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Optimizing Foam Construction for Seat Comfort

An Investigation into how the Shaping and Layering of Foams with Different Hardness Affects Seat Comfort

Master's thesis in Industrial Design Engineering and Product Development

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DEPARTMENT OF MECHANICAL ENGINEERING

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Cover: Rendering of the top and bottom foams that were designed in the second
design iteration.

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Abstract

The gaming chair market has long been dominated by maximalist aesthetics and designs inspired by motorsport without prioritising comfort. This thesis, conducted in collaboration with Fractal Design, investigates how varying the cushion hardness across the seating area can be used to optimise seat cushion comfort for gaming chairs.

Through a pre-study comprising of a literature review, patent research, competitor analysis, user studies, and expert interviews, a user needs list was established to guide the design process. Furthermore, the competitor analysis found that gaming chair aesthetics are highly flexible, allowing seat cushion geometry and material selection to be optimised for comfort without compromising market relevance.

Two iterative design phases followed. In the first, 12 concepts were generated and evaluated using a Kesselring matrix and user tests on low-fidelity prototypes, leading to the selection and subsequent manufacturing of three higher-fidelity prototypes. In the second iteration, the two best performing concepts were combined into a final design, a two-part foam cushion with an engineered mating surface that effectively varies foam hardness across the seat interface. Three final prototypes with identical average densities, but different hardness ratios between their top and bottom halves, were manufactured using 3D-printed moulds and evaluated by 15 participants.

The results demonstrate that a horizontally layered foam construction, with a softer upper layer and a harder lower layer, outperforms a homogeneous foam of equivalent average density in, terms of perceived comfort, by changing its pressure distribution properties. The concept with a 17% denser bottom layer ranked highest in comfort and was perceived as the softest, suggesting that engineered foam constructions can create a more comfortable seating experience, simultaneously providing a soft initial sensation and adequate structural support.

Keywords: product development, seat comfort, foam construction, polyurethane foam, gaming chair, pressure distribution, multi-layered foam, ergonomics, seat cushion design.

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Furthermore we want to extend a heartfelt thank you, to the people at Fractal Gaming Group AB, who have supported us greatly from start to finish, both by providing financial support as well as providing participants from the company, for several studies throughout the project. We would like to especially thank Carl Haug Hornborg, our supervisor at the company, for his diligent support, high engagement and excellent feedback at every stage of the project; through your guidance we were able to avoid several pitfalls throughout the course of the project and without your support, it would have never reached such a high level of fidelity. Additionally we want to individually thank the rest of the chair team at Fractal Design, being Magnus Bengtsson and Lukas Andersson, for their enthusiasm and support during the project.

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CLD	Compression Load Deflection
IFD	Indentation Force Deflection
IHF	Initial Hardness Factor
LLM	Large Language Model
MIF	Modulus Irregularity Factor
PU	Polyurethane
SF	Sag Factor

List of definitions

The following is the nomenclature and definitions of some terms that have been used throughout this thesis:

Compression Load Deflection	The hardness of a foam, measured in kilopascal (kPa) at a given percentage of its original thickness (Swedish Standards Institute, 2025)
Effective shape	The shape that the seat cushion will take under load
Indentation Force Deflection	The hardness of a foam, measured in newton at a given percentage of its original thickness (Swedish Standards Institute, 2008)
Hysteresis Loss	The difference in loading and unloading energy, defined as: $\frac{LoadingEnergy - UnloadingEnergy}{LoadingEnergy} \cdot 100$ (Moon et al., 2020)
Initial Hardness Factor	Change in hardness from 5% to 25% indentation, defined as: $\frac{25\%IFD}{5\%IFD}$ (Moon et al., 2020)
Modulus Irregularity Factor	A measure of how linear the change in IFD is between 20%-40%, defined as: $2 \cdot 20\%IFD - 40\%IFD$ (Moon et al., 2020)
Sag Factor	Percentage change in hardness from 25% to 65% indentation, defined as: $\frac{65\%IFD}{25\%IFD}$ (Moon et al., 2020)
Upholstery	The material used to cover a seat

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1 Introduction

This chapter will provide the background, aim and limitations of the project, as well as the specific research questions which this report serves to answer.

1.1 Background

Fractal Design is a designer and manufacturer of premium PC hardware including cases, cooling, power supplies and accessories. Recently the company has ventured into the gaming chair market, launching their first gaming chair Refine at Computex 2024 (Fractal Gaming Group AB, n.d.). Now, Fractal Design seeks to deepen its understanding of what defines comfort in gaming chairs, with the seat as the primary focus of this project.

1.2 Purpose & Aim

The purpose of this project is to investigate how multilayer foam constructions with engineered internal geometries, producing varying hardness across the seat surface, can be used to manipulate the pressure distribution of a seat cushion and thus improve its perceived comfort. Building on this, the aim is to develop and manufacture a high-fidelity gaming chair seat cushion prototype, to be tested and evaluated by users.

1.3 Methodology

The project comprised 3 distinct phases, a pre-study, and 2 subsequent design iterations. A strong knowledge foundation was initially built on a pre-study, consisting of a literature review, patent research, user studies, a competitor review audit, and several interviews with experts in relevant fields. The data derived from the pre-study was ultimately compiled into a list of user needs, to be used as a means to scrutinise concepts generated in the following stages.

Following the pre-study, design iteration 1 was initiated and concepts were generated and evaluated based on the needs outlined in the pre-study. A subsequent evaluation phase, followed by a higher fidelity concept generation phase then transitioned into a prototype manufacturing phase, after which the prototypes were put through user tests as well as pressure testing, to validate the performance of each concept. The outcomes were documented and subsequently passed onto the next design iteration.

Design iteration 2 took the outcomes from design iteration 1 and narrowed the solution space further, with the intent to raise the concept maturity. Based on the result from the prior work, a final concept was generated. A higher fidelity manufacturing process was adopted and a final prototype was manufactured. However, in order to once again widen the scope, a total of three prototypes were manufactured, with different functionality, in order to be evaluated alongside one another in a final

prototype evaluation.

1.3.1 Report structure

This report has a somewhat unconventional structure, and is therefore described here for the ease of readability. The report initially covers the pre-study and the two design iterations as their separate, yet overlapping phases. These are then followed by a summary of the results, a discussion and a final conclusion as per the standard report format.

The pre study and both design iterations are documented in the report with the following structure: a methods chapter describing the approach and methods for the iteration, followed by an implementation of methods chapter, which describes the manner in which each method was applied and goes into further detail of how every step was conducted. Following this, each iteration has an outcomes section, which covers the objective outcomes of each implementation, and finally a Key findings section describes the most important findings from each iteration and its implications for the overall project. This structure is used in order to get the method and their implementations closer to their respective results which in turn reduces the user's mental load and makes it easier to go back to previous parts of the report.

1.4 Limitations and delimitations

Some options in terms of manufacturing and types of solutions, which could have benefited the project may not have been pursued due to financial restrictions. Workshops, tools and equipment were primarily limited to what is available to thesis students at Chalmers university of technology. However, the company offered additional help on this matter, particularly in regards to the manufacturing of prototypes.

The seat cushion is only one part of many that make up a gaming chair and whilst it might be the one that affects comfort and ergonomics the most, it is not the only component that does. Despite this, in order to ensure that the project was feasible within the time frame the seat cushion was the sole focus of the project and other components such as the back and arm rests were disregarded. However, to ensure that the seat cushion's design was not limited by the arm and or back rests they were assumed to have excellent adjustability.

To ensure that the concept and prototype developed can be mass produced, manufacturing processes were limited to those used in the industry today. Whilst it was ensured that the prototype is feasible for mass production, detailed process selection was outside the scope of the project. Similarly the material selection was generally limited to materials used in the industry today. However, this restriction was disregarded as long as the feasibility of mass production could be ensured.

Since the ergonomics of a seat cushion are highly dependent on an individuals anthropometry, one singular solution cannot be optimal for everyone at once. Hence, early concepts focused on minimizing compromises between differently sized users, being anywhere between the 5th percentile female and the 95th percentile male.

In order to reduce the scope of the project to become more manageable within the time frame, the effect that posture has on the sitting experience was not a focus. Instead, the study focused on optimizing comfort for an active seating position, with an upright posture with a neutral spine, and did not explicitly account for potential effects to the results, if other types of seating positions or postures were assumed by users.

1.5 Research questions

1. How does the gaming market's expectations limit the solution space for a gaming chair seat cushion?
2. Can foams of different hardnesses be combined into a singular seat cushion in order to create a varying hardness across its surface?
3. Can a cushion's pressure distribution properties be manipulated by varying the hardness across its surface?
4. Can the pressure distribution properties of a seat cushion be manipulated in order to improve the seat comfort, compared to a homogeneous foam cushion?

