sophisticated design solutions currently available on the market. These helmets are designed to fit a wide range of people, and therefore various head sizes and shapes. A preliminary investigation was conducted to determine the range of sizes provided by helmet manufacturers and the corresponding spectrum of head sizes these are expected to accommodate. These were thought to serve as guide-lines in terms of what variations it can be expected that a helmet should accommodate. The sized varied from different producers and due to the adjustment mechanims used. Most helmets had sizes covering head circumference variations of 3-4 cm, while some had up to six.

Turn Dial Adjustment System

The most common mechanism for adjusting helmet fit is the use through a band, usually in plastic, that can be tightened around the head. There are several variations, some are adjusted by turning a turn dial while others are adjusted by a pinch grip. However, they all rely on the same principle; a plastic or textile band wrapping around the back half of the head can be tightened for a better helmet fit. The band can often rotate around the helmet's midpoint, near the temples, allowing it to be adjusted for the best fit on the wearer's head.

Advantages
The biggest advantage of the band adjustment system is ease of use. It offers Immediate adjustment and seamless adjustment.

Disadvantages
Because the length of the band is the only adjustable part, it results in a gap between the helmet's padding and the wearer's back head.

Fit Pads

Helmets often employ replaceable liner pads of varying sizes for a better fit. These liners, differing in design and customization ability, modify the helmet's interior shape. Among the surf helmets on the market, both the latest models from Gath (Gath SFC and Gath EVA), as well as Simba Sentinel, use a replaceable band for adjustment. The bands are glued directly into creases in the helmet liner.

Advantages
With well-developed replaceable inserts, one can potentially achieve a relatively well-adapted fit. The helmet is also potentially fully "enclosed" along the edge, which is positive for surf helmets.

Disadvantages
A significant drawback is the complicated adjustment process for the user. Changes to the helmet's padding are needed if one switches between surfing with or without a hood, leading to a more loosely fitting helmet if the hood is removed due to overheating. This also increases the number of components to manage, particularly for those who adjust the helmet to various situations. It not only creates more waste from unused padding inserts but also detracts from the helmet's sophistication. The rectangular fit strips used by Gath and Simba, glued directly inside the helmet, appear cheap and seems unatural to adjust multiple times.

Structural Adjustment

Cutouts in the helmet allow its overall form to be adjusted due to the flexibility in the structure. Kind of similar to Slalom Boot. The helmet is placed on the head, then a strap on the back of the helmet is tightened, causing the helmet to fit more snugly on the head. Similar adjustment is also used in rugby-style soft-shell helmets. They often have the same principle as a regular shoe, where the two sides on the back of the helmet can be tightened together with by tightening a lace.

Advantages
With these solutions, the helmet becomes more tight fitting, and reduces the space between helmet and user. It gives the feeling of the helmet hugging the head. It also has the benefit of providing seamless and immediate adjustment.

Disadvantages
At this point it's unclear how a solution like the one used in the WipFlex affects the performance of the helmet. Can it affect the shell's protective ability by reducing the displacement of the impact? Additionally the solution depends on slits in the helmet, which could expose the head to injuries.

Custom Fit Helmets

A different way helmets are made with optimal fit is through customization. There exists custom fit to user helmets within a range of sports, including surfing. However, the custom made surf helmets (Andy Caps and Nate Knaggs) use a more handcrafted approach while the custom fit helmets observed in bicycle helmets (Kav and Hexr) and American football helmets (Riddell Precision Fit) utilize sophisticated production methods such as 3D printing and 3D scanning.

Advantages
The obvious advantage of a custom fit helmet is the seamless fit it provides, minimising gaps and pressure points.

Disadvantages
Custom fit helmets also have disadvantages. They require a different production process where the customer is included, resulting in a more costly helmet. It also reduces the accessibility to the helmets, as the customer can not pick up a readily available helmet. Lastly, the customisation does not solve the additional challenge of adjusting the fit to different use cases that might occur. Kav started out as simply a customised helmet, but has later added adjustment pads to meet their customers needs (possibility to use with a beanie underneath for example).

3.5 Analysis of Helmet Rating List

Researchers at Virginia Tech have been providing the public with unbiased and independent helmet ratings since 2011, empowering consumers with the necessary knowledge to make well-informed helmet purchases (www.helmet.beam.vt.edu/). The science behind the ratings is the result of over a decade and a half of studying sports-related head impacts, and helps determine the helmets that most effectively reduce the risk of concussions. They currently have lists of helmets for the following sports; Varsity Football, Youth Football, Hockey, Bicycle, Equestrian, Soccer, Snow Sports and Whitewater sports.

I focused on studying the whitewater helmets first. This allowed me to gauge their performance in impacts and compare constructions and materials to form hypotheses about what works best. After mapping all the helmets on the list and researching their constituent materials, an interesting discovery was made. All the top-performing helmets had an EPP foam liner, while the others were made of EVA and VN foam. This could indicate that EPP is a better performing material, while also being resistant to multiple impacts and consisting of closed cells that don't absorb water. However, it's important to note that this conclusion cannot be definitive due to the limited sample size and few manufacturers. In other words, the differences could also be attributed to other factors, such as overall design, shell elasticity, liner thickness, geometric shape, etc.

Helmet model	STAR rating	Score (Total)	High impact score	Low impact score	Core material	Shell material	Weight (g)	Adjustability	Price
Sweet Protection Wanderer	5	0,25	0,25	0,00	Molded EPP?	ABS, CRP and LFT Shell technology	550	Occigrip, Fitpads	$ 150,00
Sweet Protection Wanderer II	5	0,33	0,33	0,00	Molded EPP?	ABS, CRP	550	Occigrip, Fitpads	$ 130,00
Sweet Protection Rocker Full Face	5	0,36	0,36	0,00	Molded EPP?	ABS, TLC Shell technology	850	Occigrip, Fitpads	$ 330,00
Sweet Protection Rocker Dagger	5	0,56	0,56	0,00	Molded EPP?	ABS, TLC Shell technology	550	Occigrip, Fitpads	$ 260,00
Sweet Protection Rocker	5	0,83	0,83	0,00	Molded EPP?	ABS, TLC Shell technology	550	Occigrip, Fitpads	$ 230,00
Shred Ready Half Cut	4	1,49	1,49	0,00	Molded EPP	ABS	N/A	BOA fit system, Fitpads	$ 100,00
Shred Ready Full Cut	4	1,77	1,75	0,02	Molded EPP	ABS	N/A	BOA fit system, Fitpads	$ 110,00
Shred Ready Full Face	3	1,89	1,89	0,00	Molded EPP	ABS	N/A	Fitpads	$ 150,00
NRS Chaos Full Cut	3	2,12	2,05	0,07	Dual Density EVA	ABS	N/A	Quick adjust harness	$ 70,00
NRS Chaos Side Cut	3	2,38	2,3	0,08	Dual Density EVA	ABS	N/A	BOA fit system	$ 80,00
NRS Havoc Livery	2	2,72	2,72	0,00	EVA	ABS	N/A	NRS Dial Fit (one size)	$ 50,00
Shred Ready ION	2	2,97	2,97	0,00	VN	ABS	N/A	BOA fit system, 3 Fitpads	$ 133,00
Shred Ready T-DUB	2	2,99	2,99	0,00	VN, closed cell comfort foam	Aramid/fiberglass	N/A	BOA fit system, Fitpads	$ 180,00
Shred Ready Shaggy	2	2,99	2,99	0,00	VN, closed cell comfort foam	Aramid/fiberglass	N/A	BOA fit system, Fitpads	$ 180,00
Shred Ready Super Scrappy	2	2,99	2,99	0,00	VN	ABS	N/A	BOA fit system, 3 Fitpads	$ 90,00
Shred Ready Sesh	1	3,05	3	0,05	N/A	ABS	N/A	Retention band, Fitpads	$ 55,00
Sweet Protection Strutter	1	3,06	3	0,06	EVA	ABS,LFT	400	Occigrip, Fitpads	$ 200,00
WRSI Trident Composite	1	3,1	3	0,10	EVA	Carbonfiber, Polyurethane sub shell	660	Obrace Retention system	$ 200,00
WRSI Current Pro	1	3,2	3	0,20	EVA	ABS, Polyurethane sub shell	800	Obrace Retention system	$ 140,00
WRSI Current	1	3,26	3	0,26	EVA	ABS, Polyurethane sub shell	660	Obrace Retention system	$ 120,00
Gath Gedi	1	3,32	3	0,32	EVA	ABS	360-420	Fitpads	$ 190,00
WRSI Moment Full Face	1	3,32	3	0,32	EVA	ABS, Polyurethane sub shell	N/A	Retention system	$ 180,00
Shred Ready Outfitter Pro	1	3,47	2,8	0,67	Compression molded foam	ABS	N/A	Retention system	$ 50,00
Gath RV	0	4,86	3	1,86	EVA	ABS	460-510	NO	$ 210,00

Table: Comparing Performance of Whitewater Helmets

It's important to note that several helmets with a low Virginia Tech score still meet certification requirements (all except the Gath RV). This raises questions about the adequacy of these certifications in ensuring sufficient protection for surfers, and how safe a helmet needs to be. Should it surpass these requirements? The water sports helmets are rated based on their effectiveness relative to other helmets, a method that invites criticism and highlights the influential power Virginia Tech holds. This is because manufacturers who receive a high score actively use it in their marketing. By focusing solely on impact testing, such a rating system may inadvertently encourage manufacturers to make increasingly thicker helmets to continually top the list (or at least achieve 5 stars). This could have adverse effects, as helmets could become too bulky, potentially increasing risk by reducing performance. One possible solution to this would be to implement a similar ranking method used in other categories, that is, calculating a threshold value, and assigning star ratings based on this value instead.

3.6 Interview with Virginia Tech University

Because Virginia Tech University has helmets ratings from a range of different sports, I wanted to know wether it is possible to compare helmets across different sports the same way I did with the whitewater helmet list. This would be interesting because there is a larger variation in helmet types, as it includes soft helmets designed for flag football, which I wanted to compare to water sports helmets. To better understand the differences between soft and hard helmets from a performance standpoint, and other technical issues related to anti-rotation mechanisms and promising materials, I reached out to Virginia State University, home to the most extensive independent research on helmet performance. I conducted a semi-structured video interview lasting 50 minutes, which I recorded and later transcribed to focus on the conversation.

It turned out that the different helmets cannot be directly compared across categories (sports) as the risk calculation equations vary based on the sport and because the way they test the helmets can vary depending on the sport. Thus, it's challenging to draw a concrete conclusion about how well a soft helmet designed for flag football would perform in the water sports category, even though both helmet types are tested for similar speeds. However, the interviewee, Miller, was confident that some high-performing flag football helmets could also perform well in surfing.

The reduction of rotational forces is a hot topic in discussions about brain injuries, like concussions, and in the development of modern helmet technology. Yet, understanding its importance and when it becomes significant is not straightforward. Several factors come into play, including the importance of the technology, how well the technologies function, and how they can be incorporated into a helmet. According to Miller's experience, the technology naturally has the most impact in high-tangent speed (oblique impact) tests. Virginia State focuses on realistic testing conditions, which means bicycle helmets, for example, are tested at high tangent speeds while equestrian helmets are not, based on accident analyses. Miller also explained that the actual testing setup differs significantly from real-world scenarios. While all humans have skin that can slide on the skull and most have hair offering additional sliding effects, the test heads used at Virginia State are made of a rubber-like material that creates high friction with the helmet. Hence, Miller suggested that the difference between MIPS and non-MIPS might be larger in their tests than in real-world situations.

“The specifics to how you test the helmet might determine whether MIPS is shown to be effective or not. I personally think a hair and a scalp does probably just as much as the MIPS layer because it creates a natural slip plane and helps the helmet decouple from your head. This is the basic strategy of a MIPS layer.” - Barry Miller

“I mean, you want a helmet to reduce those rotational forces, but the type of helmet you have, maybe it does that all by itself without any special technology incorporated, just

based on the type of helmet you design.” - Barry Miller

“The soft headgear moves a little bit easier than some of the other helmets anyways... So that might not necessarily be a big design criteria for you.” - Barry Miller

Regarding materials and constructions that perform exceptionally well, they have not conducted analyses or sorting based on this, as their primary purpose is to assist consumers in making informed choices. However, Miller noted variations in qualities such as EPS density, which could affect performance. He also said that many promising materials tested linearly are presented to them, but integrating these into a helmet's geometry poses greater challenges.

“Layered materials tend to work a little bit better overall. So then you have some denser material on the outside and then more comfortable material on the inside to attenuate the lower energy (impacts).” - Barry Miller

Summary
To summarise, there are several key takeaways from the discussion with Miller from Virginia State University. First, comparing the effectiveness of different types of helmets across various sports based on the STAR rating is not possible due to the fact that the testing methods and risk calculations can significantly vary based on the sport in question, thus making the STAR number sport specific.

Second, while there's high interest in reducing rotational forces in helmet technology, its significance is complex and influenced by numerous factors such as testing conditions and real-world scenarios. In their testing, the impact of technologies like MIPS might be larger due to the high friction material used in their test heads, which differs from the human head's natural sliding capability where skin and fluid on top of the skull act as a slip plane. It also depends on the activity how relevant it is, as soft helmets might slip more naturally on the head compared to a helmet with a hard eps core.

Finally, the choice of materials and construction methods in helmet design can significantly influence their performance. While promising materials often present themselves in simple tests, their effective integration into a helmet's geometry remains a substantial challenge. The focus of organisations like Virginia State University is to assist consumers in making informed choices based on such complexities.

3.7 A Helmet Pool Party

To gain a better understanding of important functional aspects for surf helmets, a series of tests were conducted at Pirbadet. The tested helmets included a Gath Neo (surf helmet), Sweet Protection Trooper (ski helmet), POC Crane (bicycle/skate helmet), ProTec Ace (wakeboard helmet), and a Jofa (ice hockey helmet).

The objective of the test was to assess how the different helmets performed in a series of tests. Based on the performance of the different designs, this would form a basis for design criterias. Prior to the testing, specific tests and factors for comparison were prepared. The test consisted of assessing the helmet's performance during diving, vertical jumps (high and low) and simulated duck diving (diving down head first from swim position). Factors for comparison included water dripping in the face, discomfort, pulling force and the overall experience after being submerged. The effect of air vents was also of interest. Would large vents feel different to not having vents for example? Furthermore, the helmets had different fits, with some being tighter than others, and two of them being adjustable. This aspect aimed to provide insights into the importance of a proper fit. The surf helmet, with its significantly lower profile compared to the other helmets, was expected to exhibit less resistance and be less noticeable.

Diving
Several "military-style" dives were performed from the edge of the pool. All helmets remained secure during the test and were comfortable to dive with. There was minimal difference among the helmets in this exercise, except that the surfing helmet appeared to have less water resistance (longer glide), likely due to its lower profile and snug fit.

Duck Diving
Duck diving is an important manoeuvre in surfing, used to dive beneath waves while holding onto the surfboard. In this exercise, there was some variation among the helmets. The POC helmet seemed to have significantly more buoyancy, making it more challenging to sink in order to dive headfirst. Despite being the lightest helmet (excluding Gath), it had the highest volume, making it the most buoyant of the samples. The Sweet helmet had a similar volume but felt more neutral in the water. The ProTec and ice hockey helmets had slightly lower volumes due to the internal padding being more segmented, making them easier sink. The surfing helmet performed exceptionally well, with its low volume facilitating effortless diving. When diving without a helmet, the water flowing over the head gives a good sensation that none of the helmets could replicate, even those with large ventilation holes.

Jumping
Vertical jump tests were initially conducted from the pool edge and later from a height of 3 metres. From the pool edge, none of the helmets caused discomfort during jumps, although the chin straps on the "larger" helmets (excluding the surf helmet) tended to pull slightly. However, the differences became more pronounced with the 3-metre jumps. The surf helmet had minimal effect on the head's movement, while the other helmets caused varying degrees of discomfort. Once again, the POC helmet performed poorly, exerting considerable force through the chin strap. The ProTec helmet was also uncomfortable. The Sweet helmet provided the best experience except the Gath helmet, possibly due to its ear protection, which contributed to a seamless transition between the helmet and the head.

Draining and Dripping
Another discovery was the helmets' varying abilities to redirect remaining water inside the helmet away from the face when on the surface. Both the POC and Sweet helmets have comfort padding covered in fabric on the inside. This layer absorbed some water, resulting in continuous dripping over the face for a period after being submerged. The Gath helmet, with a thin neoprene band over the forehead, appeared to shield the face from dripping. Surprisingly, the ProTec helmet performed well despite lacking any material to shield the face. This can likely be attributed to the foam material not attracting water and the "channels" inside the helmet directing water in other directions.

Ventilation
I also wanted to test the impact of ventilation holes on the helmet's performance in water. This was done by taping the holes on the POC helmet. It was difficult to notice any difference during diving, except that the helmet produced more sound when breaking the water surface, with water flowing through the holes. In the low vertical jump test, it seemed that the holes allowed the water that got "captured" to flow out of the helmet. With tape, the helmet felt more resistant, possibly because air did not escape as easily, creating an air bubble that contributed to buoyancy.

Additional Observations
The testing at Pirbadet provided insights into focus areas I had not previously considered. Helmets with large ventilation holes resulted in hair protruding through the holes after being submerged. While not significantly impacting the helmet's functionality, could be bothersome and lead to frequently taking the helmet on and off, to keep the hair inside the helmet.

	Gath Neo (Surfing)	**ProTec (Kiting)**	**Sweet Protection Trooper (Ski and Snowboard)**	**Poc Crane (Bicycle and skate)**	**Jofa (Hockey)**
Dive (0.1 m)	8	7	7	7	7
Straight jump (0.1 m)	9	6	6	6	6
Straight jump (3 m)	9	3	7	2	6
"Duck DIve"	9	7	6	4	6
Dripping	8	6	4	3	5
Total	43	29	30	22	30

Key takeaways

Low volume is more comfortable when jumping.

The tighter the fit, the better the experience.

Holes should be designed in such a way that the hair does not stick out.

Holes make it easier to sink the helmet under water.

The helmet should not have too much buoyancy.