2 Pre-Study

This chapter covers the foundational research of the project which was conducted in order to sufficiently define the problem space, to begin design work. The chapter is divided into 3 main parts, being: Methods, Implementation of methods, and Outcomes.

2.1 Methods

This section of the report presents the methods used during the pre-study.

2.1.1 Patent Search

According to Dentons (2026) there are five main types of patent searches out of these only what they call a landscape search will be covered here. A patent landscape search is the most general form of patent search and is usually performed early on in the product development process. They can provide the developers with valuable information about patent publications in the given area of technology and in turn guide decision making by identifying crowded areas, sparking new ideas and of course what solutions are already patented. The output of a landscape search is often a short report highlighting interesting patents, key patent filers and technology clusters. Furthermore, patents can be found by either looking at the patents that fall under a given classification or that were filed by competitors, how these differ will be explained further in the next sections. (Dentons, 2026)

Classification search

Searching patents by their classification is a powerful method in which you filter patents by categories. It starts at the highest level and then the category that is the most suitable for the type of patent that is of interest is selected. Then one of the many sub categories is selected, this step is repeated until the category has a reasonable amount of patents to investigate. A classification search can be performed on multiple different classifications until a suitable amount of data has been gathered.

Applicant Search

During an applicant search the patents are instead filtered by the applicant or inventor listed on the patent. This often produces fewer but more relevant patents than classification search but includes the risk of missing relevant patents that were not filed by the companies or individuals considered. It is a powerful tool to identify what type of patents competitors have filed and to investigate trends in their filings that could indicate what their next steps are.

2.1.2 Perceptual mapping

Perceptual mapping is a method used to identify how users or consumers perceive brands, product or services. The data gathered from the perceptual map can then be used for a number of things such as:

- Identifying market gaps
- Enhancing brand positioning
- Refining marketing strategies
- Supporting product development
- Improving decision making

A perceptual map is created by first identifying the attributes that should be used, these should reflect what is the most important for your target audience or what is of interest of evaluating. It can also be beneficial to identify to "opposite" of the attribute in order to create a spectra. This could be the direct opposite such as "warm" and "cold" but could also be more indirect such as "work" and "leisure". The next step is to select the products, brands or services that should be compared. The chosen products should provide a comprehensive view of the market, that the audience might see as a alternatives but that also could span the entire market space. Once the attributes and products have been selected create the tools needed to perform the perceptual mapping. Place the attributes and their "opposites" on the end of an axis to create a two dimensional coordinate system and provide some way for the user to position the product/brand/service onto the perceptual map. This can be done both digitally and physically based on what is most suitable. The participants in the study should be selected carefully to ensure that they are representative of the market that is being investigated. Finally, ask the participant to position the product in relation to the attributes and other products and record the results. (Atlassian, n.d.)

2.1.3 Interviews

Interviews are powerful tools that can be used in many different ways; however, the main goal is often to gather some type of information related to an interviewee that is uniquely related to their experiences or knowledge. This project exclusively utilized semi-structured interviews, and thus only this interviewing approach will be described in detail.

A semi-structured interview uses a set of pre-prepared questions to guide the discussions. However, it relies on the use of probing and follow up questions in order to gather information beyond the initial answer. Due to this it provides space for the interviewee to elaborate on their answer and for the interviewer to gain a deeper understanding of why they answer they way they did. Furthermore, interviews can often feel like interrogations and the reduced formality can often lead to the participant being more relaxed which in turn can lead to them providing more genuine answers which results in more accurate data. Semi-structured interviews does this whilst ensuring that the essential questions and topics are covered across participants.

2.1.4 Needs list

A needs list is a tool used to present the needs that a user would like a potential solution to fulfil. Each need should be phrased in terms of what the product should do and not how it should do it and be formulated in the positive, i.e. what it should do and not what it shouldn't do. The needs should be phrased with the same amount of specificity as the data used to generate them and be expressed as a property of the product and not the user. Finally, words like "should" and "must" should be avoided as they indicate the importance of the need, instead each need is given a numerical rating based on how important it is in relation to the other needs. (Ulrich & Eppinger, 2016)

2.2 Implementation of methods

This section describes the way different methods have been implemented during the pre-study. The purpose of the section is to provide the nuance necessary to recreate the study.

2.2.1 Literature review

The literature review aimed to identify what aspects of a seat cushions design that impact seating comfort the most. Additionally it aimed to find any design guidelines that should be adhered to. Furthermore, it attempted to create an understanding of how comfort can be defined and how it should be defined within this project.

The literature review started very broad with the intention of creating an understanding of the literature that was readily available. Sources were mainly found via Scopus and examples of keywords that were used are:

- seat
- cushion
- seat cushion
- comfort
- material

As the literature review continued and more information was gathered the literature review gradually became more specific. The focus thus over time shifted from an initial screening in order to get a grasp of the literature landscape to one where the aim was to gather the information that was deemed to be the most helpful for the rest of the project.

2.2.2 Patent search

A patent search was conducted using two separate methods, classification search and applicant search, both of which were performed using *Espacenet*. The aim with the patent search was to identify interesting solutions that solve important problems. Both to ensure that developed concept don't encroach on existing patents but also to provide inspiration for the ideation phase.

Classification search

In order to get a general grasp of some of the patents available, a patent search based on their classification was conducted. The main classification investigated was *A47 - CHAIRS; SOFAS; BEDS* but more focus was put on *A47C 7/02 - Seat parts* and *A47C 7/00 - Parts, details, or accessories of chairs or stools*.

Applicant search

To identify what competitors within the market are planning on doing an applicant based patent search was conducted. This was done by using the "advanced search" function and filtering for the applicant names of competitors such as Secretlab, Razer and Herman Miller.

2.2.3 Competitor analysis

A competitor analysis was conducted in order to gain insight on market trends and what competing brands are doing well in the industry. The analysis consisted of two parts, one part using a perceptual map, combined with a user study to compile a comparative analysis between brands, followed by a competitor review audit to gain wider insight on the market's perception of various aspects of competing brands' products.

Perceptual mapping

On one axis Office chair - gaming chair was used in order to derive what form, function and material design choices that are related to which market. Gaming was assigned on the left of the x-axis in order to not subliminally influence the participant to assign a higher value to the "gaming" category. On the y axis, minimalist-maximalist was assigned, with maximalist at the bottom of the axis and minimalist at the top, contrary to what one would intuitively expect. This triggers the participant to invoke their critical thinking and forces them to engage more critically in the exercise. Furthermore, these scales were selected because the company is a minimalistic gaming brand and thus the goal was to identify how it can be ensured that the seat cushion matches this perception.

Initially 25 office and gaming chairs of varying designs were gathered for the perceptual mapping process. Once these were identified, an internal perceptual mapping was performed. Afterwards, 10 chairs that were deemed less indicative of their positioning on the perceptual map were removed. This was done as to reduce redundancy, without any major consequences for the results. The investigated chairs can be seen in Table 2.6.

The user study for the perceptual mapping method was carried out with seven workers at the company, who are both themselves users and have a background in the gaming industry and a deeper understanding of subtle design cues than the layman. This in order to gather as much quality information as possible from a small sample size to later analyse and derive some of the design guidelines for the project. Throughout the process, comments and reasoning by the participants in

the study were also noted for further analysis.

In order to verify the company's internal perspective, a secondary study was carried out, this time with seven potential users/customers. Once both studies had been carried out, the data gathered was transferred to a graphic plot, deriving coordinates of each participant's results using affinity design as a tool. The coordinates for each chair and of each user was recorded in an excel sheet, to allow a graphical visualization comparing each study. A graph compiling the results of each participant was then created in order to create an overview of the overall user's perception of the products investigated.

The comments recorded from each study were fed through a large language model (LLM) system with engineered prompts to derive a framework according to each respective study of how the company compared to the user base perceive various design elements of office versus gaming chairs. This data can then be applied as the foundation for the design framework of a perceived comfortable gaming chair.

Competitor review audit

Reviews were collected on some of the most popular brands of gaming and office chairs, in order to further understand the psychology of the users. A multitude of reviews were scoured, and those focusing on qualities relating to the product itself were recorded in an excel sheet. Once a sufficient amount of data had been collected, it was summarised and categorised through the use of prompts given to a LLM. The data served to contextualise the needs of the targeted user, by providing background on previous experiences. Subsequently this information could therefore predict the expectations as well as the opinion of users on any given concept.

2.2.4 Expert Interviews

Semi-structured interviews were conducted with experts in their respective field with the intention of discussing the findings made in previous steps of the data gathering phase in order to get a more complete understanding and to get explanations of any questions that had been identified. Furthermore, these interviews aimed to identify in which areas further data gathering was necessary.

What individuals that were interviewed was selected on an ad hoc basis and it resulted in interviews being conducted with experts in:

- Comfort
- Foam manufacturing
- Comfort testing

2.2.5 Specification of user requirements

By using the results from this chapter, design guidelines were created to serve as a form of summary of the results. Afterwards, these guidelines were used to gather the most important user needs, how important each user need is in relation to the others as well as which part of the seat that will affect each need the most. For

some of the needs, a short note was also added to give extra context. This could be anything, but some examples are clarifications of the need, explanations of its origins, or a proposed requirement.

Furthermore, The user needs were split up into four different categories; comfort, posture, quality and aesthetic. Similarly to how each need has a relative importance, these categories have a relative importance as well. The importance of each need is based upon how frequently it appears in literature and how large of an impact the literature deems it to have on the comfort. Additionally, the needs list was presented to experts within the area of seating comfort for gaming chairs and the importance of each need was modified based on their expertise.

2.3 Outcomes from Pre-Study

In this section, the findings of the data gathering phase of the project are presented.

2.3.1 Literature review

In this chapter the findings from the literature review are presented. It mainly consists of summaries of various different sources on different topics but also includes some key- and general takeaways from said sources.

The concept of comfort

The definition of the word "comfort" is according to Cambridge Dictionary (n.d.), "a pleasant feeling of being relaxed and free from pain". Despite this clear definition of the word, there is no universally agreed upon framework to describe the constituents and influencing factors for this feeling. However, this does not mean that researchers have not tried to define one; in fact, several previous attempts have been made. Two popular takes on the concept of comfort versus discomfort are: (1) comfort and discomfort lie on the same scale of reference and are entirely dependent, meaning low discomfort equals high comfort, and (2) comfort and discomfort are their own unique scales however, they can depend on interconnected factors.

Cambridge Dictionary's definition of the word "comfort" would likely agree with the first take (1) however, as research on the subject has become more nuanced, many researchers tend to adopt the second approach (2). One early publication on the subject does this, as shown in Figure 2.1, a theoretical model of comfort proposed by Zhang et al. (1996) puts comfort and discomfort on separate axes with the resulting feeling being interdependent on both values.

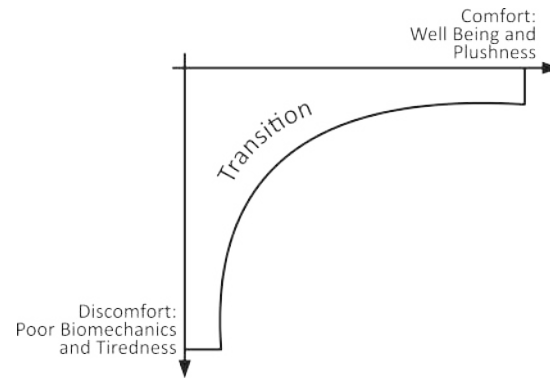


Figure 2.1: Hypothetical model of discomfort and comfort (Zhang et al., 1996). Adapted with permission

With time, our perception of comfort and its determining factors have developed and become more detailed. As written by Makris (2026), when referring to the theoretical model of comfort proposed by de Looze et al. (2003) which can be viewed in Figure 2.2. "Although influencing factors still relate to the context, product, and the individual, they extend beyond physical elements to include psychosocial aspects of the context, aesthetic qualities of the product, and the individual's expectations and emotions".

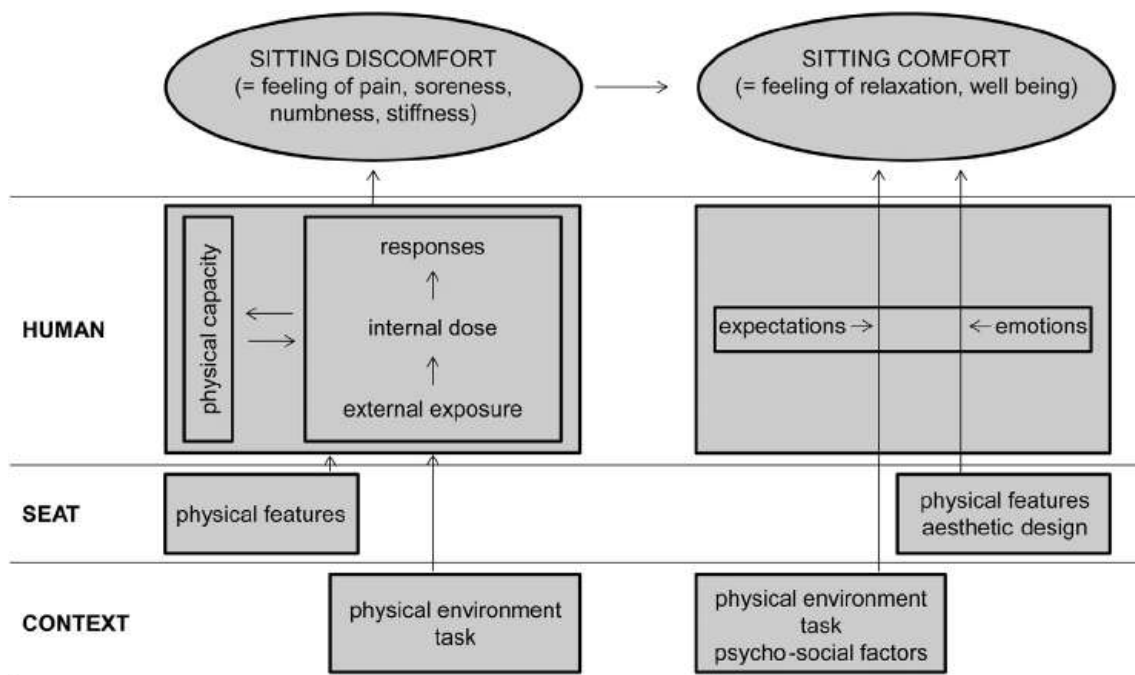


Figure 2.2: "Theoretical model of comfort and discomfort and its underlying factors at the human, seat and context level" as proposed by de Looze et al. (2003), reprinted by permission of Informa UK Limited, trading as Taylor & Francis Group.

Makris (2026) further expands on previous theoretical models of comfort and discomfort by proposing their own theoretical model depicted in Figure 2.3. This

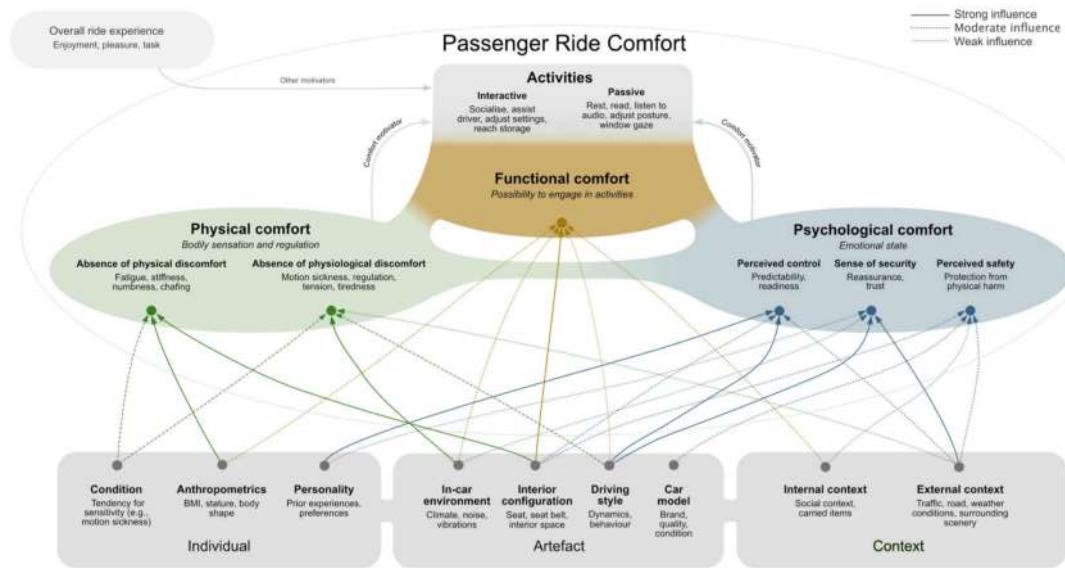


Figure 2.3: "The Passenger Ride Comfort Framework, representing the synthesis of empirical insights across Papers A to E. It illustrates the elements involved in passengers' perceptions of ride comfort, including the relationships between and within comfort dimensions and influencing factors" (Makris, 2026), reprinted with permission.

model, named the "Passenger Ride Comfort Framework" is based on empirical data gathered throughout Makris (2026) previous work. As written by Makris (2026), the model "describes passenger ride comfort as a multidimensional phenomenon, involving physical, psychological and functional comfort dimensions, and influencing factors of the individual, artefact and context.". Whilst this model is specifically within the context of passenger ride comfort, the general framework can be applied to any given context, by modifying the elements within to fit a new setting.