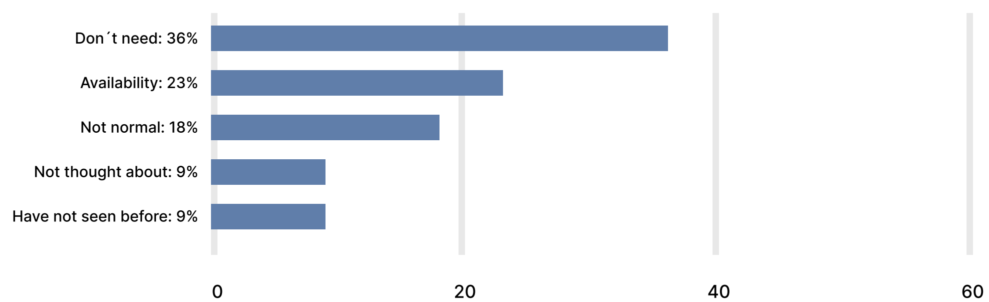
The helmet should minimise dripping. Get water out of the helmet, but away from the face.

3.8 Survey

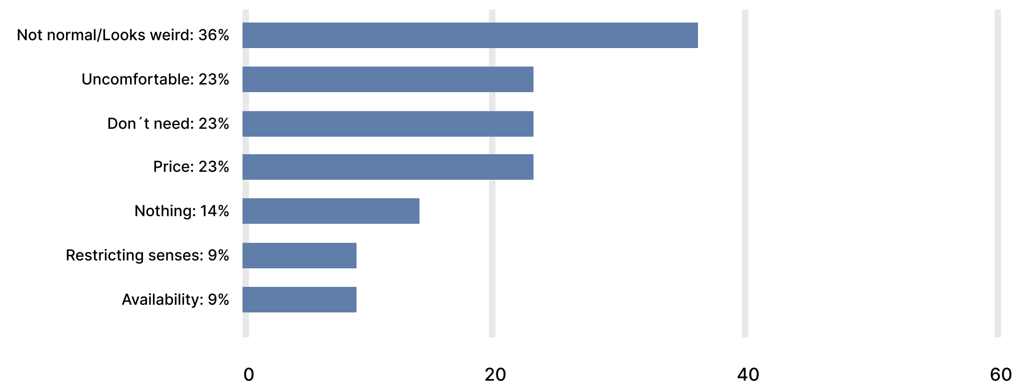
In order to understand what surfers consider to be the most important functional aspects of a surf helmet, and some of their attitudes about them, I conducted a digital survey. To reach as many surfers as possible, the survey was posted in multiple surf related groups on facebook, both national and international with some having more than 20 000 members. However, it proved difficult getting attention in these groups, as most of the answers I ended up receiving were from Norwegian surfers. Many of the questions were open ended, a decision made to get unbiased answers. However it also increased the barriers of completing the survey, which was evident as 19 respondents aborted after the first part.

In total 23 respondents completed the whole survey. The respondents were 80% male and 20% female. They had the following age group distribution 18-24 (16%), 25-34(44%), 35-44 (16%), 45-54 (20%) and 55-64 (4%). Regarding self reported skill level the following distribution was found; beginner (8%), intermediate (64%), advanced (24%), expert (4%) and professional (0%). The answers of each question were analysed and grouped in emergent categories. The following tables show the most significant findings.

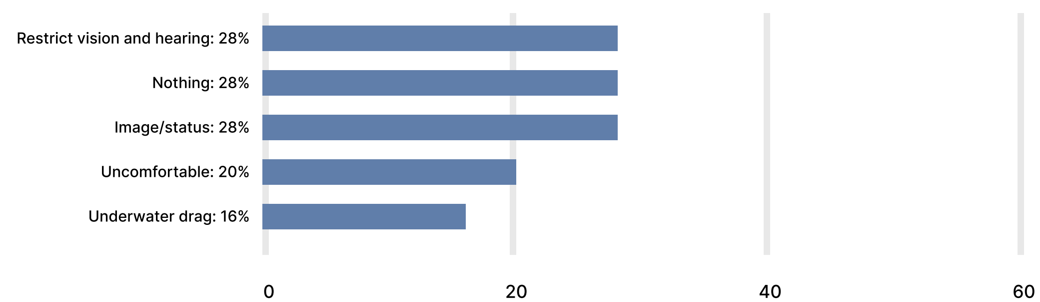
Why surfers don´t use helmets



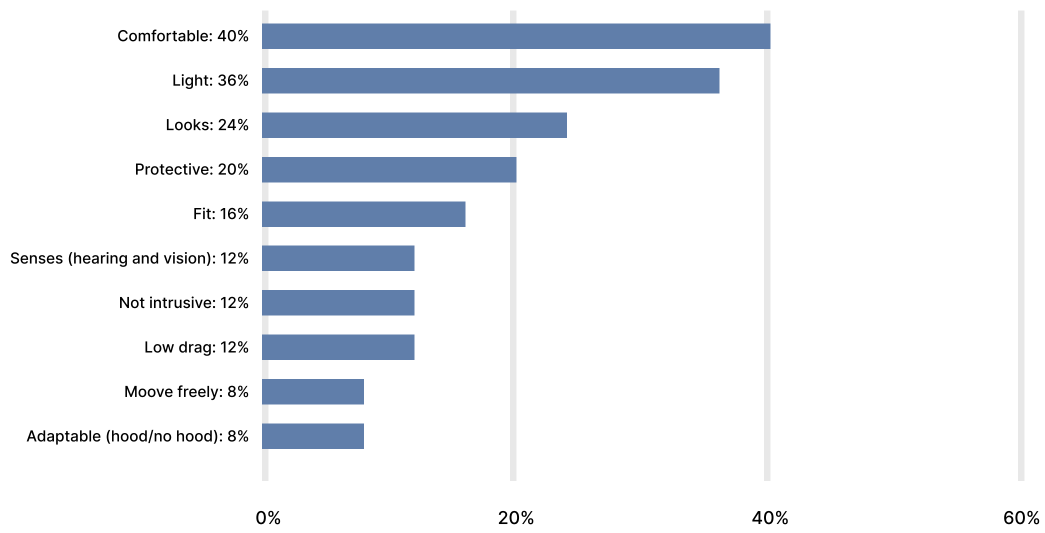
Factors holding surfers back from using helmets



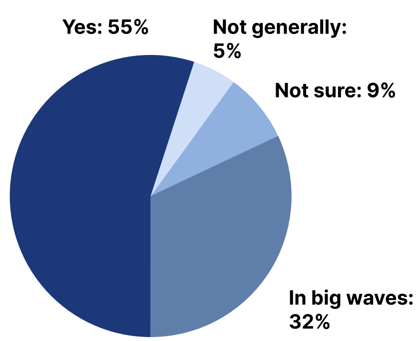
Helmet disadvantages



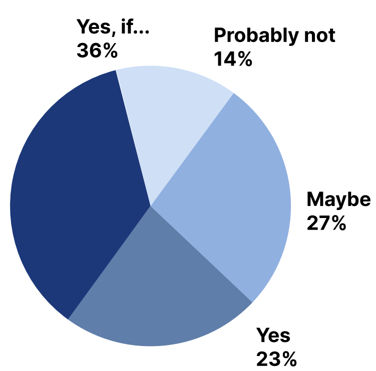
The most important aspects



Helmet relevance to surfers



Will they ever use a helmet?



Insights summarised

Based on the survey results, following functional aspects to focus on emerged:

Provide Comfort

Not Restrict Field of view

Optimise Hearing

Avhieve low water resistance

Optimise weight

Low profile

Not restricting movement

While it is clear from the survey that some of the problems related to surf helmets might be solved by better designed helmets, others relate to social and cultural barriers. If no one wants to take the step and be the first with a helmet, better helmets might not make any difference. We can see this for example because 18% cited not normal as why they dont wear a helmet and 36% of the respondents felt held back to wear one because of reasons connected with not normal/looks weird. These challenges might be better tar-geted with other strategies and will not be focused on in this thesis. As there already is a growing use of surf helmets among professionals and experts, it’s possible that this can lead to an increased use in general.

3.9 Interviews

To gain a more in depth understanding of surfers' thoughts and experiences regarding helmet usage, I conducted four semi-structured interviews, each lasting approximately 45 minutes. The format was chosen as a way of leading the conversation but also being able to follow up and explore interesting directions. The structure consisted of two main parts, other than introduction and final remarks. The first part focused on their thoughts and experience in regards to helmets. In the second part, the participants were shown pictures of the six most common surf helmets and asked to comment on these, in regards to how they look, which they prefer, etc. Two participants reached out after seeing the survey, where I expressed my interest in further discussions and the remaining two were recruited through my personal network. They were all surfers with more than 15 years experience, two were intermediate surfers and two were experts. The interviews were recorded to not miss any data, and after the interviews, notes and quotations were adjusted according to the audio recording.

The notes were analysed through affinity mapping. It allows a deeper understanding of the information through finding emerging themes and comparing the views. This made it easier to see the big picture of the information, what the interview subjects agreed on and where they were divided. It also gave some pointers as to what findings mattered more. The following paragraphs summarises the most important findings.

Attitude and experience
The participants shared the view that the risk in surfing is highly dependent. Even though one of them stated that she got injured in small waves, they agreed that surfing in general can be quite safe, and that helmets might not always be critical. However changing under certain circumstances. Sand bottom breaks are looked upon as safer than reef and rocky breaks. Shallow surf is looked upon as more dangerous, because of the risk of slamming into the bottom. Wave size and crowded lineups are looked upon as further increasing the risk.

None of the participants had thought about helmets for surfing, until encountering a special situation. Only one of the surfers had prior experience with helmet usage, the reason being surfing shallow waves and often alone. Two of the participants had recently sustained head injuries, one surf related and one unrelated. One of them had already purchased a helmet and intended to use it going forward and the other participant was actively searching for a helmet. The last participant had no experience with surf helmets, nor any plan of using one. However he explained specific spots he would only surf with a helmet, if he were to surf them. This seems to reflect the general situation, some surfers at heavy waves opt to use helmets and also people that have experienced traumatic injuries.

It was interesting how the expert surfers explained increased control due to experience

as a reason to not wear helmets, and that beginners are at risk due to lack of experience. The intermediates on the other hand looked at the more extreme conditions, which usually are exclusive to experienced surfers, as the most relevant case for helmets. The experts also shared this view in some sense, but the definition of extreme seems to evolve with experience.

"You get more instinct as you get more experience" (Expert surfer)

Important aspects
Similar to the survey results, the interview participants agreed on many of the performance aspects, highlighting the importance of not restricting senses such as vision and hearing. Low weight and volume was also seen as critical. One of them described the ultimate comfort as feeling like an extension of the body. Despite being slim, all surfers saw protection against serious injuries as the most critical reason for a surf helmet. The surfer with helmet experience stated that he thought the Gaths are on track with effective water drainage, light and slim design. However he had also noted that the comfort of the helmet could be increased with better fit and softer liner.

Regarding helmet coverage the answers were more divided. The two expert surfers saw ear protection as an added benefit of helmets. The intermediate surfers on the other hand saw removable ear covers as more important, in order to feel more in contact with the surroundings. Although not restricting hearing is highlighted as important by all, the more experienced surfers might be more familiar with surf related chronic ear injuries such as surfers ear. These are common for cold water surfers, but take time to develop.

"Why not have the full package, if you are going to use a helmet?" (Expert surfer)

Type of helmet
When reacting to the pictures of the surf helmets, all participants saw the soft helmet as the most comfortable option, without any of them having tried it. It was also commented to be suitable and fit for surfing.

“The rugby one, if it has the right contours it looks quite suitable. Something like that looks more comfortable. It looks decent. Hitting the head, the hard shell stops cutting your head open, but not much absorption” (expert surfer)

However, the participants also questioned whether a soft helmet would provide the necessary safety, and that the hardshell helmets would offer better protection. The surfer who had recently bought a helmet stated she required it to have a hard shell, similarly the other surfer looking for a helmet also questioned the safety of the soft helmet. One of the expert surfers stated that he also looked at the hard shells as more protective, however he was inclined to change his views based on the use of innovative materials and construction and product reviews.

“I was about to order the Soft Surf helmet, but i’m uncertain whether it protects as much as the Gath helmets” (Intermediate surfer)

“Depends on what kind of bottom it is, if it’s flat rock, a soft shell is probably good enough. Coral, uneven bottom, hard shell might be safer.” (Expert surfer)

Wrong associations
An interesting finding that was quite consistent across the participants was that some helmets give the wrong associations. In the case of the helmets shown, both the Gath Gedi and the Simba Sentinel gave associations such as “skiing helmet” or “bicycle helmet”. While the soft surf helmet also was referred to as “the rugby helmet”, it still was perceived as fitting to the context of surfing. One reason for this might be that many people are quite familiar with skiing and bicycle helmets. We know how they fit and how bulky they are, and mixing these attributes with being in the water contributes to the associated helmet being unfit for surfing. The Soft Surf Helmet on the other hand, while it is a rugby scrum cap with slight modifications, it gives more the associations to a surf hoodie and looks close fitting to the head and lightweight.

Gath EVA

Gath NEO

Gath SFC

Gath GEDI

Simba Sentinel

Soft Surf Helmet

The pictures of the six surf helmets shown to the interviewees

Through a series of semi-structured interviews with four experienced surfers, valuable insights were gained regarding surfers' attitudes and experiences towards helmet usage.

Insights Summarised

It should look comfortable and close fitting - this makes it seem suitable for surfing

Adjustment is wanted for better fit and adaptability

It's mostly relevant for powerful shallow waves over reef or rocks and in crowded surf

Balance is important; protective but not to bulky and intrusive (thickness and coverage)

Helmet should protect against serious injury, but the thinner the better

Hard shell is associated with better protection

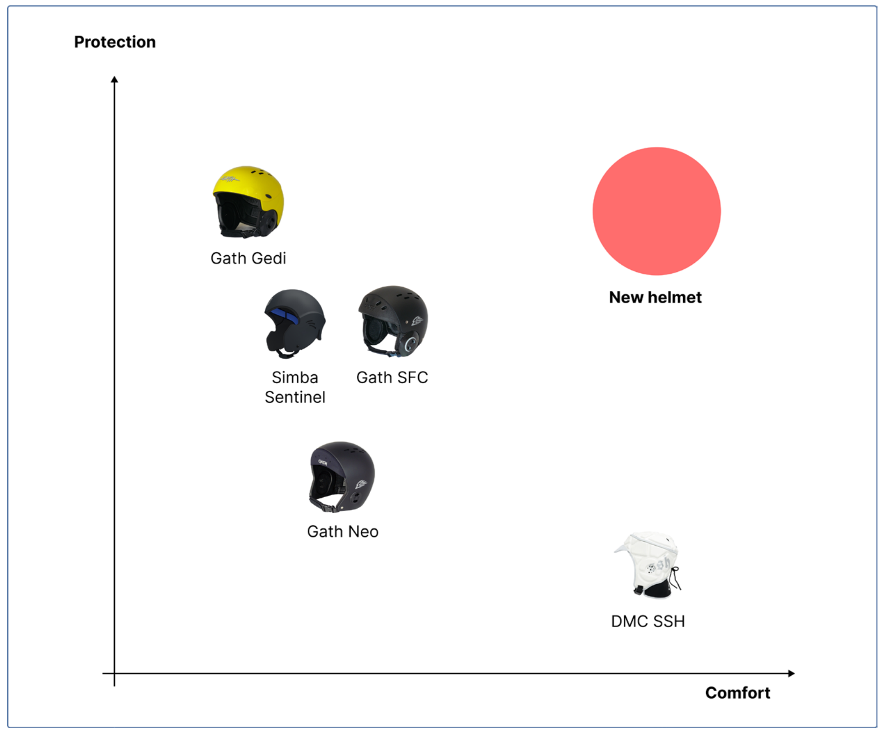
Soft shell helmet seem suitable for surfing and most comfortable to use

Innovative materials and construction can influence choice of helmet type

3.10 Target Market Segment

Based on the research, survey and interviews, helmets are most relevant and also most accepted in more critical surfing, especially in shallow tubular reef break waves. This segment of surfing is also where the growing interest in helmets have been reported, and therefore will be targeted in this work. Waves of this category are usually exclusive to highly experienced surfers, simply due to the skill needed to navigate these waters and successfully ride these waves. Focusing on this segment does not mean that the helmet will not be suitable for other surfers. It means that it's designed to be the most high performance helmet. It has been reported that professionals embracing safety equipment might increase adoption by amateurs (Bickley et al., 2021). Therefore, a better helmet that is more comfortable to use could result in more professionals using one. This might ultimately be the most effective strategy to increase the helmet wearing surf population.

Based on my own expereience with testing the Gath Neo helmet, insights from the survey and interviews, and based on the current gap in the market, the focus will be to create a new helmet that differentiates from the rest by offering superb protection and comfort.



3.11 List of Requirements

Many insights have been gathered during the research process. To help focus the design process and ensure that the most critical needs are met first, these insights have been transformed into a clear list of requirements, and prioritised using the "MoSCoW" method.

Must
Protect against impacts with rocks, reef, fins and boards
Fit as closely to the head as possible
Offer easy adjustment for optimal fit
Minimise gaps between the head and the helmet (prevent bucketing effect)
Be soft on the inside/Be comfortable
Not have gaps that can catch water
Be as light as possible
Offer full field of view
Provide optimal hearing
Follow the certification for water sports
Not cause dripping/running in the face
Have safe ventilation (hair, fins)
Provide cooling as well as effective drainage (drainage)
Have minimal buoyancy
Be designed for multiple impacts

Should
Provide better impact protection than market leaders
Be soft on the inside (comfort and fit)
Be adaptable to fit with and without a wetsuit hood (One helmet!)
Provide protection against surfer's ear (protect ears from wind and water)
Have detachable ear protectors
Be well ventilated
Be easy to use, even with cold fingers or wetsuit gloves
Feel like a part of the body
Shouldn't resemble a bicycle helmet (gives wrong associations)

Could
Be easy to pack (transport)
Incorporate new anti rotational technology

Won't
Have a visor or cap for sun protection (field of vision prioritised)
Have eye protection
Have excessive face protection
Be a smart helmet (sensors)
Have additional equipment such as audio ready, communication, emergency float

Additional comments
As the list shows, a range of other additional functionality have been observed. Some of these have potential benefits, such as smart components that can alert in case of an emergency. However, it has been more important to meet the core functional needs initially.