Multilayer seat cushions

Moon et al. (2020) investigates how seat cushions consisting of multiple layers instead of mono layers could impact the comfort of automotive seats. The source claims that whilst having similar hardness to that of the medium hardness foam the multilayer seat cushion has a similar Initial Hardness Factor (IHF) value to that of the soft foam. This, whilst simultaneously having a slightly higher Sag Factor (SF) value than all individual Polyurethane (PU) foams. However, there seems to be no significant difference in hysteresis loss and whilst the difference in IHF, and SF are relatively minor Moon et al. (2020) claims that they are improved for the multilayer seat cushion.

More interestingly Moon et al. (2020) show that the multilayer seat cushion has drastically improved Modulus Irregularity Factor (MIF) compared to the medium hardness foam. Since Bang et al. (2017) claims that passengers will experience a smoother sensation the closer to 0 the MIF value is this shows that the multilayer seat cushion could prove advantageous to that of a monolayer seat cushion. Whilst

(Moon et al., 2020) show promising theoretical results regarding the utilization of multiple layers with varying hardness the perceived comfort of such a solution has not been validated with users.

In order to perform a fair comfort comparison between multilayer and monolayer seat cushion the authors assume that their hardness should be similar. It is however difficult to approximate the hardness of a multilayer cushion by using the the IFD of the individual layers. This is in big part due to the non linear behaviour of flexible PU foams that can be observed in Figure 2.4.

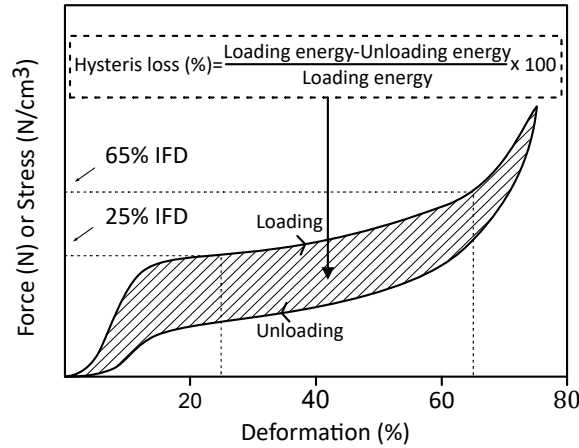


Figure 2.4: "A typical IFD curve of flexible polyurethane foam" (Moon et al., 2020). Adapted with permission.

In Moon et al. (2020) their multilayer foam consists of three foams with different IFD values, the values for the individual layers as well as for the multilayer cushion can be seen in Table 2.1.

Table 2.1: Approximate IFD values for the cushions investigated in Moon et al. (2020).

Layer	25% IFD values
Soft	87.5
Medium	155
Hard	200
Multilayer	150

The multilayer seat cushion investigated in Moon et al. (2020) has a hard layer in the bottom, two medium layers in the middle and one soft layer at the top, each layer is 1 cm thick.

If considering each layer as a spring, and the multilayer cushion as multiple springs in series whilst using Hooke's law the resulting IFD value becomes 136. How this number was achieved can be seen in equation 2.1.

$$\begin{aligned}
 F &= IFD = kx \Rightarrow k = \frac{IFD}{x} \\
 k_{Soft} &= \frac{87.5}{0.1 \cdot 0.25}, k_{Medium} = \frac{155}{0.1 \cdot 0.25}, k_{Hard} = \frac{200}{0.1 \cdot 0.25} \\
 \frac{1}{k_{eff}} &= \frac{1}{k_{Soft}} + \frac{2}{k_{Medium}} + \frac{1}{k_{Hard}} \Rightarrow k_{eff} \approx 1364 \\
 IFD_{eff} &\approx 1364 \cdot 0.4 \cdot 0.25 = 136
 \end{aligned} \tag{2.1}$$

If we instead simply take the average IFD value of all the layers the resulting IFD value becomes approximately 149, the equation can be found in equation 2.2.

$$\frac{IFD_{Soft} + 2 \cdot IFD_{Medium} + IFD_{Hard}}{4} = \frac{87.5 + 2 \cdot 155 + 200}{4} \approx 149 \tag{2.2}$$

Neither of these approximations are anywhere near accurate enough to provide a definitive measurement of the IFD for multilayer seat cushions, however they are useful to provide a grasp of roughly how hard the resulting composition will be when using multiple layer with varying hardness.

Pressure distribution

Zemp et al. (2015) conducted a literature review investigating if pressure measurements are a suitable tool for evaluating comfort/discomfort. Unfortunately they were unable to definitively answer if pressure measurements of the seat pan are suitable for assessing comfort due to limited available data. However, it seems that peak pressure, pressure distribution and pressure pattern changes are reliable tools for evaluating the comfort of a seat pan.

In order to determine the sensitivity of the ischial tuberosity Goossens et al. (2005) conducted research regarding how large of a pressure increase that is needed for a user to perceive it. The source comes to the conclusion that the pressure needs to increase by 13%-14% for the pressure increase to be noticeable in 50% of the trials. The source admits that their method of applying pressure is not representative for normal seating and that their test group was relatively young and that sensitivity could be expected to be different for elderly. However, a takeaway from this article is that it requires a relatively large difference in pressure for it to even be perceived.

Ebe and Griffin (2001) investigates how different material properties of a seat cushion affect comfort. They concluded that static seat comfort seems to increase as the IFD decreases but that the comfort drastically decreases if the cushion bottoms out and cannot be compressed further. However, this correlation only appears around the ischial bones and the surrounding area and there are no correlations when looking at the whole hip or only the thighs. Furthermore, Ebe and Griffin (2001) acknowledges that only short term comfort was investigated and that other factors may affect long term comfort.

In another study by Naddeo et al. (2024) they use the pressure distributions from 41 individuals and various seating positions to create a shaped pan. The resulting seat pan had a negative shape and is deeper where the average pressure was higher. The shaped seat pan was then compared with the standard one and 79% of participants preferred the shaped over the standard seat pan. Furthermore, in most cases; and on average the shaped seat pan resulted in lower average pressure and higher contact compared to the standard seat.

In Vink and Lips (2017) they investigated which part of the back and buttocks that is the most sensitive to pressure. They found that the parts of the buttocks that made contact with the front portion of the seat pan was more sensitive to pressure than the rest of the buttocks. Multiple of the presented sources claim that lower peak pressure and improved pressure distribution improve the seating comfort. However, the findings in Vink and Lips (2017) provides interesting context and it is thus uncertain if the pressure should be evenly distributed across the seat pan or if it is better if the pressure is higher in certain areas and thus lower in others.

2.3.2 Patent search

A list of 26 relevant patents were identified and summarised in a table. Each patent was given a relevance rating between 1-3 to indicate its feasibility of implementation onto the project. The identified patents that were given a relevance rating of 3 can be found in Table 2.2. This patent search provided valuable insight into existing solutions and serves to aid the concept generation.

Table 2.2: The patents with the highest rated relevance.

Patent ID	Description	Applicant	Relevance
US10219628B2	Pivoting seat cushion with a deformable ring	iii solutions GmbH	3
US10595636B2	Seat with collapsible function to change seat shape	UE FURNITURE CO., LTD	3
US11672356B2	Fluid filled bladders used to distribute pressure	COMFORT CONCEPTS PTY LIMITED	3
CN101166443A	Spring loaded mechanism at an angle	BOCK 1 GMBH & CO. KG	3
EP2764798A1	Rear placed springs to allow entire seat to pivot	KINNARPS AB	3
US12396571B1	Geometry and types of foam in Secretlab seat cushion	Secretlab SG Pte. Ltd.	3

2.3.3 Competitor analysis

The competitor analysis included a study using perceptual mapping in which users explained how minimalistic/maximalistic and office/gaming they perceived 15 differ-

ent chairs. Additionally it also included a competitor review audit in which reviews of gaming chairs were analysed. Both will be presented in this section.

Perceptual mapping

From the Perceptual mapping process several conclusions could be made around the perceived expression of different office and gaming chairs on a maximalistic-minimalistic scale as well as on a gaming - office scale. The first study was conducted with seven employees at the company. The results of the first study indicated a greater consensus on the different values compared to the second study conducted with seven various different types of potential users of the company's products. The chairs that were used in the perceptual mapping can be seen in Table 2.3, the mean position for where the chairs were placed on the perceptual map can be seen in Figure 2.5 and the placements of some selected chairs can be seen in Figure 2.6. The position for each chair, split up into groups for Fractal and students can be seen in appendix A.

Table 2.3: Chairs used for the perceptual mapping (*Colour in italic*).

1. DPJ Kontorsstol Ergo 312 - <i>Vit bas</i>	9. Office Chair Watford - <i>Black</i>
2. Fractal Design Refine - <i>Fabric Light</i>	10. LiberNovo Omni - <i>Space Grey</i>
3. Kinnarps Plus[8] - <i>Grey</i>	11. DPJ Kontorsstol Pirum - <i>Black</i>
4. Secretlab Titan Evo - <i>Artic White</i>	12. DPJ Kontorsstol Bliss (with headrest) - <i>Ljusgrön</i>
5. Herman Miller Aeron - <i>Mineral/Satin</i>	13. Hbada E3 Pro Ergonomic Office Chair - <i>Black</i>
6. Herman Miller Embody Gaming - <i>Cyan</i>	14. LightUp 250 Profim - <i>Grey</i>
7. TX3 Core Smart Loft - <i>Dark Grey</i>	15. ROG Destrier Core Gaming Chair - <i>Black</i>
8. Razer Iskur V2 - <i>Black/Green</i>	

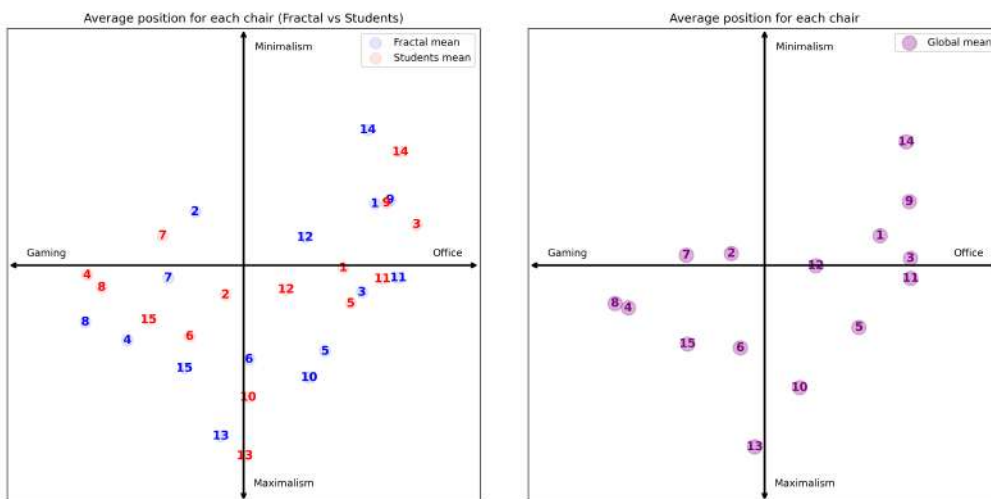


Figure 2.5: Mean position where each chair was placed, split up into students and employees (left) and not split (right).

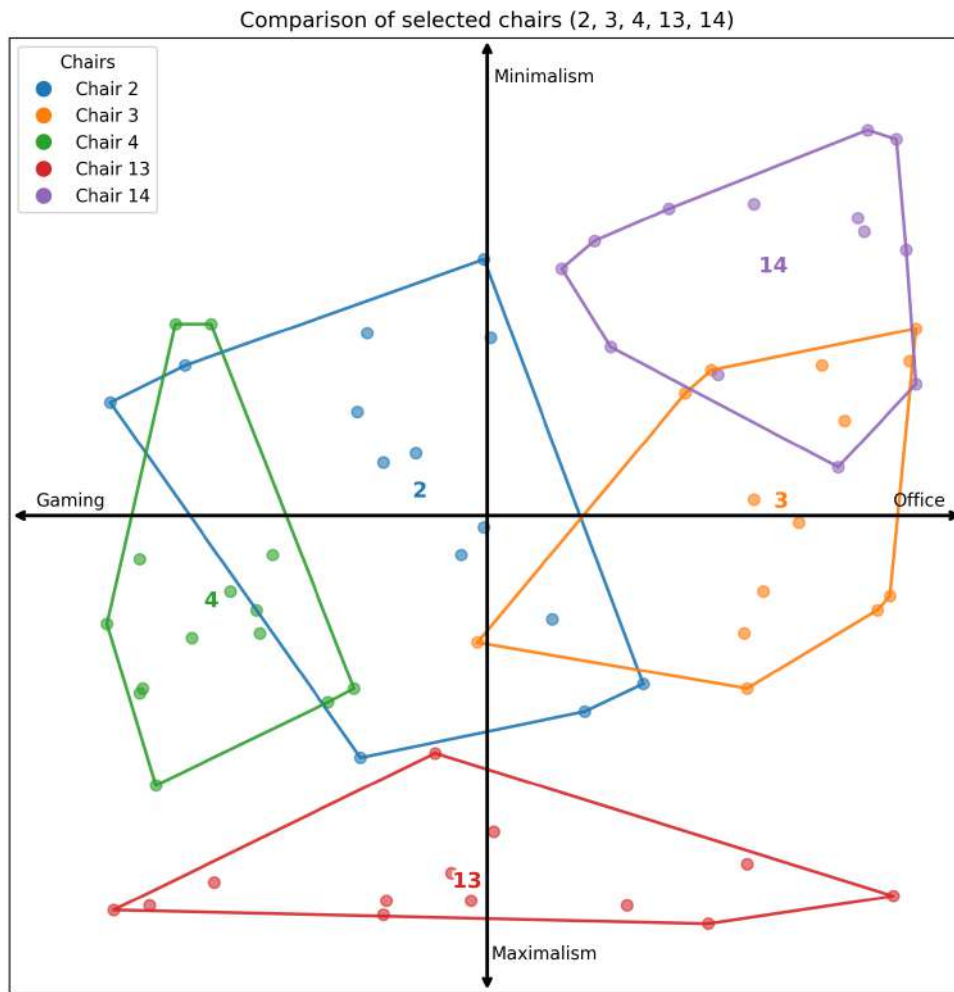


Figure 2.6: Positions for chair 2, 3, 4, 13 & 15 with bounding boxes.

From the first study, common sentiments regarding the two different axes can be viewed in Tables 2.4 and 2.5 below. What the students perceived as office or gaming can be seen in Figure 2.6 and what they perceived as minimalistic or maximalistic can be seen in Figure 2.7. How the perception differed between the participants in study 1 and 2 can be seen in Figure 2.8.

Table 2.4: Study 1: Office vs. Gaming Perception Framework.

Feature	Office Chair Perception	Gaming Chair Perception
Philosophy	Functional tool, active sitting, ergonomic focus.	Relaxation, escapism, "couch-like" comfort.
Shape	Straight lines, thin profiles, separate headrests.	"Racing" silhouette, bucket seats, integrated headrests, side bolsters/wings.
Material/Feel	Mesh, firm padding, "airier."	Thick padding, leather/PU, enveloping ("cocoon").
Aesthetics	Neutral, blends into environment, anonymous.	Aggressive, "sporty," attention-grabbing, centrepiece.

Table 2.5: Study 1: Minimalistic vs. Maximalistic Perception Framework.

Feature	Minimalistic Perception	Maximalistic Perception
Visuals	"Clean," "dipped" (one color/material), cohesive form.	High contrast, multiple colors, visible stitching, large logos.
Mechanics	Hidden controls, integrated mechanisms.	Visible levers, knobs, exposed frames ("exoskeleton").
Complexity	Simple geometric shapes, unified silhouette.	"Busy," many separate parts, complex curves ("blobs"), "gimmicky" features.

Table 2.6: Study 2: Office vs. Gaming Perception Framework (Students).

Feature	Office Chair Perception	Gaming Chair Perception
Vibe/Keyword	"Ergonomic," "Corporate," "Tråkig" (Boring), "Functional."	"Racing," "Space/Alien," "Relax/Lounge," "Centerpiece."
Shape	Slim/Thin profile, separate parts ("disconnected"), rounded/organic forms.	"Bucket" shape, side wings, integrated headrest, "square/blocky."
Material	Mesh, fabric, transparent/airy.	PU Leather, thick padding, solid/opaque.
Color	Monochromatic, neutral, "office grey/black."	High contrast (Red/Black, Green/Black), neon details.

Table 2.7: Study 2: Minimalistic vs. Maximalistic Perception Framework (Students).

Feature	Minimalistic Perception	Maximalistic Perception
Visual Complexity	"Clean," "Dipped" (one color), hidden mechanics, simple silhouette.	"Busy," visible levers/knobs ("skeleton"), exoskeleton frames.
Form Factor	Unified shape, continuous lines.	Many separate parts, "features suspended in air," "over-engineered."
Perception	Simple, "basic," "nätt" (dainty/neat).	"High-tech," "Expensive," "Grotesque," "Monster."