4 Initial Concept Development

4.1 How to Achieve a Seamless Fit?

Based on the insights I had acquired, I chose to focus on the seamless fit as a main starting point for the concept generation, as this was the most critical functional criteria in terms of affecting the user experience. I was also convinced that having a snug fitting helmet, that acts more as an extension of the body, would resolve many of the concerns that surfers have regarding the comfort. The perfect design in this sense would be a helmet that adapts to the user's head, allowing for a snug fit and possibly adapting to different use cases such as with or without hoodie. This choice did not mean that I would scrap all the other requirements, however they would be less of a concern in the beginning stages of the development phase.

In order to achieve a seamless fit, the helmet had to be adjustable, but how? It was also a goal that the adjustability would allow surfers to achieve optimal fit with and without a wetsuit hood, as a large portion of surfers would need two helmets otherwise. To find out how much the difference is, I measured my head with and without a 6 mm wetsuit hood, which is the thickest hood used in coldwater surfing. The difference was found to be 2 cm, which might vary a bit depending on head size and shape, but 2 cm was used as the minimum difference in circumference.

From the market analysis, I came across three principles for size and fit adjustment of helmets: turn dial, fit pads and structural adjustment. The typical turn dial adjustment was seen as unfitting due to the gap that is created in the back of the helmet, which causes the uncomfortable "bucket effect". Interchangeable fit pads were also deemed too cumbersome and lacked the possibility for immediate adjustments. The mechanism used in the WIP Flex and some soft headgear seemed more appropriate, since the helmet as a whole gives a more hugging feeling on the head. Soft headgear also has the added benefit of being more flexible and adaptable to each user's head. These findings spurred some initial concept directions that I wanted to explore.

4.2 Three Concept Directions

The exploration of different possibilities to achieve a helmet that fits as closely to the surfers head as possible led to three initial design directions. The first idea is a continuation of the WIP Flex helmet, however I wanted to investigate how the mechanism worked together with a hard shell. The second direction is a soft shell helmet, that is more close to a wetsuit hood than rugby helmets, and should provide optimal comfort. The third direction is a mix of the two. It consists of a hard shell that covers the majority of the head, but with a soft lower edge that can be tightened for a more hugging helmet.

Flex-shell

It's based on the same concept as WIP, but using a hardshell. Cuts in the helmet allow it to be tightened for a closer fit. The tightening mechanism can consist of a BOA tightening wheel or a simple barrel lock.

Hybrid

The idea is that the helmet consists of a hard shell at the top (most crucial) and has a soft foam part at the bottom. The soft part is designed to ensure that the helmet fits snugly on the head at the transition (it may have a tightening system in the soft part)

Soft-shell Wetsuit Hood

A soft-helmet variant. Maximising comfort, lowering the threshold for use. The task is about shaping the padding into a wetsuit hood (without being too warm). Can it also provide more safety than current soft-helmets?

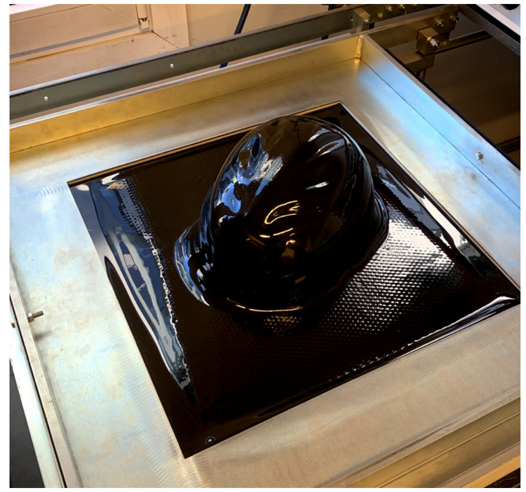
4.3 Flex-shell Prototype

Based on the WIP FLEX, I wanted to develop a quick prototype to get a feel for the idea with the hard shell. In addition to wanting to test if it would give a good fit,I was curious about how the hard shell would behave and how it would be perceived.

To quickly create a shell with an approximate helmet geometry, I used the EPS liner from an old helmet as a mould in the vacuum press machine. A 2 mm thick ABS plate was then melted and moulded over the helmet core with vacuum. This resulted in a helmet shell, quite realistic in shape, thickness and materiality to conventional hard shell helmets. Drawing inspiration from the WipFlex helmet, I used a similar cutout design as a starting point. A dremel cutting tool was used to cut the shell, using carpenter tape as guides.

After the cutouts had been done, the helmet shell lost a significant amount of its structural integrity, transitioning from a solid structure to a quite fragile one. This gave an immediate feeling of being a wrong combination of design and materiality.

Strips of soft EVA foam were attached to the inside of the shell, with a similar thickness as the EPS liner that was used as mould. To get a feel for how well it would adjust and fit the head, a simple adjustment strap made of fabric and velcro was attached to the back of the helmet.



Evaluation
The concept of adjusting the size of the shell proved effective. The sides allowed the total width of the helmet to be adjustable while the rear part adjusted the length. However, it wasn't as seamless as in the WIP Flex helmet, which is completely made out of EPP. When the hard shell flexes on the other hand, it also bends due to the curved surfaces. While the inner liner and especially the adjustment strap provided the shell with more structural strength, I still had a feeling of being a vulnerable, low quality and fragile structure. For a helmet that should give a protective feeling, it became clear that this direction was a dead end.

The evaluation led to some interesting discussions regarding the difference in perceptions and the feeling of having something rigid and trying to make it flexible in contrast to having something flexible and adding more rigidity. It was hypothesised that a flexible helmet with added protection would be perceived as a more protective helmet than its origin, while a hard shell helmet with cutouts would be perceived as a less protective helmet.

4.4 Soft-shell or Hard-shell

Before embarking on the project, I was inclined towards traditional hard-shell helmets due to the protection it provides against sharp objects. However during the project, soft helmets emerged as highly suitable from a user perspective. They were seen as more comfortable to use due to their superior ability to adapt to individual heads compared to a hard helmet, thus resulting in a less bulky helmet that is more like an extension of the body. Looking for other solutions than hard shell helmets was also a way to differentiate from the current helmets in a more radical way. However, I was uncertain about the safety performance of these helmets compared to a hard helmet. On the other hand, not all helmets we consider as “hard” are as impenetrable as we might think. The shell of most in-mould bicycle helmets for instance is not thick enough to stop sharp objects, although the hard foam core offer some resistance.

Looking at the certification requirements for rugby headgear by World Rugby (Approved Equipment, n.d.), the required impact performance and test set up is comparable to that of whitewater sports. Each headgear is tested by placing it on a headform with a weight ranging from 3-4 depending on size and dropping it from a height that results in 13.8 J impact (approximately 300 mm depending on size). To pass the test, acceleration must be below 200 g´s. This served as proof that in terms of impact protection, soft shell helmets can provide excellent protection. To further analyse differences between hard-shell and soft-shell, a matrix with advantages and disadvantages was created.

Advantages

Soft-shell

- Superior fit
- Superior comfort, especially in the ocean
- Lighter?
- Matches better with surf gear (neoprene wetsuit, hoods)
- Easier to transport

Hard-shell

- Better protection?
- Most helmets are hard shell for a reason
- Compatible to with new rotational acceleration mitigating technologies
- Protection against sharp objects

Disadvantages

Soft-shell

- Reduced protection against sharp objects

Hard-shell

- Inferior comfort and fit
- Heavier?

4.5 Inspirations

The whole process of studying different helmets and understanding more about how helmets work, I was more open to the idea of finding an alternative approach to traditional hard shell helmets.

During the project, I connected with another student at NTNU who had begun working on a soft surf helmet to be worn under a wetsuit hood. He had obtained some samples of a visco elastic material from the German supplier, SAS-TEC. The material is already used in various sports protection equipment, including knee pads and back protectors. Although this specific material hasn't been studied in the literature for helmet use, as previously mentioned, visco elastic materials have proven to be more effective than traditional soft foam in soft helmets and an American football helmet (Ganly & McMahon, 2018; Ramirez & Gupta, 2018). With the material at hand, I was interested in examining how a helmet made of this material would be perceived and received among surfers as well as how it would perform in the surf.

Initially, a mood board was created to inspire and capture the idea of the concept. The fundamental idea was to blend the sensation of a wetsuit hood with a more precise and dynamic design language made possible through the moulding of the material as a future vision.

Soft but solid

Protective

Modern

Flexible

The environment

Fits like a hood

4.6 Soft-shell Prototype

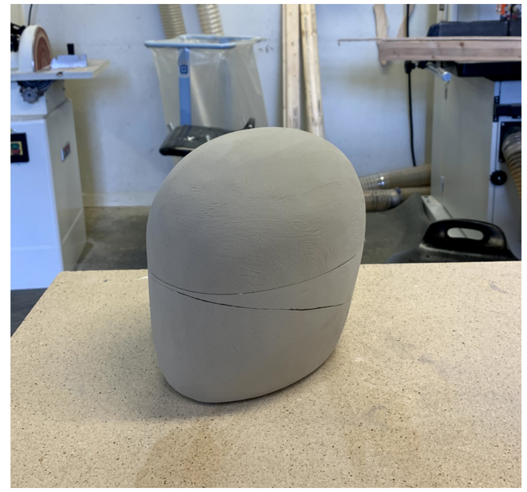
Because the main objective at this level was to test the concept in regards to general comfort, underwater drag, temperature and how it compared to the benchmark Gath Neo, I focused my effort mostly on creating a functional prototype, more than spending time on the details and looks. In order to create the prototype, I considered two different production techniques: using a vacuum press machine or cutting flat material in a textile pattern that could be pieced together to fit the head.

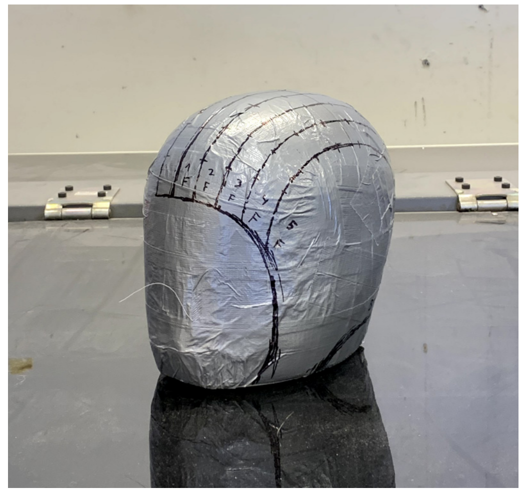
Initially, I was attracted to the precision and speed of the vacuum forming technique. However, this method required a head form over which the foam could be drawn. Opting for the quickest alternative at that time, I made the head form manually using measurements from my own head for circumference, width, and length, and an existing helmet as a template. When a test was conducted using EVA foam and the vacuum form technique, the foam quickly became malleable and easy to shape. However, when the same approach was attempted with the SAS-TEC material, it was revealed that this material was not thermoplastic and therefore couldn't be re-shaped using the vacuum press machine.

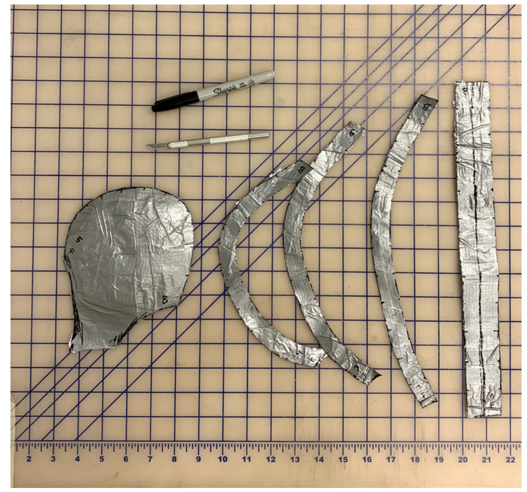
Since the material couldn't be vacuum formed, the head form was instead used as a basis for the helmet pattern. The method was found by searching for DIY helmet pattern creation. The method involves first covering the head form with aluminium foil followed by duct tape. After covering the form, the desired pattern is drawn on it. I chose to follow the principle used in wetsuit hoods, adding more parts to achieve a rounder form and accommodate the material's inflexibility compared to neoprene. Marker lines were also drawn for easier reassembly. The pattern was then cut out, and the pieces were flattened, allowing the 2D material to be transformed into a helmet with the same shape as the head form.

Before using the SAS-TEC material, a model was created with EVA foam to check if fit adjustments were needed. The pattern was used to cut out the pieces, and marker lines were transferred. Different types of adhesives were tested before assembly to find the most effective option. Rubber glue was chosen for its solid bonding and lack of hard glue edges. The pieces were then glued together, and the prototype was ready for evaluation.

The helmet's fit was subsequently tested by me and other available students. The model seemed to fit well and be adaptable to a range of heads, so work started on the second version using the SAS-TEC material. The same method was used, although gluing the pieces together was more challenging as the new material wasn't as flexible as EVA foam. Ventilation holes were added along the top of the helmet, along with ear holes for better hearing before the pieces were glued together.








Upon evaluating the prototype, it was clear that the pattern should have been slightly adjusted for size to compensate for the material's reduced stretch. The helmet was too small for me and several students. However, the helmet was intended to have an adjustment feature, and by making a cut on the back of the helmet, it became more spacious and adaptable. A simple strap was then created to tighten the helmet around the head, and a basic chin strap with Velcro was added to secure the helmet.


4.7 Testing, Feedback and Evaluation in the Dominican Republic

I went on vacation to the Dominican Republic in March, and got the opportunity to test the helmet prototype. There were multiple aspects I was keen to explore: What would it be like to wear the helmet? How would it compare to the Gath helmet? How would it perform in warm weather? Would people react to it? How would I feel wearing it myself?

The weather was warm, around 25 degrees Celsius in the morning air and 26 degrees in the sea. I typically wore swim shorts and a wetsuit top while surfing. I was curious about whether I'd receive any comments about the helmet in the water. To be honest, I was initially hesitant to wear it. I believe this hesitation exemplifies why many might feel deterred from wearing helmets. Normally, my confidence as a surfer is quite high since it's an activity I've been involved in for a long time. I didn't experience much embarrassment about testing a helmet, as I found comfort in my status as an experienced surfer. However, the situation was slightly different in the Dominican Republic. There was a large international competition taking place, with many young professional surfers present during and after the competition. Compared to these professionals, my skill level isn't exceptionally high, which heightened my worry about appearing more novice-like. I didn't see any other surfers wearing helmets, and there were very few wearing any form of headgear. Suddenly, I felt my status diminishing in the presence of the professionals. This led to me first venturing out without the helmet, before eventually gaining the courage to test it.

The helmet stayed securely in place during duck dives and didn't present any significant discomfort, apart from the sensation of having the head covered. I noticed that the small ventilation holes on top of the helmet allowed water to enter quite effectively. Even underwater in waves, the helmet didn't interfere with my movements and remained snugly fitted. I noticed that the strap came loose once, which wasn't ideally fixed, indicating a potential improvement point - protruding straps might cause them to unfasten.

The coverage over the ears meant that I wasn't particularly bothered by wind, despite it being quite breezy. Occasionally, I could hear faint whistling when the angle was 'just right,' due to wind blowing into the ear holes. This wasn't a significant nuisance but requires some sort of resolution. I found that I could hear the sound of water and converse with others easily, but at the same time, I realised that the helmet could potentially offer better audibility.

One minor nuisance was a greater amount of water running over my face. Without a helmet, water runs over your face after a duck dive, but it stops relatively quickly, especially if you wipe it off. With the helmet, small amounts of water could continue running down for a slightly extended period, which was slightly annoying when paddling out and diving under waves repeatedly.

Temperature-wise, it varied depending on the weather. The first time I used it, I found the temperature comfortable, with the helmet not becoming excessively hot. However, I later found that the helmet could get warm, leading me to frequently cool down my head by dipping it underwater. It was reassuring to feel that the holes easily allowed water in but could have benefited from an enhanced flushing effect.

Feedback from Professional Surfers

Given the presence of many professional surfers at the surf competition, I seized the opportunity to gather feedback on the helmet prototype. I spoke with four professional surfers on the beach, informing them upfront that the helmet was an early prototype made from a modern material that hardens upon impact.

The surfers demonstrated interest in the prototype. Three of them frequently wore helmets while surfing in Hawaii, and one surfer noted the likelihood of using a helmet in the coming season for specific hazardous waves. Among those experienced with helmets, it was described as more comfortable than the Gath helmet. Particularly, the pressure on the ears from the Gath helmet was singled out as a very negative aspect by one surfer. The prototype also earned praise for its aesthetics. However, the surfers expressed concerns about the lack of a hard shell, which led some to prefer the Gath helmet, as they only use helmets over shallow reefs. At the same time, they noted that the prototype appeared very effective against being hit in the head by the board or potentially surfing over sandy-bottom waves. One surfer was more hesitant, indicating it was difficult to determine the necessity of a hard shell given the availability of new materials.

Comparison test with Gath Neo

After several days of using the prototype helmet, I decided to reevaluate the Gath helmet for comparison. Immediately, the Gath helmet felt different in the water, behaving more like a detached piece on my head that moved with each dive, rather than an integral part of my body. While duck diving, I could feel the water dragging the helmet.

I experienced a particular dive where the water really got a hold of the helmet, causing an unexpected jerk that I likely wouldn't have felt without the helmet. There were several wipeouts where I was pulled slightly by the helmet, one of which was particularly uncomfortable. In a sudden motion, the helmet was jerked and rotated at an angle, abruptly pushing the endpoint into my jaw. This also showed that the helmet's endpoint design by the jaw strap is problematic. A tight fit is necessary to minimise underwater discomfort, but this results in the sharp endpoints pressing against the jaw.

The hearing capability with the Gath helmet was superior to the prototype, due to its larger direct opening. However, the design caused considerable discomfort as the relatively sharp plastic pressed against the ears, resulting in prolonged pain.

The Gath helmet's ventilation was far from optimal, as it was warmer and less breathable than the prototype. Moreover, it didn't provide the same immediate cooling effect as the ventilation is not direct.