Table 2.8: Comparative Summary of Perceptions Between Groups.

Feature	Study 1 (General)	Study 2 (Students)
Defining Gaming Trait	"Racing" Silhouette & Integrated Headrest	"Massive" Size & "Thick" Cushioning
Defining Office Trait	Separated Headrest & Straight Back	"Skinny/Thin" Profile & "Boring" Colors
Visible Mechanics	Maximalist Office (It's a tool)	Maximalist Gaming (It's high-tech/sci-fi)
Logos	Seen as "Contrast" or "Visual Noise"	Seen as "Identity" & "Status" (Brand recognition)
Minimalism	"Clean lines," Hidden features	"Pinnstol" (Wooden chair), "Scrawny"

Competitor review audit

The result from the competitor review audit can be found in Table 2.9 and includes what factor that were deemed the most important, what common complaints were and what aspects that were given praise.

Table 2.9: User expectations: Ranking of factors affecting seat experience.

Rank	Factor	Negative Aspects (Complaints)	Positive Aspects (Praise)
1	Seat Comfort & Hardness	“Rock Hard” / “Wooden Plank”: The most common complaint. Users hate unyielding foam. Pain: Reports of tailbone pressure, numbness (“träsmak”), and leg pain. Too Thin: Bottoming out on the seat base.	Supportive Softness: Praise for “memory foam” or cushions that are soft but don’t bottom out. Leg Room: Wide, flat seats that allow for cross-legged sitting are highly valued.
2	Adjustability & Ergonomics	Aggressive Lumbar: Lumbar supports that are too hard, poke the back, or won’t stay in place. Fit Issues: Seats that are too deep (cutting into knees) or too short for tall users.	Recline Function: Ability to lean back fully (“watch movies”) is a favorite feature. Headrest: Adjustable headrests that support the neck properly are a key win.
3	Build Quality & Durability	Catastrophic Failure: Bases snapping, hydraulics failing, or wheels breaking within a year. Cosmetic Defects: Scratches, stains, or bad stitching upon arrival.	“Heavy” Feel: Weight is directly equated with quality and durability. Silence: A chair that makes <i>no noise</i> (squeaks/rattles) is seen as premium.
4	Armrests	Wobble: Loose or rattling armrests make the entire chair feel “cheap.” Cracking: Armrest foam splitting or peeling is a specific durability issue.	4D Adjustability: High praise for armrests that pivot, slide, and angle to support different tasks (typing vs. gaming).

2.3.4 Expert interviews

The result from the expert interviews is split up into different sections, one for each expert and their area of expertise. The section presents the summarised input from experts in three separate fields, being: Comfort, foam manufacturing and comfort testing.

Expert in comfort

This experts research is focused on seating positions, belt positions and comfort in cars. The result from this interview mainly regarded how the perceived comfort is affected by a multitude of different factors as well as the comfort concept presented in 2.3.1.

The expert mentioned that the possibility to adjust the seating implement so that it

fits the individual is a really important factor. They mentioned that it is important to ensure that the seat pan depth is appropriate, it cannot be too short since that will result in higher pressure on the back of the thighs and that it cannot be too long since that will result in the user not being able to have their buttocks at the rear of the seat and thus their lower back will not be able to have contact with the back rest. Furthermore they mentioned that the lumbar support is an important factor.

One quite interesting aspect that they mentioned was that users will have previous experiences with seating implements and these experiences will shape what aspect of the seat that they focus on. They mentioned that users often look for the issues they have had previously in order to ensure that this new seating implement does not have the issues that has bothered them previously. This works inversely as well, if a user has found some aspect of a seat especially nice they will look for this feature in new seats that they try.

Lastly, they mentioned that temperature regulation is an important factor, mainly because the user does not want to get sweaty. This is very dependent on the material selection but it also needs to consider what the user is wearing. This is because if they are wearing shorts there is a risk for skin contact with the seat pan material which can, especially if synthetic leather or similar is used, cause the user to sweat more than if the seat pan is covered in a fabric or similar.

Expert in foam manufacturing

Foam moulding using polyurethane foam includes mixing a isocyanate and polyol solution in a nozzle and injecting it into a mould, where it can then expand and fill the mould to create a shaped polyurethane foam. The method allows for different ratios of mixture of the solution to be injected into the same mould, which affects the compression behaviour of the foam in that area.

Any given density of a foam has an optimal ratio between polyols and isocyanates, where the reaction becomes complete throughout the entire foam; that foam would be labeled "index:100". Different indices e.g., 85 or 90, mean 85% or 90% of the amount of isocyanate required for a complete reaction were used for the foams. The lower the index, the less complete the reaction will be, resulting in a low index or a "polyol-rich" foam. A polyol-rich foam will result in a softer overall foam, as the polyurethane will contain less cross-linked polymer chains. However, the lower the index becomes, the higher the risk is that the foam might collapse during manufacturing.

A process called multi-hardness reaction injection moulding (MHRIM), described by the expert, is a technique which allows for the hardness to be varied throughout the foam, using the same shape and mould. However, the expert also mentioned that this technique has one major flaw, being that it can only section off areas of a part in the horizontal plane, meaning layers of different hardnesses can not be achieved vertically and instead requires other methods. Instead, in order to achieve varying hardnesses and behaviour of a part in vertical layers, the sections would need to be moulded separately and subsequently bonded together to create the finished part.

For this project, the expert suggested using 3D-printed plastic moulds for prototyping purposes. This allows for rapid prototyping and decreases lead-times of prototype manufacturing, thereby increasing flexibility within the project. Additionally, this method would allow for the mould manufacturing to be cheaper and thus be feasible within the limitations for this project.

Expert in comfort testing

Pressure testing is done by placing a flexible pressure mat with sensors in a 0.5 inch by 0.5 inch grid onto the seat pan and then applying a force onto the pressure mat. This force can be applied in one of two ways, either via a moulded tool or by a user taking a seat onto the chair. Out of these two methods the expert deemed the second more appropriate in this circumstance since it allows for testing of different body types as well as different seating positions.

Another important aspect of comfort is the seat pans thermal and moisture related properties. If the seats moisture transfer rate is too low it will counteract the body's ability to sweat and thus regulate its temperature (Research Institutes of Sweden, n.d.). Furthermore, it can also result in local discomfort caused by contact with a damp material (Research Institutes of Sweden, n.d.). Thus it is important to measure a seat pans thermal and moisture related properties. This is done by measuring the moisture level and temperature at the surface of the seat pan during prolonged contact with a sweating manikin.

2.3.5 Specification of user needs

The resulting user needs can be seen in Tables 2.10 – 2.13. These tables are split into four different categories based upon which aspect of the seating experience the need primarily effects, these aspects are comfort, posture, quality and aesthetic. Each table consists of five columns, the first column simply indicates the needs number, the second what the need is, the third the needs importance, the fourth contains some sort of note or explanation if necessary and the fifth column indicates what part of the seat that has the potential of impacting the need, if it is in parenthesis it means that it would effect it to a lesser extent. Similarly to how each need has a relative importance, each category has a relative importance as well.

Table 2.10: User Needs – 1. Comfort.

Need no.	Need	Imp.	Note	Primarily Affected By
1.	Comfort	5		
1.1	Smooth to the touch	3	Material sensation against the skin	Upholstery
1.2	Soft to the touch	2	Behave like a cloud	Cushioning & (Upholstery)
1.3	Warm to the touch	2	Low thermal conductivity	Upholstery & (Cushioning)
1.4	Gradual support	4	Cushion should deform a considerable amount as a user sits down	Cushioning
1.5	Cushion should have a firm hold	4	Supportive cushioning	Cushioning
1.6	Reduce pressure in tailbone area	3	Lower imp. due to being similar to 1.5	Cushioning
1.7	Reduce pressure in ischial area	3	Lower imp. due to being similar to 1.4	Cushioning
1.8	Reduce peak pressure	3	(From literature)	Cushioning
1.9	Cushion should not "bottom out"	5		Cushioning
1.10	Proper support under thighs	4	Support should extend all the way along the hamstrings	Cushioning & Shape
1.11	Reduced pressure on the back side of the knee	3		Cushioning & Shape

Table 2.11: User Needs – 2. Posture.

Need no.	Need	Imp.	Note	Affected By
2.	Posture	5		
2.1	Allow for various seating positions	4		Shape, (Cushioning) & Function
2.2	Seat pan depth should allow sitting all the way back	5		Shape & Function
2.3	Seat pan surface should be tilted backwards 0–10°	2	(From literature)	Shape & (Cushioning)

Table 2.12: User Needs – 3. Quality.