These trials convinced me that the flexible attributes of the soft helmet were superior, as it felt much more comfortable and adaptable in the water than the Gath helmet. I believe the user's concerns about protective qualities should be addressed by adding elements to protect against sharp, hard objects. If the helmet undergoes testing and achieves a high score comparable to existing helmets, it could alleviate doubts and establish the new helmet as a superior product.

5 Further Concept Development

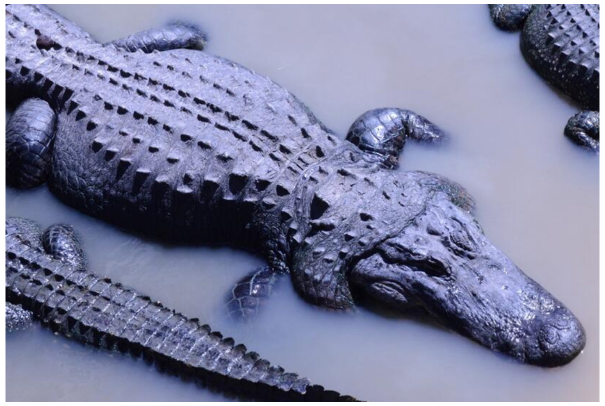
5.1 Updated Vision and Inspirations

Following the prototype testing, I was convinced that I was on the right path. However, I acknowledged the feedback suggesting the helmet might not provide sufficient protection. Based on the feedback from the prototype development and earlier interviews, it was clear that the product required adjustments for both safety and to be perceived as an effective helmet. Nonetheless, I wished to distinguish my product from others in the market.

Therefore, I decided to retain the concept's fundamental feeling tested in the prototype. The helmet must offer safety while also feeling like an extension of the body. Instead of reverting entirely to hard-shell helmets, I aimed to enhance the product's safety features while preserving its flexibility, resulting in a solution that strikes a balance between different helmet types.

Increasing Helmet Protection

The initial decision was to determine the method for helmet reinforcement. Aramid fibers, such as Kevlar, are effective against penetration and cuts while retaining the helmet's flexibility and adaptability. A layer of such materials could enhance the helmet's resistance against sharp objects like rocks or fins. However, the downside of this approach is that the force from a pointed object won't be as evenly dispersed over a larger area as it would be with a hard surface. Thus, the use of textiles like Kevlar alone was deemed insufficient in terms of protection. To achieve high protection, it was concluded that the helmet must have hard exterior elements. However, to maintain flexibility, the helmet's shell would be divided into zones offering extra protection and flexible zones. The divisons were explored through sketching different variations. A moodboard was created to guide the design process.



“Protective Skin”
Extension of the body

Advanced and High Tech

Focus

Adaptable

Tight Fit

Precise and dynamic
Elevated Protection

Protective

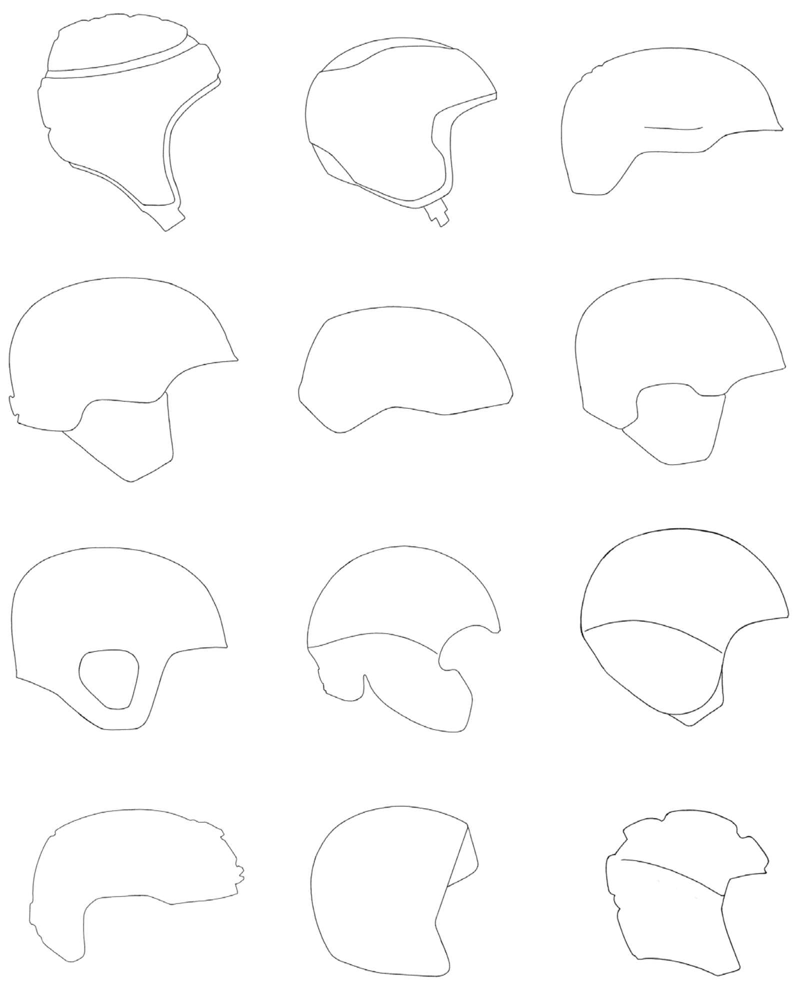
Reinforced

High performance

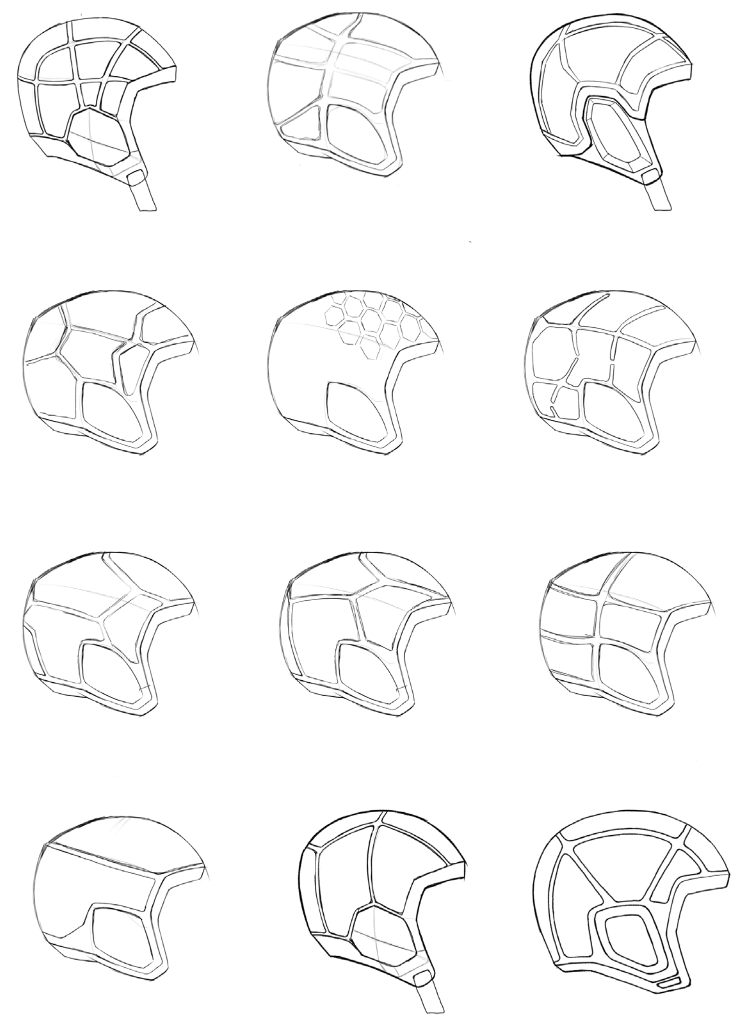
Powerful and critical conditions

5.2 Developing the General Outlines and Panel Divisions

Finding the shape of the general outline was one of the first steps in the developing the new concept. I wanted to introduce some more defined lines compared to the soft-shell prototype, to make the helmet achieve a higher quality and more technologically advanced look. I had studied many helmets up until this point, and by combining some of their features I started exploring the main lines of the surf helmet.

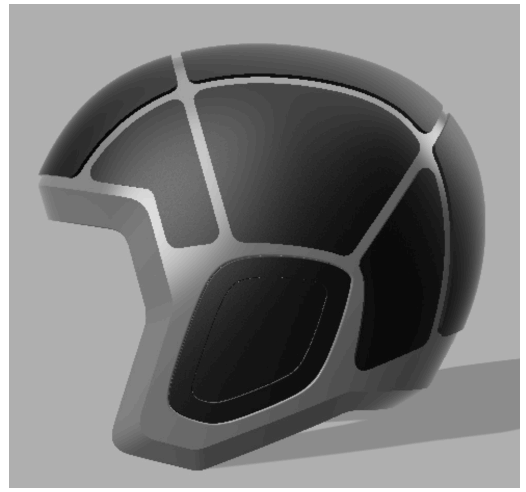


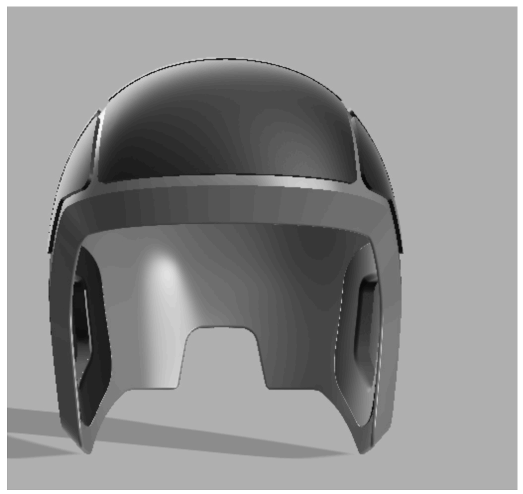
The zones with increased protection needed to be divided in a sensible way, so that the helmet would achieve the needed protection without loosing its flexible fit. More divisions would result in greater flexibility, but it would also increase the surface area without extra protection. I hypothesized that the ideal compromise was to minimize division: the helmet should have enough divisions to retain the prototype’s flexibility and close fit, but fewer divisions would also enhance safety against sharp objects.

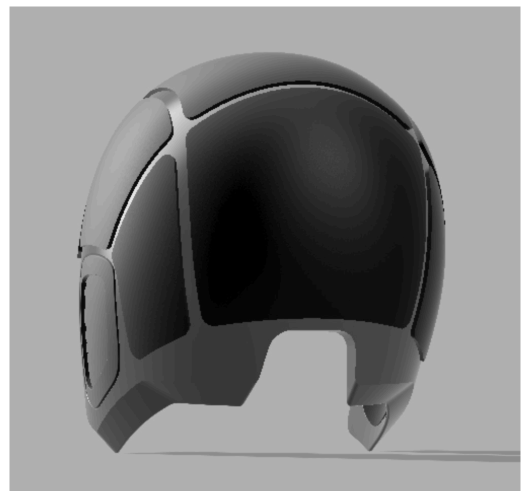


The chosen pattern was based around two principles. First, the gaps need to align to provide the optimal flex. Second, the flex should be focused along the top sides, front and back of the head, further maximise the effectiveness of the flexibility, since these are the areas of the head that head curve changes most.

Based on the last sketch, I created a 3D model of the helmet in Fusion 360. Even though I still had many details to design, I wanted to get a sense of how the design turned out in 3D, and also to use the 3D model as a basis for further sketching. I was quite happy with the general design, although it needed further development. One of the areas I wanted to improve was the uneven spacing around the ear cover. I also wanted to put place more emphasis on the contrast between the hard panels and the flexible gaps.







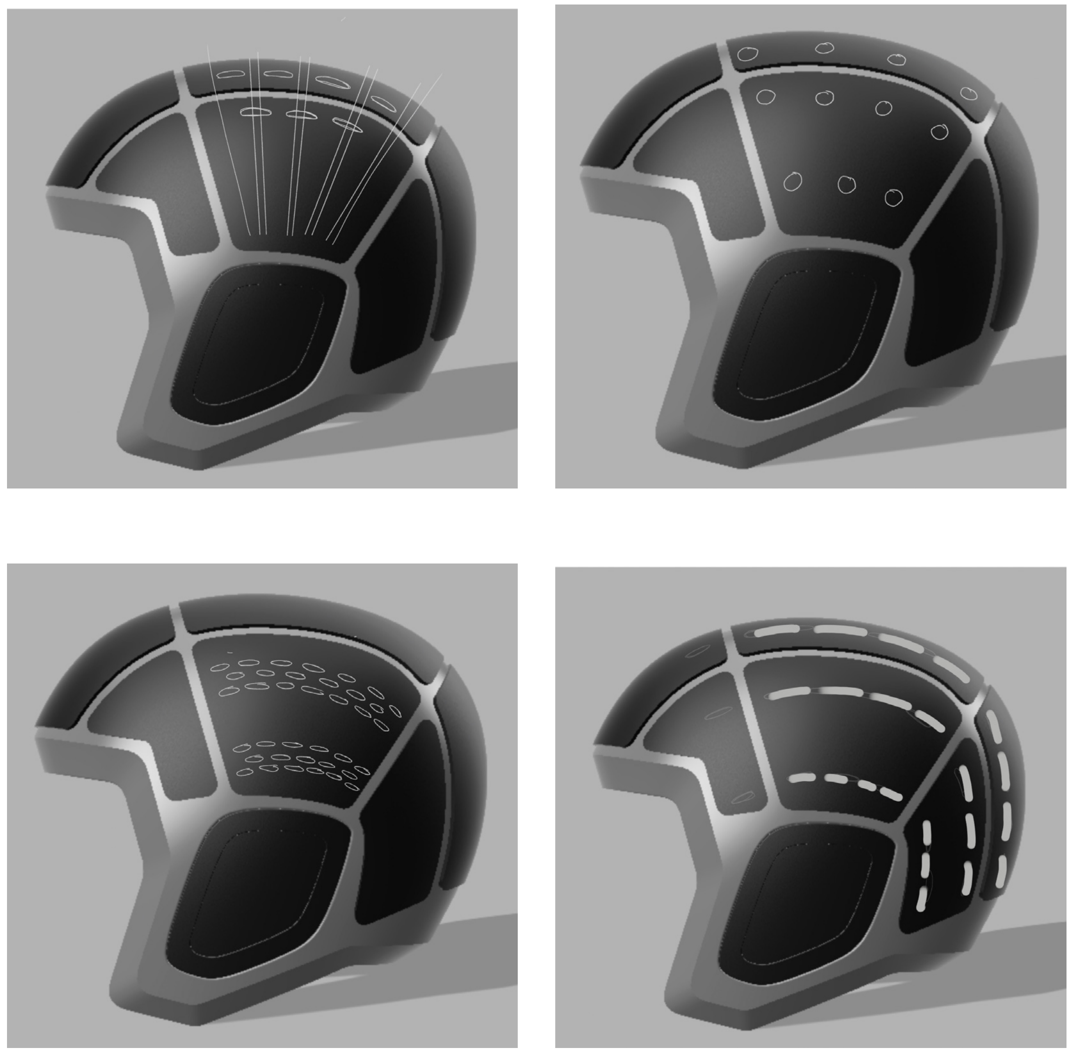
5.3 A Test Model with Panels

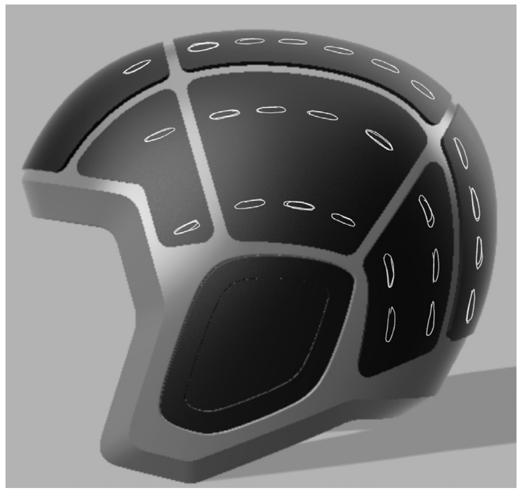
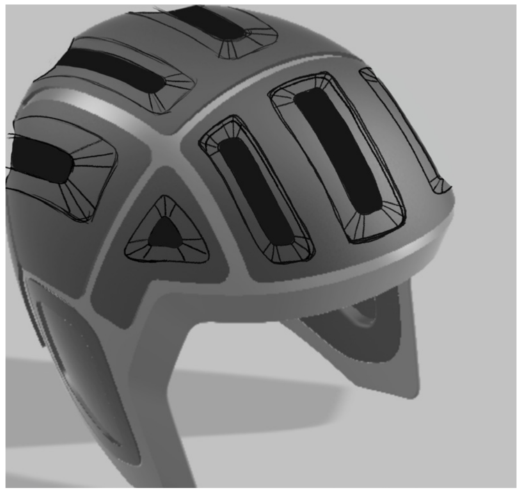
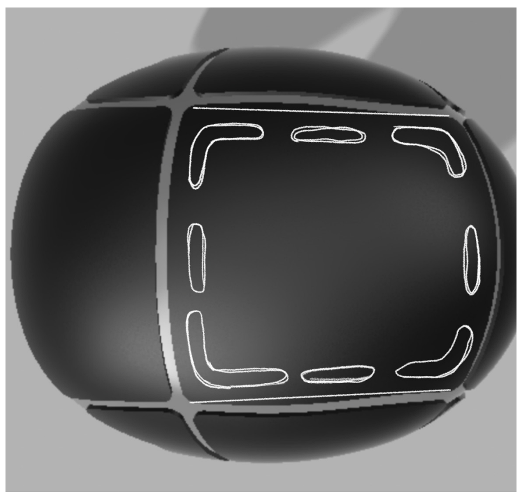
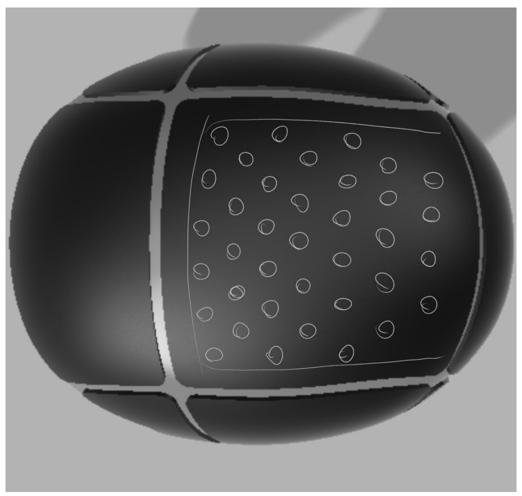
When I had designed the general outlines of the helmet with the exterior panels, I decided to make a quick update to the soft-shell prototype to get a feel for how it functioned with the panels. The panels where made by first, using a vacuum press machine to get the general helmet shape before cutting out the pieces. The pieces were then assembled and temporary fastened to the prototype.

I was happy to find out that the fit of the helmet remained quite similar. Even though the model was stiffer due to the panels, the same comfortable and hugging fit was still there.

5.4 Ventilation

Ventilation was explored by sketching on top of pictures of the 3D model. The focus was to create vents that would be safe against the tip of the board, fins etc and to not let hair easily find its way out of the helmet. Typical large ventilation holes found in fast bicycle helmets for example would make it look more similar to those helmets, which I wanted to avoid. Therefore, the size of the vents were limited.



As stated earlier, I wanted to put more emphasis on the exterior panels being extra protected zones. This was done by elevating the panels slightly, to create a clear picture of the panels being the first barrier and with increased protection.

5.5 Core structure

The main goal of the core is to reduce the impacts. With more thickness the better impact attenuation is achieved, however at the cost of being more bulky. The balance is tricky, especially without the technical competence. I decided to base the thickness on helmets that had passed the certification, being around 1 cm. This was the same thickness as the soft-shell prototype. However the back head is usually more protected, so I increased the thickness in the back to almost 2 cm.

I wanted to achieve four goals with the structure of the core, other than providing protection against impacts: provide ventilation, reduce water running in the eyes, reduce weight and reduce rotational forces in oblique impacts.

It became evident in the testing that controlling the draining of the water is important prevent water running in the eyes, which depends primarily on two factors. Firstly, a helmet that have water absorbing materials will result in prolonged dripping. In addition, the water should be able to drain effectively out of the helmet while being diverted away from the eyes. Just as helmets for road cycling have thoughtful ventilation to minimize air resistance, a helmet for water sports should effectively expel water.

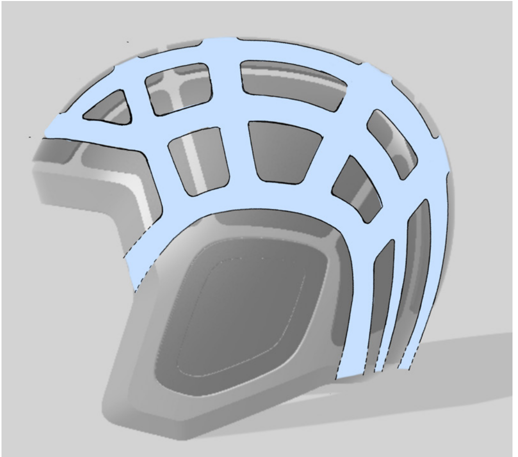
Second, it was important to minimise the weigh to increase comfort. The chosen material is comfortable and effective for impact, but its heavier than both EVA and EPP. Therefore removing material from the core was the option left, which the channels did.

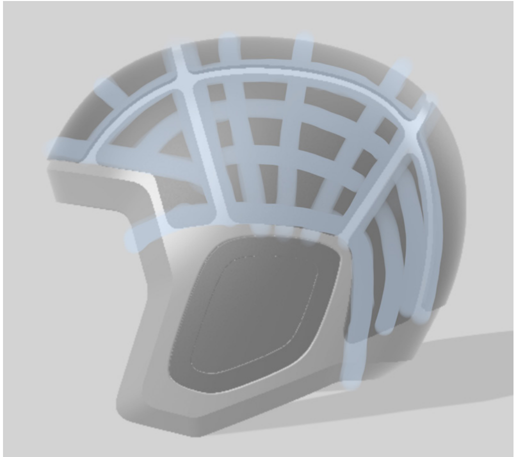
While MIPS is used in the majority of bicycle and snow sports helmets, the technology is not fit for a softer core material. However I came across other technologies that seemed more fitting, such as the Atomic AMID and Rheon. These both based on providing the structure shearing properties, by creating space in the material in different ways. The simplicity of the solution was fitting, as well as it would allow creating channels for the water and also reduce the weight of the core.

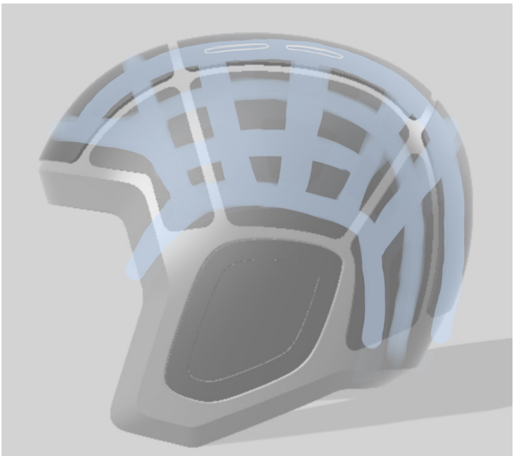
The channel structure was explored through sketching and by drawing on a headform, to get a better understanding of how the sketches could translate to 3D.

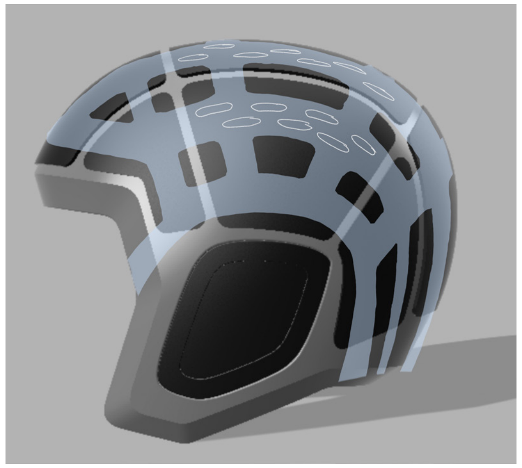
Atomic AMID

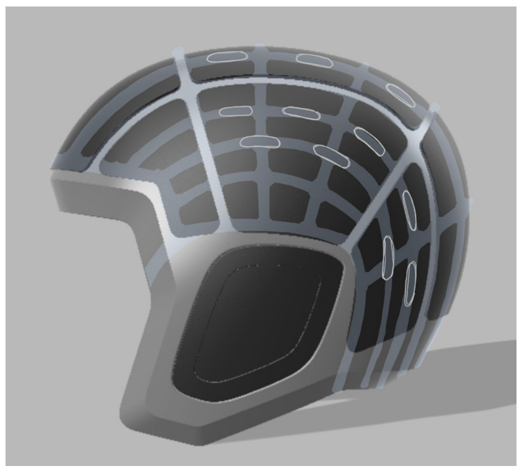
Schutt Helmet With Rheon Padding

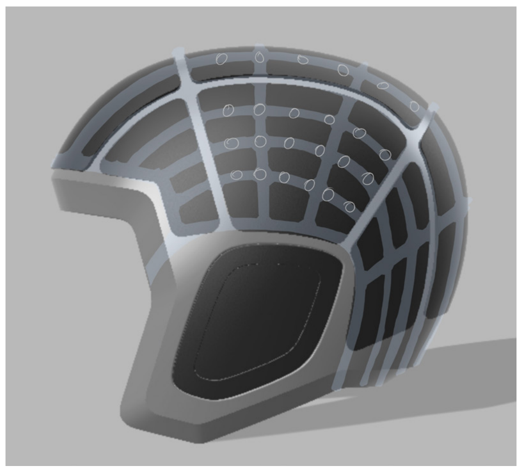








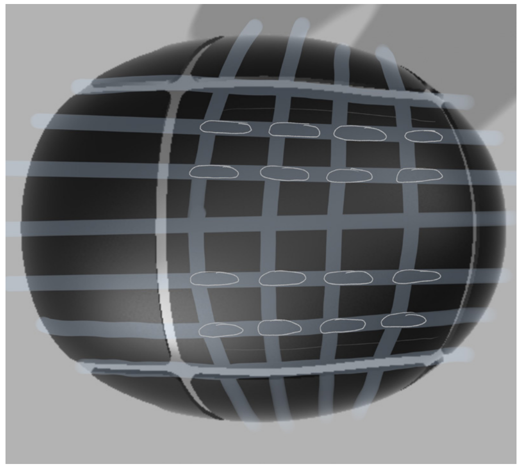


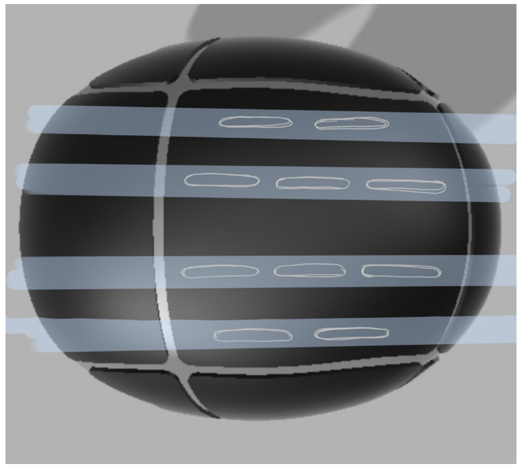


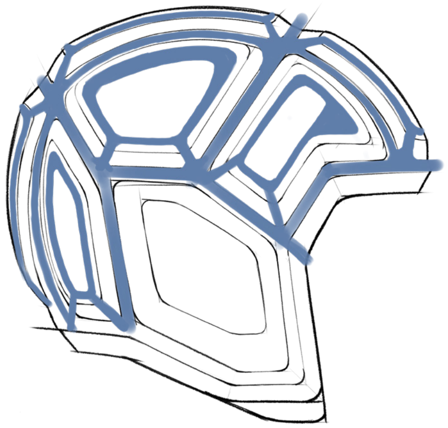
The blue lines represent the channels inside the helmet. To keep the water out of the face, designated exits have for the water where designed. One exit around the cheeks, and the rest towards the back of the helmet. Padding along the edge of the forehead stops the water from running in the face when the helmet is tightened.

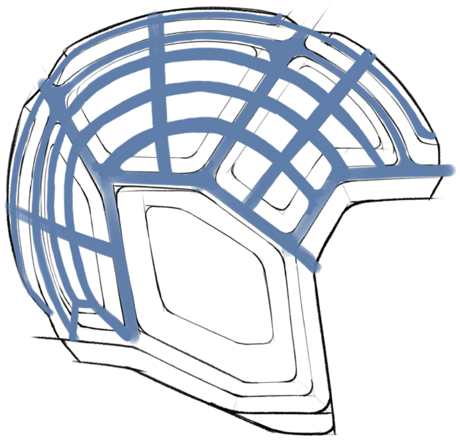
With the channel pattern I was developing, I had to decide whether the helmet should have full thickness in the gaps, maximising safety, or channels, maximising flexibility. Because the added panels would make the helmet stiffer than the original soft prototype, I decided that the channels should also run along the gaps to provide flexibility.

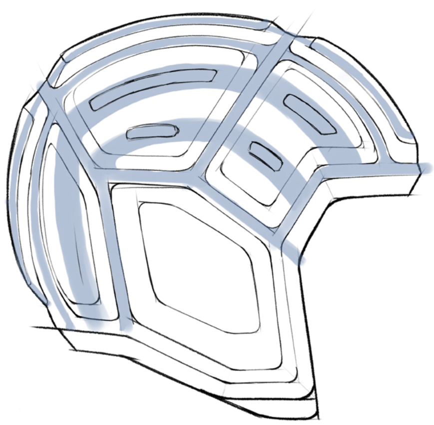
For the ventilation to work properly, I wanted to place the ventilation holes along the channels, so that both the air and the water moves easier through the helmet. It was therefore a bit of a puzzle to match the ventilation holes with the channels.





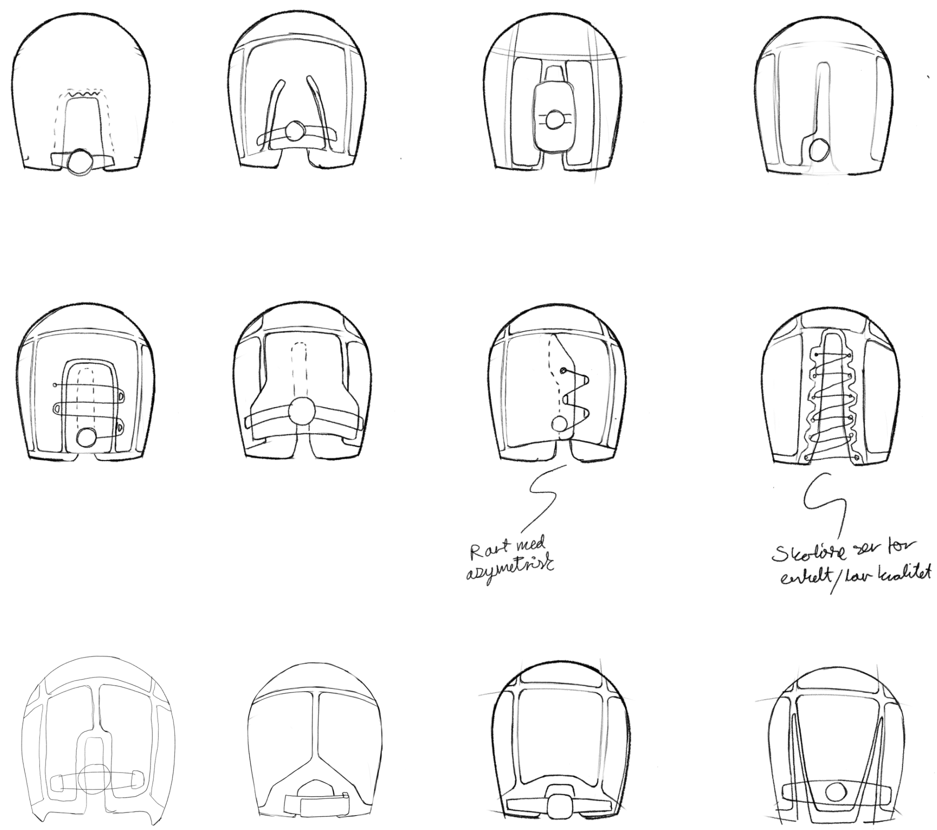


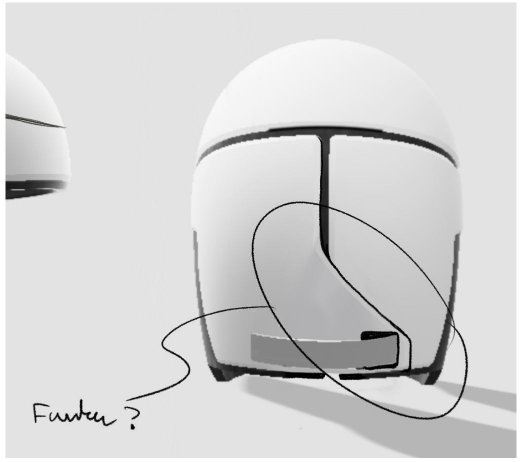


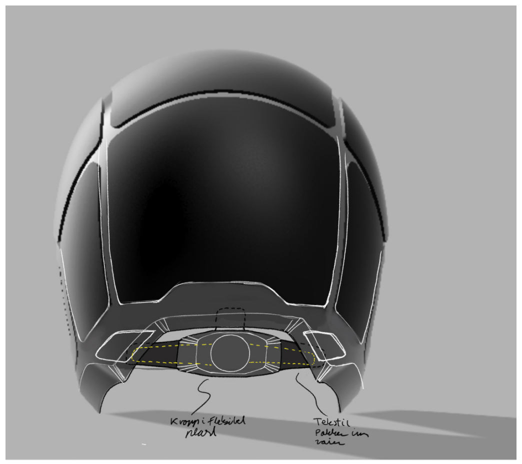
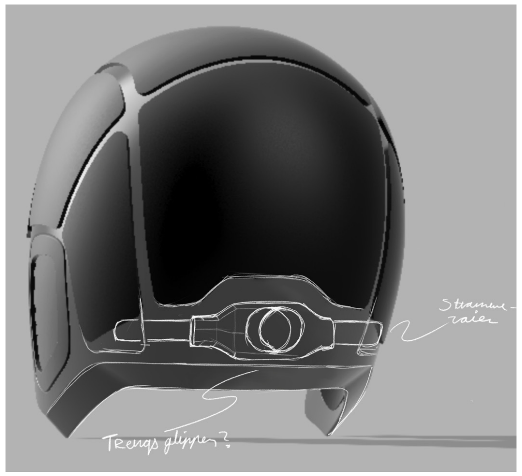


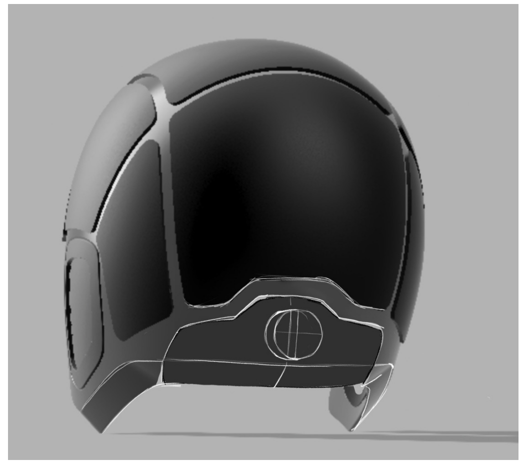
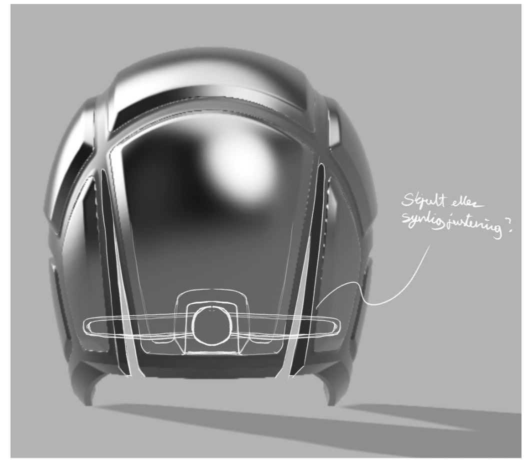
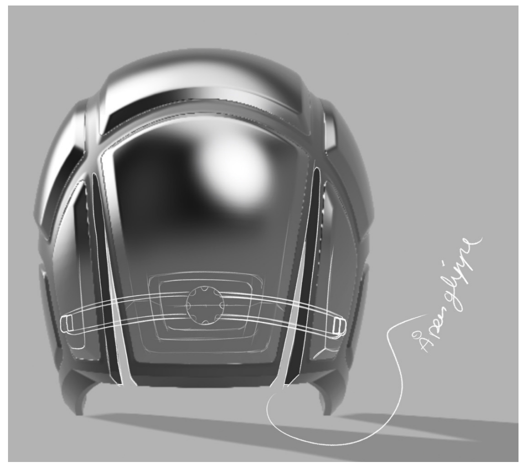
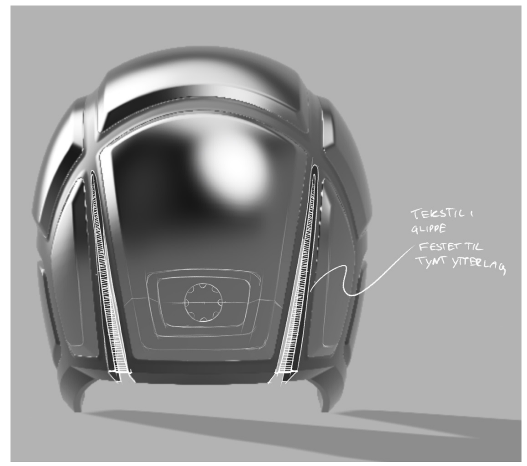
5.6 Adjustment Mechanism

The design of the adjustment mechanism was based on my experience with the prototype, and the possibilities that had been discovered during market research. The same hugging feeling as the prototype was the goal. However, as the concept had been developed and was more complex, some changes were needed. Firstly the Velcro strap seemed a bit to simple to fit with the helmet, as well as it was not possible to get a symmetrical mechanism. I also wanted a more user friendly mechanism, because achieving a good fit was key. Even though the strap was quite simple, it both hands to be adjusted and some precision to fit the strap correctly. Different solutions of adjustment mechanisms was explored, together with how the core and the panels would work together with the adjustment mechanism.