Need no.	Need	Imp.	Note	Primarily Affected By
3.	Quality	5		
3.1	Durable materials	4	Stretch, tear and stain resistant	Upholstery
3.1.1	Long lifespan	5	5+ years without noticeable sagging	Cushioning
3.2	Stable base	4		Cushioning & Function
3.3	Should operate quietly during movement	3	No squeaking, creaking or rattling	Function & Upholstery

Table 2.13: User Needs – 4. Aesthetic.

Need no.	Need	Imp.	Note	Primarily Affected By
4.	Aesthetic	1		
4.1	Seat pan and backrest should have a unified silhouette	2		Shape & (Function)
4.2	Fewer dividing/transitional lines	3		Upholstery & (Shape)
4.3	Relatively flat in the rear of the seat pan	2		Shape
4.4	Subtle and/or integrated control elements	4		Function
4.5	Bucket seat aesthetic (side bolsters)	3		Shape
4.6	Trustworthy appearance	2		Shape & Upholstery

2.4 Key findings from Pre-Study

This section of this chapter summarises the most important findings from the pre-study. The section is split into five sections; Comfort, Multilayer seat cushions, Pressure distribution, Foam Manufacturing and Competitor analysis. This section serves to provide a conclusion to the pre study and to summarise the key takeaways before starting the first design iteration.

2.4.1 Comfort

Comfort is a word that is hard to describe and that everyone has their own interpretation of. The efforts made by Zhang et al. (1996), de Looze et al. (2003) & Makris (2026) provide excellent insight into what factors that can impact the perceived comfort and shed light onto how complex the landscape is.

For the purpose of this paper the main takeaways from these papers are that comfort and discomfort are related but not the inverse of each other. If evaluated, they thus need to be evaluated separately since the solution with the least amount of discomfort might not be the one that is the most comfortable and vice versa.

The work and insights from Makris (2026) provide further insight into what aspect that can impact a users comfort during seating. They describe how it not only the users physical interaction with the seat that impacts their comfort but also their

expectations and the scenario. Thus it is important that the scenario during a comfort evaluation is similar to the one where the product is planned to be used. Furthermore, whether or not the user will be comfortable is also dependent on their previous experiences and subsequent expectations and thus these need to be taken into account when designing both the product and the comfort evaluation.

2.4.2 Multilayer seat cushions

It seems that a multilayer seat cushion could prove to be more comfortable than one with homogeneous hardness. Furthermore, multilayer seat cushions are theorised to provide two different benefits. Firstly, it could provide a soft initial contact with the buttocks during seating whilst still being hard enough to avoid fatigue and discomfort during extended seating periods. Secondly, by using harder and softer foams in various sections of the seat, the pressure distribution could be manipulated, which in turn could impact comfort without the need of modifying the shape of the seat pan.

2.4.3 Pressure distribution

There are sources such as Zemp et al. (2015), Ebe and Griffin (2001) and Naddeo et al. (2024) that seem to indicate that a reduction in peak pressure and a more even pressure distribution could result in higher comfort. However, Ebe and Griffin (2001) also indicate that the correlation only appears in proximity to the ischial bones. Furthermore, Vink and Lips (2017) showed that the part of the buttocks that are in contact with the front portion of the seat is more sensitive to pressure. All of this makes it very convoluted whether or not the pressure should be evenly distributed across the seating area or not. The takeaway from this is that it is most likely beneficial to have a more even pressure distribution over the seating area but that it should not be perfectly even.

2.4.4 Foam manufacturing

In regards to the manufacturing of foam the possibility to manufacture a tool using 3D-printed plastic moulds could prove to be incredibly beneficial. It would allow for rapid prototyping as well as ensuring that the creation of tools would be feasible in regards to the projects resource limitations. Additionally, despite the flaws in the MHRIM process the possibility of varying the hardness of the cushion across the surface of the cushion by using two separately moulded parts seems very promising.

2.4.5 Competitor analysis

The competitor analysis provided interesting insight into what individuals perceive to make chair more gaming/office and minimalistic/maximalistic. The main takeaway is that whilst it helps, a chair does not necessarily need to have a typical racing chair silhouette to be perceived as a gaming chair. Other factors such as colours, branding and visual weight can ensure that a chair feels like a gaming chair despite not having the traditional silhouette. Thus, whilst features such as side bolsters on

the seat can help make it feel more like a gaming chair it seems like visual weight and it being comfortable and less like tool contribute a lot too. To summarise, whilst the seat design makes an impact, it is not what determines whether or not a chair feels like a gaming chair. Therefore, for the purpose of this project, the aesthetic implications of the form language do not need to be considered.

3 Design Iteration 1

The design part of the project is split into two iterations. The first iteration presented in this section will explain the process of generating ideas, developing these into more refined concepts and how these were conceptually evaluated. Furthermore, it includes the concept selection and subsequent prototype manufacturing. Finally, it ends with how these prototypes were evaluated and the result from the evaluation.

This chapter is split up into three sections, beginning with the methods used, which is then followed by their implementation, and ending with the results from each step of the process.

3.1 Methods

This section serves to describe and contextualise the methods utilized for the first design iteration. The section describes the definition and purpose of the following methods: Braindrawing, Kesselring matrix, User testing, Likert scale, and Pressure mapping.

3.1.1 Braindrawing

Braindrawing is a "quick and dirty" way of generating ideas using a visual medium, being drawings/sketches on paper. Ideas are rapidly put out and discussed among participants and potentially further developed following said discussions. The major advantages of the method is its potential to generate many concepts in a short amount of time, combined with providing a visual result that reflects the ideas generated.

3.1.2 Kesselring matrix

A kesselring matrix is a structured decision-making tool which is used in order to evaluate and compare different concepts against each other, based on weighted criteria. This method allows for a somewhat objective ranking of concepts and for the purpose of this work, it allows for an early filtering of concepts which carry a low rating. One major flaw of implementing this method in this work is the results of incorporating criteria based in soft values and/or abstract concepts, as the scores given tend to become more subjective. However, the method still provides much more nuance to decisions made and is therefore still of value. (Ulrich & Eppinger, 2016)

3.1.3 User testing

User testing was incorporated at this stage in order to further evaluate physical prototypes and to gather both quantitative and qualitative data in order to rank the performance of the prototypes manufactured. User testing can be carried out

in many ways, but for the purpose of this work, users got to participate in a semi-structured observational study. This means that users are put in a semi-controlled environment and are provided a task to solve whilst observational data is being recorded. In order to gain further quantitative data, subjects are also asked to complete surveys which aim to gauge their comfort in a numerical fashion.

3.1.4 Likert scale

The Likert scale was first introduced by Rensis Likert in 1932 and is a tool commonly used in surveys (PaperSurvey, 2026). The scale presents a statement and asks the respondent to state their level of agreement along a series of ordered options, for example from strongly agree to strongly disagree.

One of the key design considerations when creating a Likert scale is how to label the options. The two main methods are endpoint-only labelling and full labelling (PaperSurvey, 2026). For the fully labelled option each possible response is given an explicit descriptor, meanwhile, for the endpoint only option, only the poles of the Likert scale are labelled.

3.1.5 Pressure mapping

Pressure mapping of a seat pan is performed by first placing a flexible pressure mat with pressure sensors ordered in a 40x40 grid, where each cell is a square which is 0.25 inches² onto the seat pan. A user then sits onto the seat pan for a duration of time to ensure to account for the creep that naturally occurs in foams. The pressure in each of the cells on the grid is measured continuously and once the desired duration has passed the last measurement is saved. This is then repeated a set amount of times to account for anomalies in individual tests. If multiple seat pans are tested they should be tested in a rotation to avoid variance that can occur over time. It is important that the user is seated the same way for each test, thus the chair should be positioned the same for each test, with the seat pan and arm rests at the same height and the user should place their feet in the same position and be seated with the same posture for each test. Once the tests are performed the data is collected, processed and analysed. (*SENSORS LX210:40.40.02*, 2016)

3.2 Implementation of the first design iteration

This section describes the methodology used to create the first round of prototypes. This includes the early ideation which laid the groundwork for the following concept generation. Afterwards the methodology used to select some of the generated concept and how prototypes of these were created and evaluated is described. This first iteration will have lower fidelity and will focus on evaluating the cushioning composition whilst the second iteration will combine the results regarding the material composition and combine it with more complex shapes.

3.2.1 Ideation

The ideation was executed concurrent with the pre-study. It mainly used braindrawing to capture ideas and to create inspiration for new ones. It was performed on an ad hoc basis meaning that ideas were captured as they came to mind and braindrawing was then used to document, communicate and create discussion around these ideas.