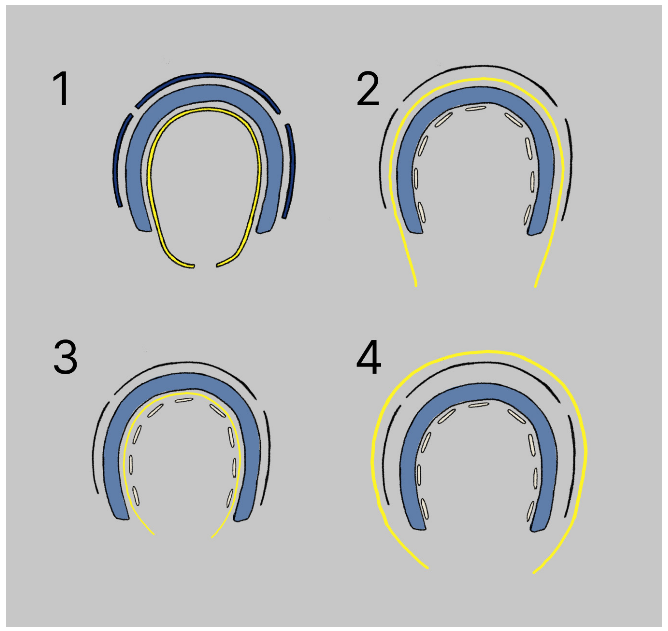





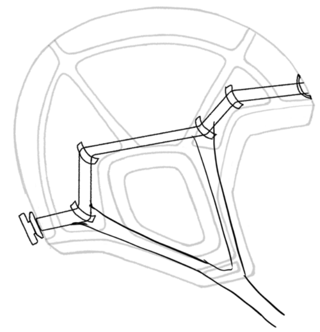
To achieve the amount of adjustment that would allow surfers to use the helmet both with and without a hood, and for the helmet to achieve the hugging fit, two slits in the core between the panels in the back. This also allowed connecting the turn dial to the solid panel, which made it possible to integrate the rest of the mechanism. The gaps are covered by a strong and durable textile. This leaves some protection against the elements, and keeps the users hair inside the helmet and away from the adjustment mechanism.

5.7 Reinforcing the Core

While the visco elastic foam is effective against impacts, the same cant be said for it´s structural durability. This became evident during the testing of the soft-shell prototype, as the material started to tear in the jaw strap. While this also might be due to the low production quality of the hand made prototype, it seemed like the helmet would need reinforcement, especially to provide solid attachment points for the retention strap. I first explored how a band on the inside could be added, to provide more structural strength in specific areas. However this would be complicated with the complex core structure. I drew some schematic figures on the different possibilities in terms the different layers.

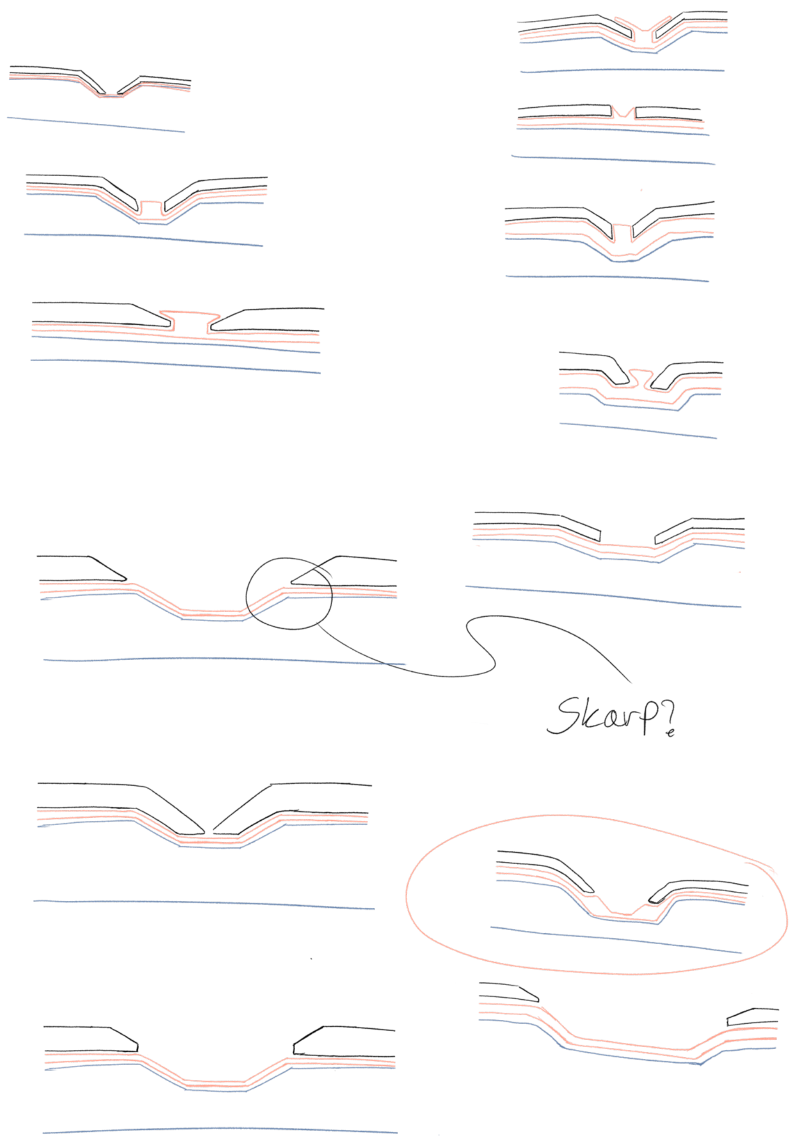
The first drawing represents the added band on the inside. This was seen as complicated. The third option would place a reinforced layer between the core and the smaller “pads” in the core. The forth was to cover the whole outside. This did not make sense since the hard panels should be the outermost protective barrier. The second has a reinforced layer between the plates and the core. This could give better fastening possibilities for the panels, as well as making it possible to add some resistance to cuts in between the panels.





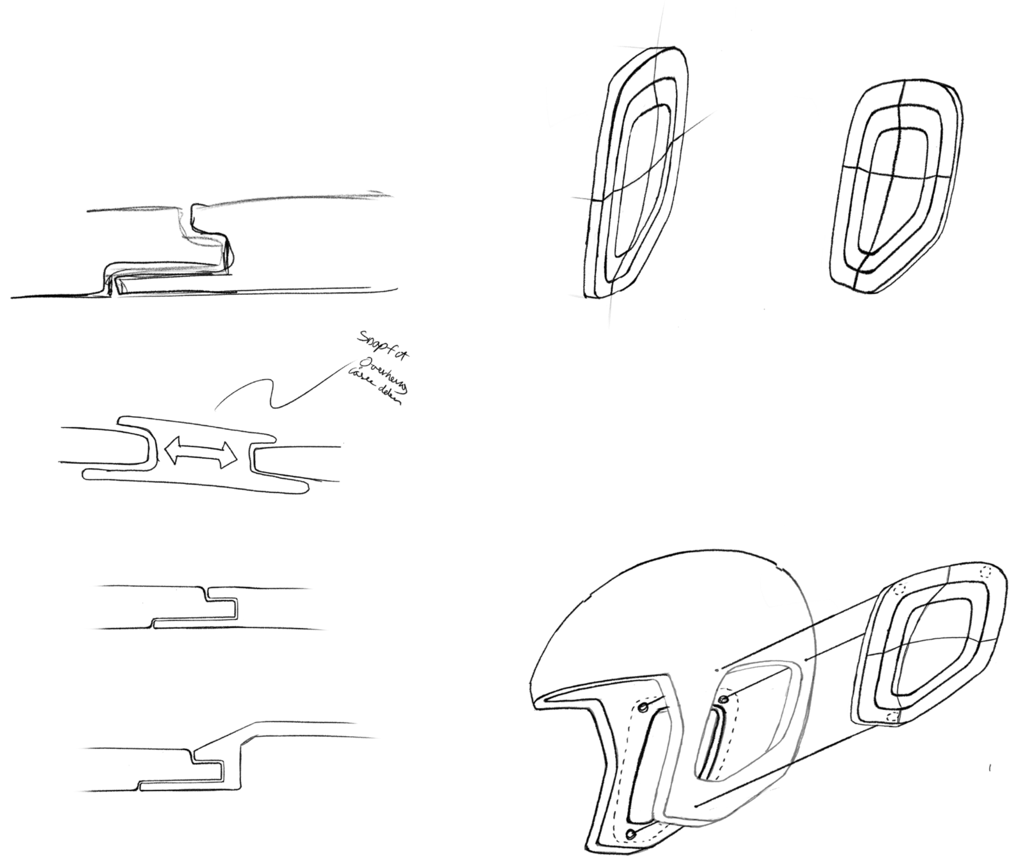
The drawing lower drawing to the right shows the chosen concept for reinforcement, with a thin layer of a material with more tensile strength than the core. It could also vary in thickness, achieving extra strength in the necessary regions.

How the reinforcement layer would meet the panels was explored in schematic sketches. I wanted to create a defined transition between the to different materials. The reinforcement should also not be too thick in the gaps, as it would reduce the flex.



5.8 Snap-Fit Ear Pads

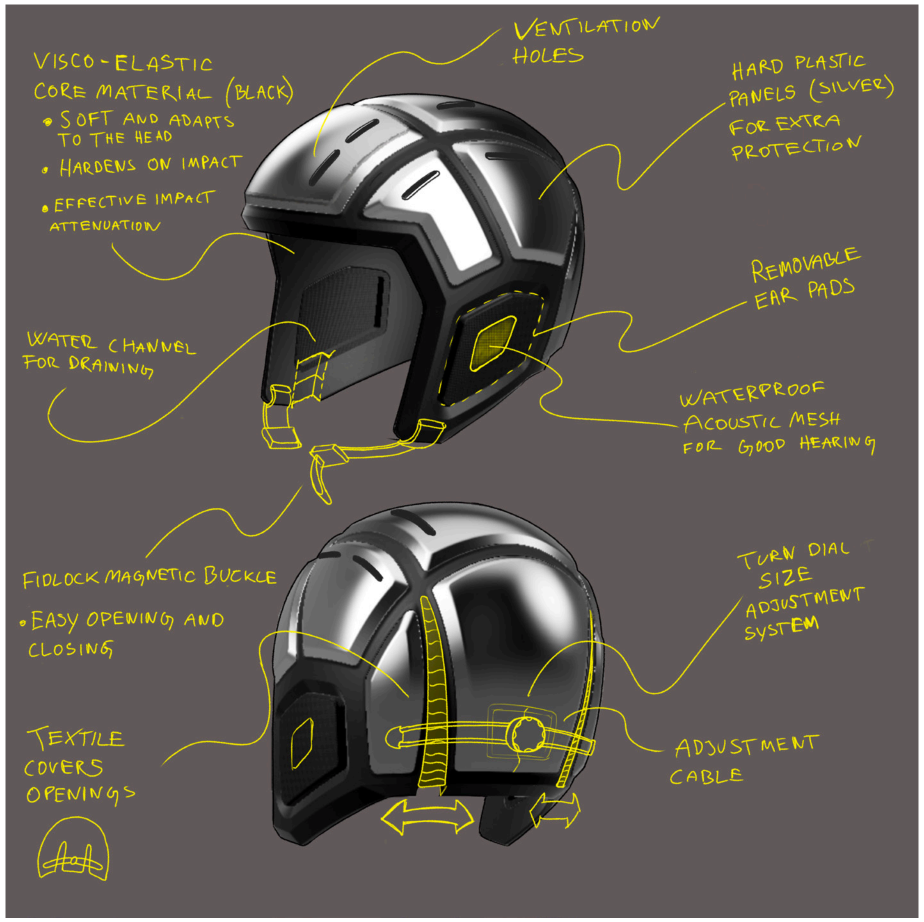
Because surfers reported that they did not like their ears covered, having the ear pads detachable would be a bonus for the product. These were designed to snap into a cut out around the ears. As the ear pads cant fall off inwards when pushed against the head, the main lip of the snap cover would prevent the air pads from falling outwards and a smaller lip on the outside that snaps in place. While it needs some rigidity to snap properly, its important that the feature does not worsen the experience when the ear pads are worn, as this likely achieves the best performance in the water.



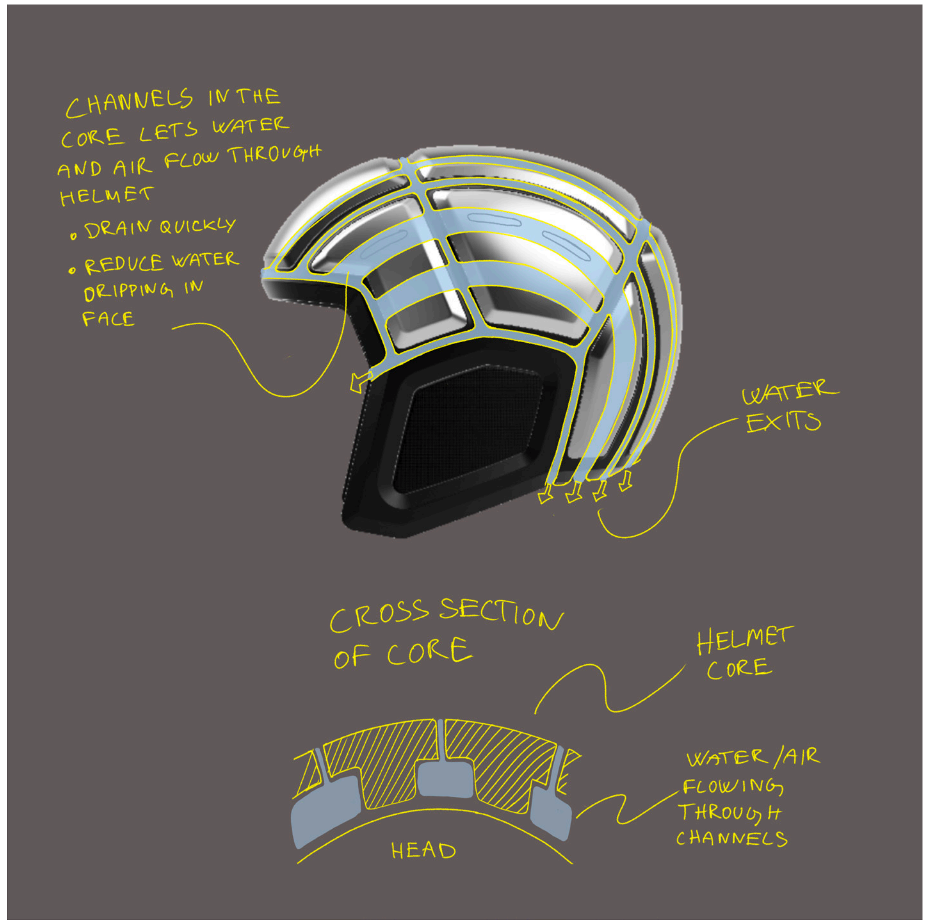
5.9 Concept Feedback

In the final stages of detailing the concept, I wanted to get some feedback on the design from the surf community. I therefore contacted and got feedback from nine of the most experienced surfers I could reach. They were presented with the following description and explanatory images.

> The surf helmet concept combines a soft helmet core with hard exterior panels, to give a feeling that the helmet is more part of the body (kind of like a wetsuit hood, but thicker). It uses a visco elastic core material (black in drawing) that is soft and adapts to the head, but due to its visco elastic properties it hardens on impact and provides effective impact attenuation. To provide optimal fit, to gaps in the back (covered by textile) make the helmet adjustable and close fitting, easily operated with the turn dial.



On the inside of the core, channels make the helmet more ventilated. These also lets water drain out quickly and guide the water to reduce dripping in the face.



While it can be assumed that surfers I know will be kind in their feedback, it was very positive none the less. Both in terms of appearance and functionality.

> “The helmet looks epic! Let me know if you ever make them! I´ll buy one for sure. I hit my head bad a couple of years ago and have been looking into helmets but there isn´t much variety. Looks like you have thought everything. Especially that soft part to adapt to the head because a lot of helmets can be loose and actually make it more dangerous than not wearing one.” - Tim Matley, expert surfer

> “Wow that looks awesome!” - Male Expert surfer

> “Don´t know much about surf helmets, but that looks completely next level!” - Male Expert Surfer

> “Such an exciting and cool project! It looks like you’ve thought of everything.” - Female, Expert Surfer

> “Think it looks really good actually! Have only tried one type of surf helmet (olaian soft helmet) and have friends using helmets. We have all discussed that a shapeable and “soft” seems like the best. I like this concept as it is soft, but with hard on top” - Female, Norwegian National Team Surfer

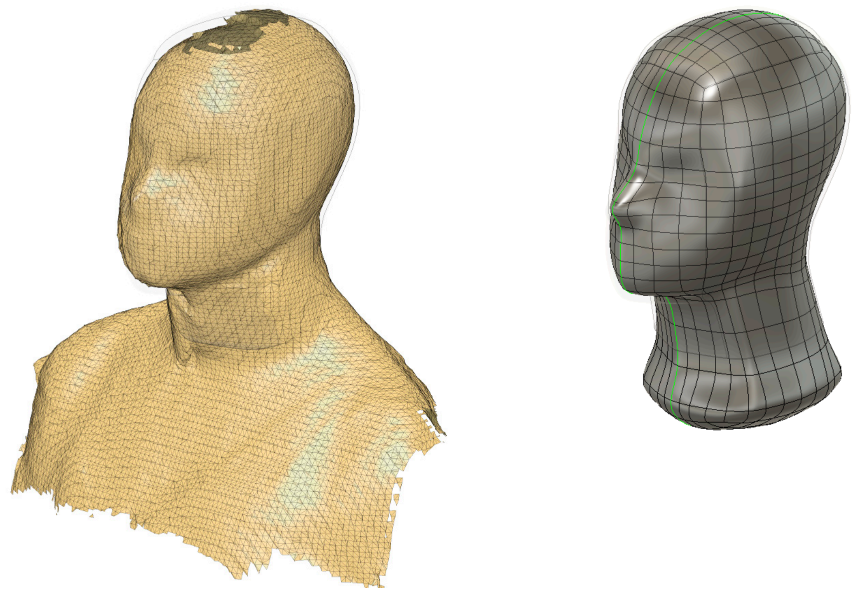
> “Looks pretty rad! If they work and the fit is good, I´d buy and sell them. Hard to get a proper feel for it off a drawing but it looks good, especially the first drawing. Whats the plan?” - Male, expert surfer and owner of Surfshop. no (top 10 largest singular hardware shop in Europe)

Two surfers stated that it would be nice with a small brim, as a sun protector but also for aesthetic reasons. This was countered by another who stated that not restricting the field of view is the priority when surfing the type of waves that he wants a helmet for, and a brim can get brushed by the wave resulting in blocking the vision. With the positive feedback, I was eager to continue the development.

5.10 Fit Adapting the 3D Model

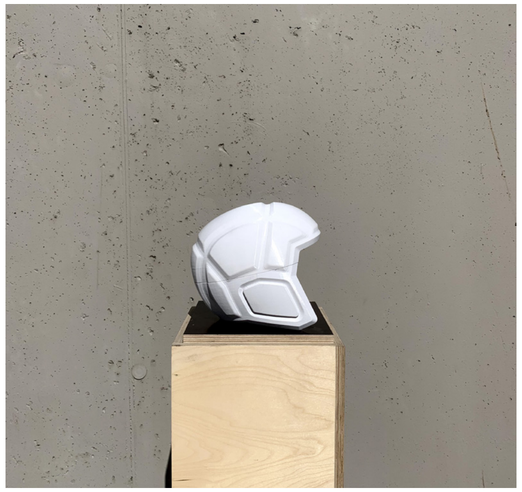
Getting a physical model that had the correct dimensions and ergonomic fit would make it possible to test the helmet further. To achieve this, 3D scanning was chosen as the best tool to capture a human head shape. With some help from my girlfriend, I was able to capture my head using the Lidar-scanner on the Ipad Pro.

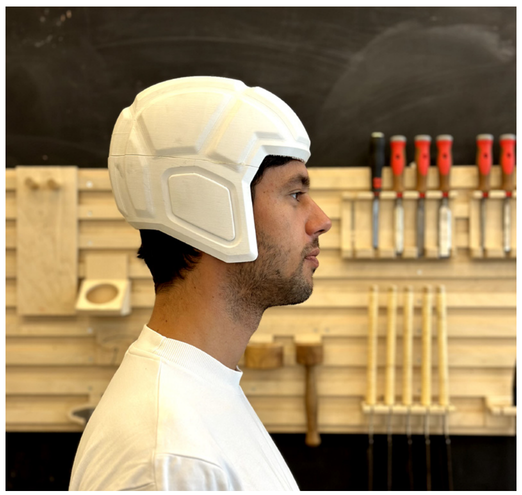
As the scan was not of high quality, the mesh was remodelled in Fusion 360 using the scanned shape as a guide. While the scan was not of high detail, it was thought to be enough for it´s purpose. The shape was then incorporated in the internal shape of 3D model.

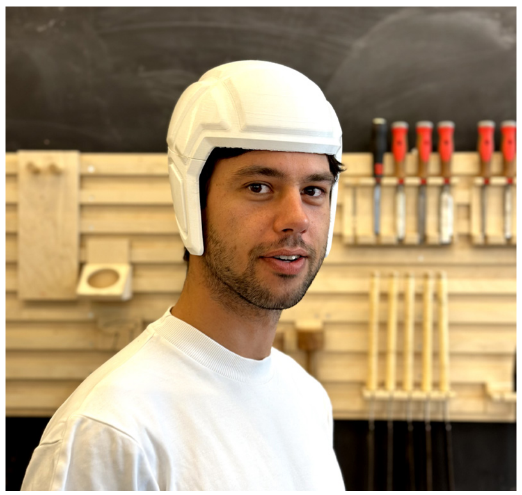


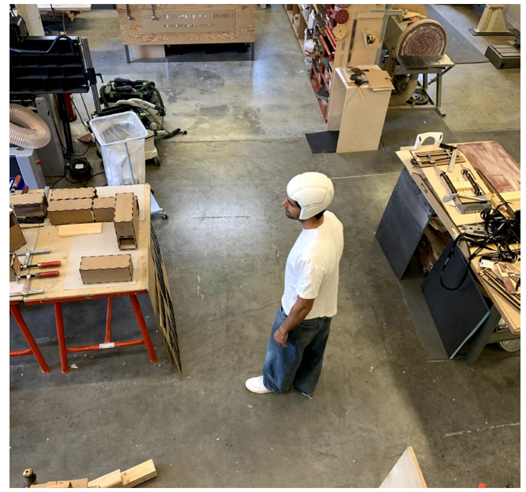
5.11 Physical Evaluation

The 3D model of the helmet was 3D printed, to see how the it looked in physical form as well as testing the fit. Seeing the elevated panels in real 3D, they clearly communicated the extra protective zones effectively, as well as giving it a distinct character. The channels along the sides also achieved giving the helmet a clear direction.



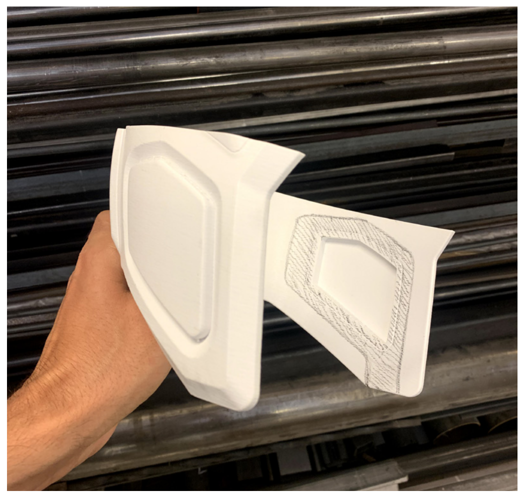






Even though the model was printed in hard PLA plastic, the overall fit and dimensions seemed to be good, prooving that the technique of using 3D scan was effective. There was no problem with the field of view, as the helmet could not bee seen at all.

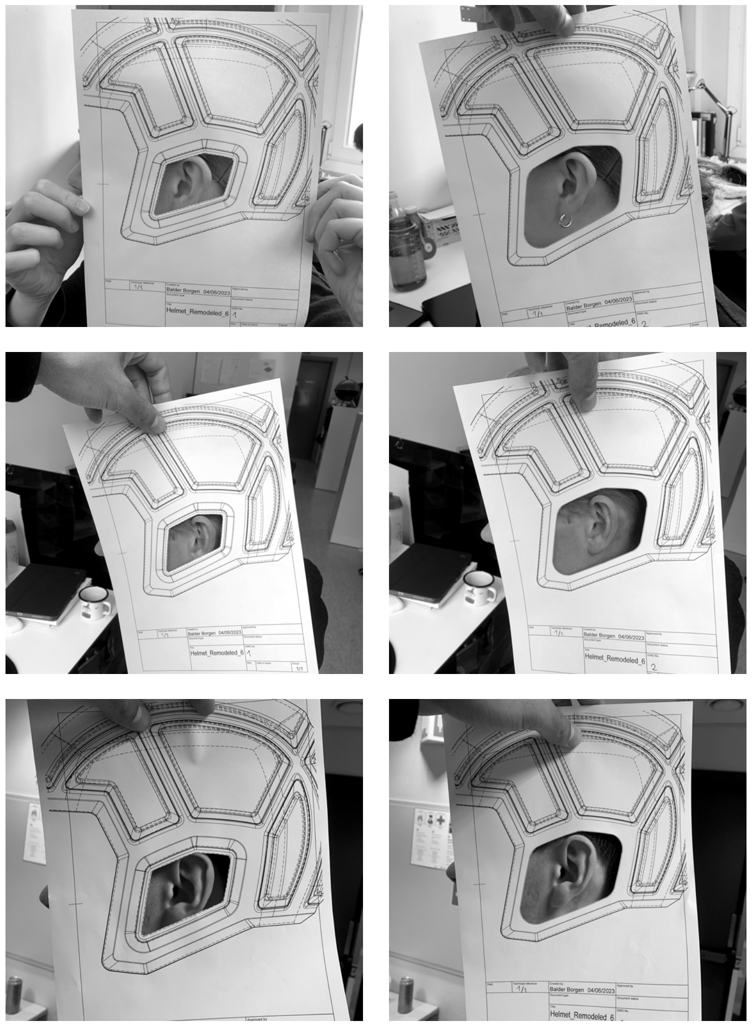
One drawback was the fit of the earpads, which was too small. Even though this problem probably would have been less noticable with soft core materials and flexibility, I still wanted to achieve a great fit for the ears. I marked the area on the model that should be removed to get a better fitting earpad. I also tried to see if the helmet fit with a wetsuit hood. As can be seen in the photo below, it was a bit small, but this was thought to be solved by the flexibility and adjustment mechanism of the helmet.



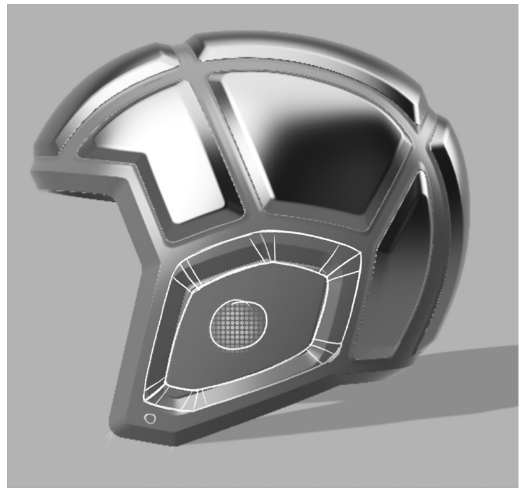
5.12 Fit Adapting the Ear Pads

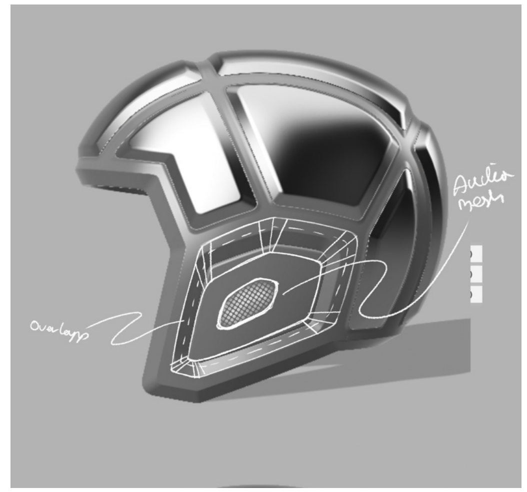
To makes sure the ear covers were nicely dimensioned, I carried out a simple study. By printing out the side view technical drawing and cutting out the ear pads, both the original size and the maximum size, I could use this to check how well other people´s ear would fit. Six ears were tested, three male and three female. The original was clearly too small, while the maximum gap a lot of room.

Original   Enlarged



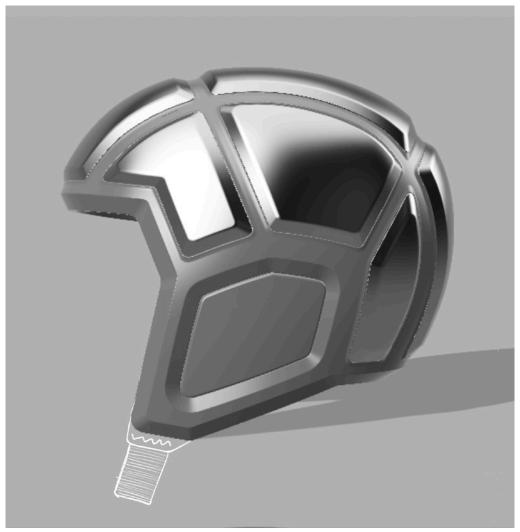
The ear pads were adjusted to make more room by increasing the circumference and changing the form. The angled surfaces, similar to the panels, allow for more ear space and integrate the ear pads more seamlessly into the helmet design. By adding an acoustic mesh instead of simple holes, the idea is to achieve less reduction of hearing, as well as better ear protection against the harsh elements, helping preventing surfer´s ear.

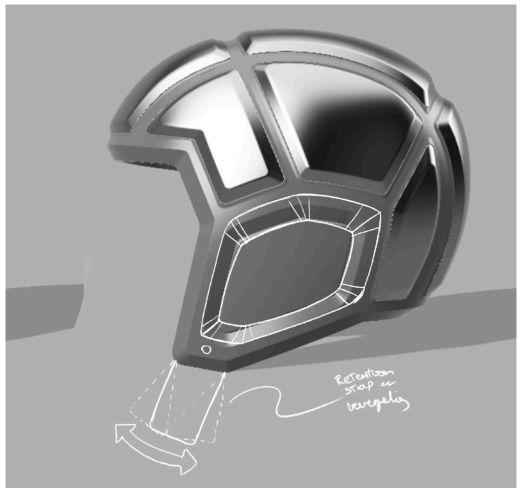


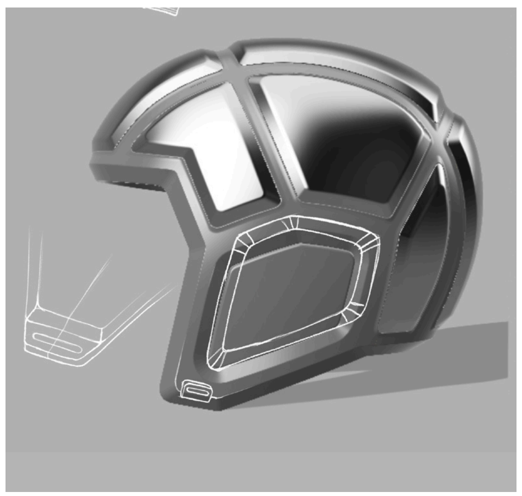


5.13 Chin Strap

I explored a couple of simple solutions for the chin strap. Because of the reinforced layer, the lower part of the ear loop would provide necessary strength. I chose the last solution, as it was the most visually pleasing and looked to be the most durable as well.

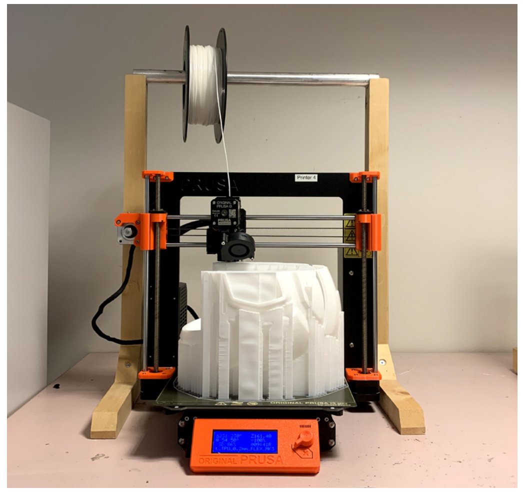


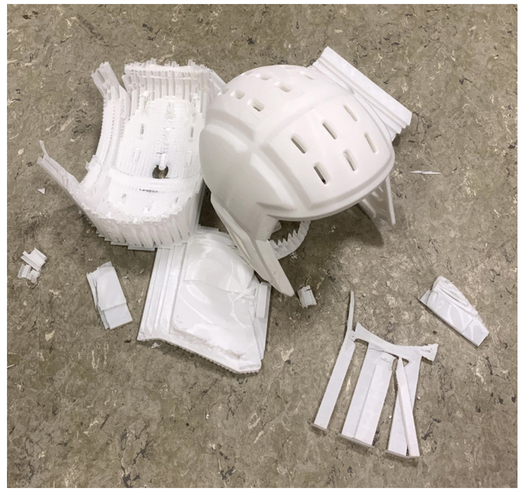




5.14 A Prototype for Further Testing

With the purpose of further testing the concept, a more functional prototype of the concept was created. It was made through 3D printing with TPU, a flexible plastic. The prototype will be quite close to the envisioned product, however the TPU makes the construction more stiff. Padding pieces of the visco elastic material will be glued inside the helmet, a boa adjustment mechanism in the back and a retention straps with buckle to fasten the helmet. With 3D printing with TPU being readily available, this will be the way forward in regards to further prototyping and testing.





6 Result

6.1 Optimal Fit With Ease

The helmet is adjusted using a turn dial Boa adjuster. It allows for ease of use with quick and precise fitting of the helmet. The mechanism cable are fitted within the durable fabric that closes the gap. By doing so, a clean look with no loose exterior parts is achieved. Due to the flexible construction, the helmet fits surfers from day to day and season to season, both with wetsuit hoods and without.

6.2 The Core Structure

The shock absorbing core is made of a visco elastic material, which is soft at rest and hardens on impact. This unique feature of the material makes it possible to provide excellent comfort, while also offering optimal impact protection.

The channels in the core are carefully designed with four aspects in mind: providing effective ventilation, controlling water flow, reducing the weight and mitigate rotational accelerations in oblique impacts.

Controlled Water Flow
The channels are guide the water that enters the helmet in the right directions, with exits over the ear pads in the front and in the lower back of the helmet. A band of padding along the forehead edge keeps the water from running into the users eyes.

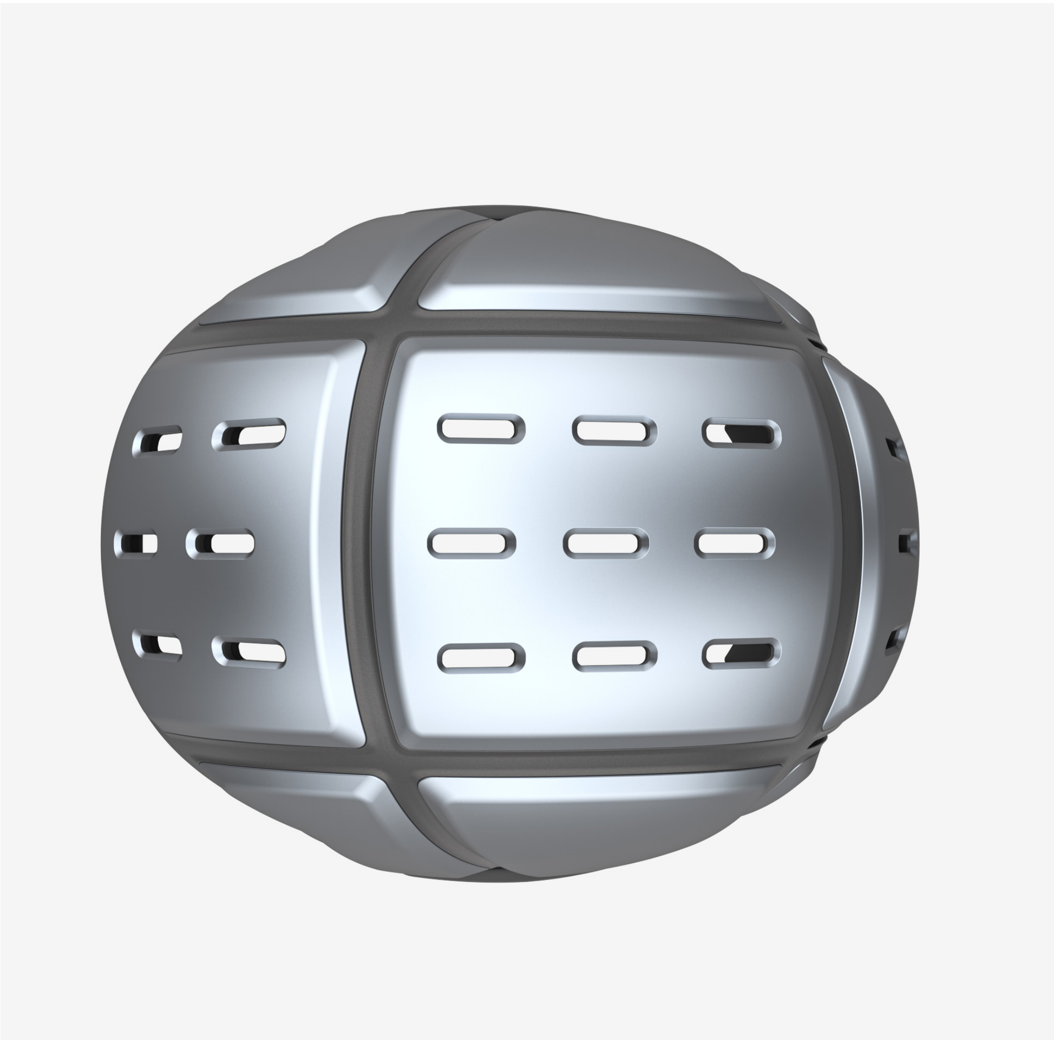
Effective Ventilation
The ventilation holes are direct openings that by matching with the channels, increase the breatheability and cooling of the helmet.

Weight Reduction
By removing material from the core, the weight of the helmet is drastically reduced.

Mitigation of rotational accelerations
Due to the division of the core and the flexibility of the material, each “pod” has the ability to shear. This gives the helmet as a whole the ability to reduce rotational accelerations that occur in oblique impacts, further increasing the safety of the user.

Core Channels

The ventilation holes matches with the channels in the core, increasing the effect of the ventilation, as both air and water travels easier in the helmet.



6.3 Ear Pads

Snap Fit

The ear pads are an important part of closing the helmet for optimal performance in the water. However, surfers might experience warm conditions where having open ears increases comfort. Therefore, having the ear pads as cut outs instead of additional pads, the ear pads are an integrated part of the helmet, and it communicates that it is the primary way of using it. The ear pads are fitted to the helmet using a snap fit profile. This makes them easily detachable for surfers that want a less covering helmet in warm conditions.

Waterproof Acoustic Mesh

The ear pad has a waterproof acoustic mesh. This reduces the harmful effects of the wind and water to the ears, while still providing excellent hearing.

6.4 Quick and Easy to Use Buckle

Quick and Easy to Use Buckle

The buckle on the helmet is a Fidlock Hook. This type of buckle offers great ease of use, as a magnet connects the buckle. It is fastened “automatically” by placing the two pieces close together, and is released by pulling the red strap. This feature makes it easy for surfers to both fasten and release the buckle, even with cold finger or wetsuit gloves.

6.5 Components Overview

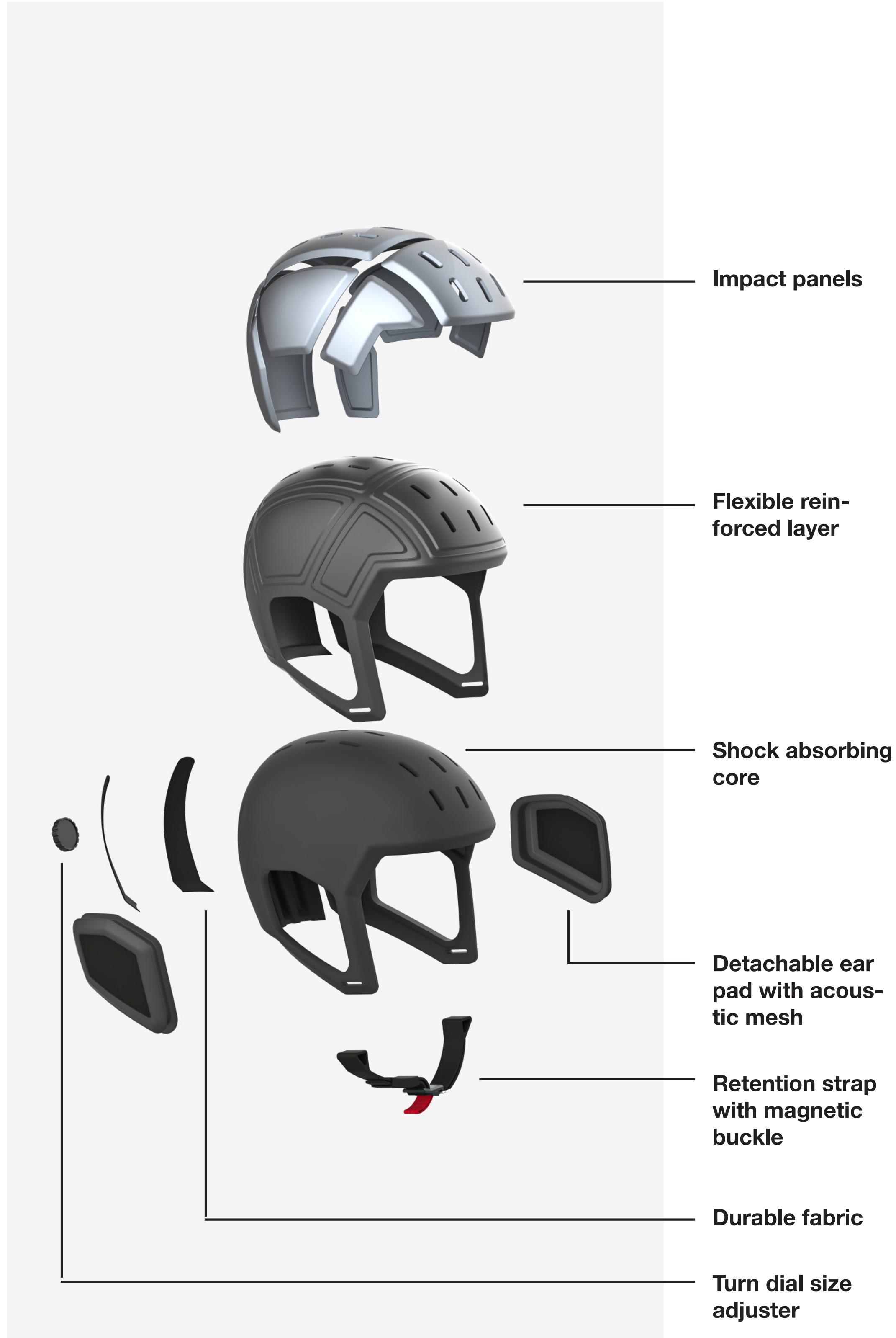
Shock Absorbing Core
Starting on the inside, the core made of SAS-TEC visco elastic foam, provides both comfort by adapting to the user's head and excellent impact attenuation. It has a varying thickness from 1 to 2 cm, where the lower parts are thinner and the back of the helmet is the thickest to provide extra protection in the most critical area of the head. The channels in the core have three purposes. First, it provides better ventilation and makes the water drain quickly and away from the user's eyes. Second, it reduces the overall weight of the core. Third, it gives the helmet shearing properties that can reduce the rotational accelerations in oblique impacts.

Flexible Reinforced Layer
Fused to the core is a thin flexible layer of fibre reinforced TPU. This layer provides more durability to the foam core and strength for fastening the retention strap, while still being flexible. It also increases the resistance to penetration and cuts in the flexible zones.

Impact Panels
Lastly the helmet has nine ABS impact panels, that provide extra protection against sharp objects and help distribute impact forces over a larger area. They also give the helmet a more protective look, which helps distinguish it from typical soft-shell helmets. The shells are bonded to the TPU reinforcement layer with industrial grade glue.

Detachable Ear Covers
The ear covers are fastened by a snap fitting mechanism, locking them inside the ear loops. They are padded with the same material as the core, but have a waterproof acoustic mesh that provides optimal hearing while protecting the ear from harsh winds.

Fit and Size adjustment
The helmet comes in the sizes S, M, L, and a boa adjustment mechanism is used to adjust the helmet size and fit. Due to the twin cutouts in the core, covered by durable textile, the helmet is highly adjustable and gives the hugging feeling. It fits like a glove whether the user chooses to use a hood underneath or not. The adjustment is operated easily by the turn dial, which lets the user turn to tighten and loosen, to find the sweet spot. The cables are hidden inside the textile to give a cleaner look.



6.6 Visual Expression and Form Language

It has been a challenge throughout the project to design a helmet that visually fits surfing. To accomplish this, the focus has been on avoiding strong associations with inappropriate helmets, such as cycling and skiing helmets. These are perceived as too bulky and out of context, contributing to an impression of the helmet being uncomfortable for surfing because most people are familiar with how these kind of helmets feel. Therefore, the aesthetic aspect of the task has largely been based on promoting what is unique about the helmet, namely its functional qualities; flexible but protective, fitting closely and sleek in the water.

The soft-shell prototype might arguably fit with surfing because it resembles wetsuit hoods that already exist. However, it has also become clear that it does not communicate protection well enough to be accepted as a serious helmet. As the concept has evolved, it has therefore become important to also promote the helmet as a protective product. The most crucial element here has been to include hard panels. However, esthetic changes have also been made, inspired by other sports protection, that highlight the panels as extra-protected zones. This includes elevating them from the rest of the helmet and slightly increasing the thickness of the padding under the panels. By doing so, the zones communicates enhanced protection, while also making clear that the hard panels are the outermost layer of protection. Elevating the panels also naturally makes the areas between the panels perceived as more flexible. The helmet can then be read as soft and comfortable but also effective as protection. At the same time, there is a balance to be struck to avoid making the helmet bulky, making increasing the visual water resistance. It is also a form of honesty not to hide what may be seen as a safety weakness, namely the gaps between the plates, and that one consciously chooses this helmet because of its unique attributes. The helmet’s interior further contributes to this, both visually and functionally, by having thinner padding in the flexible areas. These channels also clearly communicates thoughtful optimising of weight, ventilation and water draining capabilities.

It has also been essential to design in a way that communicates the helmet as a modern and high-tech product. To achieve this, it has been key to use a precise form language. The angled transitions highlight the helmet’s three-dimensional shape, contributing to a dynamic expression, and promote that it is manufactured with advanced industrial production methods. This makes the helmet perceived as more modern than current surf helmets, which have a more two-dimensional expression. Additionally, the slanted surfaces contribute to a more streamlined appearance. The slanted surface along the edge of the helmet, combined with positioning of the hard plates, especially contributes to conveying the helmet as closely fitting, enclosed, and offering little resistance in the water.

6.7 Colours

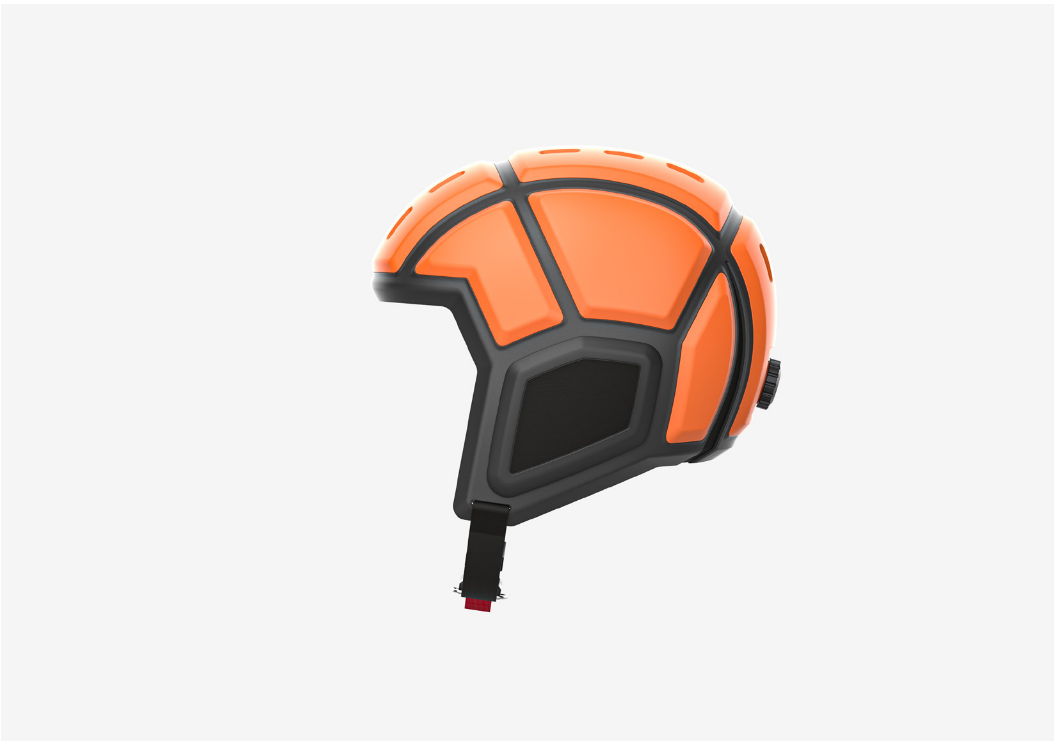
The helmet is designed in four initial colour schemes: metallic blue, metallic black, signal orange and white.

The metallic blue has been chosen as the main colour way, as it adds a modern, high-tech feel, highlights the hard panels and contrasts the soft black core to reinforcing the impression of the helmets core functionality. It also captures and reflects the different blue colours of the sea, making it appear different but always in harmony.

The orange colour way is made for surfers looking for added visibility in the sea, as an extra safety precaution or just to stand out from the crowd.

The black is the most anonymous, and is made for surfers that simply want a clean black look, or for added warmth.

The white helmet is designed to keep a cooler temperature in warm weather.



6.8 Reflections and Future Work

Challenges

Surfers with Helmet Experience
Because the use of helmets are not normal in surfing, it has been challenging to find surfers that use helmets, to find out what can be improved from their experiences. I made up for this challenge by getting my own experience with using a helmet, before and during the project.

3D Modelling
The tecnicality of 3D modelling at the level I wanted was a roller coaster. It was such an important tool to detail the concept in the end but also when used as a guide for sketches. Seing models come to life with the precision that is achieved together with 3D printing has been amazing. However achieving this has a been a huge challenge and a great learning experience.

The technicality of Helmets
Digging deep into the subject of helmets has been very interesting, however navigating this technical field of different types and solutions was difficult. It has helped to base parts of principles or materials on already existing products, as a way of insuring that it is within reason.

Future Work

Now that I have successfully made a promising concept that both delivers on key user needs such as comfort in the water and with appealing looks, i am motivated to continue the development.

Because the 3D printing with TPU together with padds of visco elastic foam, adjustment mechanism and a retention system makes a pretty realistic prototype of the concept, the first focus will be on testing this prototype together with other surfers. This will allow to make necessary adjustments for optimal user experience.

Moving forward, the impact performance of the helmet also needs to be tested and optimised. Checking if the intended materials achieves the necessary performance for certification and how it compares to other competitors.

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