Parametrisation of seat pan shape

In order to aid in the concept generation a basic model that is able to describe the shape of the seat pan was derived. This model was created by looking at two different cross sections, one as viewed from the front and one as viewed from the side. The aim was to create a model that in simple terms can describe the shape using a number of discrete variables in order to easily categorise different shapes.

3.2.2 Concept generation

Due to the chosen prototyping method, the concept generation in iteration 1 mainly explored the effects different material constructions and foam layering techniques have on comfort. The main focus of this iteration was to evaluate the effectiveness different material constructions have on dispersing and reducing pressure in different areas and determining how this affects the perceived comfort. Minor shaping concepts were assessed in order to make general assumptions on how to explore shapes in the following iteration.

Most concepts were generated through a version of brain drawing, based in conclusions made from the literature review and the specified needs list. Some concepts were also adapted to material construction concepts, inspired by early ideas and patents reviewed.

3.2.3 Initial concept selection and evaluation

The concept selection and evaluation was an iterative process, where concepts were developed, evaluated and modified in cycles. Three rounds of concept evaluations were performed in parallel with concept selections.

The initial concept evaluation was performed using a kesselring matrix, in the secondary round, concepts were put together as temporary prototypes and evaluated using a simple comfort scale. In the final round three chosen concepts were developed into prototypes of higher fidelity and these were put through a round of user testing. In this round the pressure distribution of each prototype was also tested. After these evaluations had been performed the results were analysed and the most promising concepts were brought through to the second design iteration. How each of these steps was performed is described in more detail in the following sections.

Kesselring-matrix

The kesselring matrix used criteria gathered from the needs list in order to scrutinise and rank concepts. Since the concepts don't vary in shape or upholstery only the needs that were deemed to be affected by the cushioning were used. The needs used for evaluation, their importance and the potential maximum score can be seen in Table 3.1 and each concept was evaluated against these needs.

Table 3.1: Needs, importance and maximum score of the kesselring matrix.

No.	Need	Imp.	Max
1.2	Soft to the touch	2	5
1.4	Gradual support	4	5
1.5	Cushion should have a firm hold	4	5
1.8	Reduce peak pressure	5	5
1.10	Proper support under thighs	4	5
1.11	Reduce peak pressure on the back side of the knee	3	5
2.1	Allow for various seating positions	4	5
3.2	Stable base	4	5
			150

Comfort ranking of low fidelity prototypes

In order to physically test the comfort of some concepts in a quick and non destructive manner three blocks of foam with varying hardness were stacked on top of each other. Multiple different constructions were tested at the same time and a user was asked to rank them based on comfort, after test sitting on each prototype. The user was allowed to swap between the prototypes as many times as they liked whilst ranking them. The test was intentionally set up in a loosely structured manner, as the purpose was to make broad conclusions on these low fidelity prototypes. This, in order to gain general insights into what concepts have most vs. least potential and which foam hardnesses should be incorporated into any of the concepts.

Whilst the user knew which constructions were being tested, they did not know where they were positioned, and thus did not know which construction they were seated upon at any given time. A picture showing the setup for the low fidelity prototype evaluations can be seen in Figure 3.1.



Figure 3.1: Evaluation setup for low fidelity prototypes.

Using the results from this as well as the Kesselring matrix the 3 or 4 most promising concepts were selected.

3.2.4 Prototype creation

For this first iteration a lower fidelity manufacturing method was selected for the prototypes in order to allow for rapid prototyping. The method was to manually cut and glue together foam pieces to create prototypes which serve to test the potential of different material constructions. The method allowed for limited shaping capability, therefore testing of shapes was further explored in iteration 2 with a higher fidelity manufacturing method. Tools to be used for the shaping were laser cut jigs and an electric bread knife. In Figure 3.2 one of the setups for cutting the foam at an angle can be seen. Furthermore a modified version of an old Refine chair provided by the company was used to test each prototype cushion, this chair, with the accompanying prototypes attached can be seen in Figure 3.3.



Figure 3.2: Angle cutting jig



(a) Prototype without upholstery



(b) Prototype without upholstery

Figure 3.3: Depiction of the chair used for the evaluation with the prototype cushion attached.

3.2.5 Comfort evaluation of prototypes

After the identification of the three most promising concepts and fabrication of the respective prototypes they were evaluated using two different methods. The first method was a user evaluation and the second one being pressure mapping. Both of these methods were performed with the intent of identifying which of the concepts that had the best subjective and objective comfort.

User evaluation

In order to subjectively measure the comfort of the chosen concepts users were asked to evaluate their comfort and discomfort after being seated onto each prototype for a set duration of time.

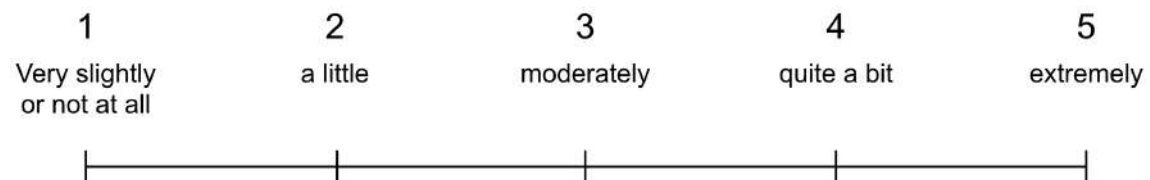
The evaluation was conducted as a blind test following a predetermined testing order, which was varied between participants to reduce order effects. For three prototypes there are $3! = 6$ possible testing orders. These orders were distributed as evenly as possible across participants and while it was acceptable for some orders to occur more frequently than others, no single order appeared disproportionately more frequently than another.

The comfort/discomfort evaluation form used can be seen in Figure 3.4. It consists of two sections, perceived comfort and perceived discomfort and both use a 5 point likert scales to assess comfort/discomfort. The perceived comfort section consists of a fully labelled likert scale whilst the perceived discomfort section has an ac-

accompanying visualisation that indicates three different regions of the seating area. Each region has an accompanying Likert scale with endpoint labelling, where their discomfort in each of the regions is evaluated.

Comfort/Discomfort Assessment

Perceived Comfort



Perceived Discomfort

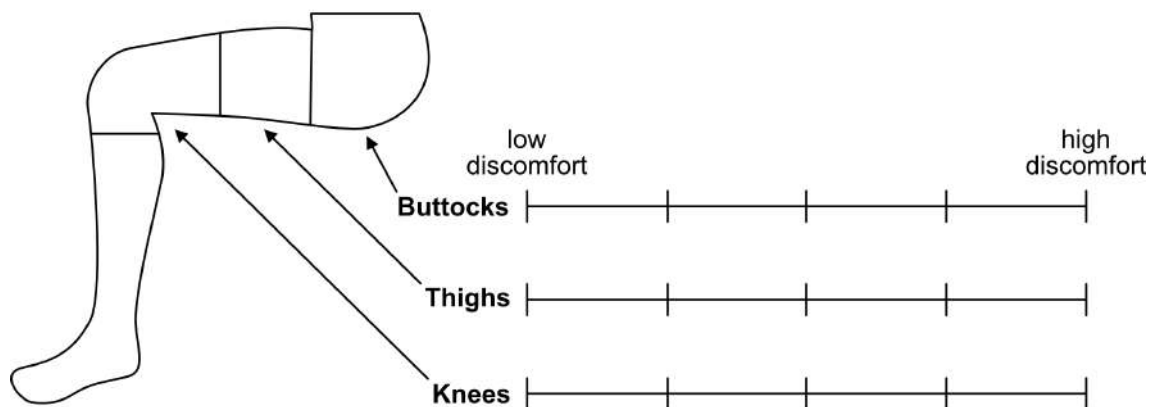


Figure 3.4: Comfort/Discomfort evaluation form.

The evaluation was executed as follows:

1. Instruct the test subject to take a seat onto a wooden bench and ask them to remember this feeling as it will be used as a reference later on.
2. Instruct the test subject to take a seat onto the prototype.
3. Explain how the prototype can be adjusted and ask the test subject to adjust it as they see fit, whilst maintaining an upright posture.
4. Start five minute timer and instruct the test subject to start playing a game on a computer, converse with them for the duration of the timer.
5. Once the time is up, provide the test subject with the comfort/discomfort evaluation form.
6. Explain that the wooden bench the test subject sat on should be used as reference for the lowest comfort value.
7. Ask the test subject to evaluate their current comfort in relation to the reference bench and to mark their comfort level on the comfort scale.
8. Explain that the discomfort scale is split up into three regions; buttocks, thighs

and knees. The lowest value on each scale represent an absence of discomfort or pain and the highest value represents pain.

9. Ask the test subject to evaluate their discomfort in each region and to mark their discomfort in each region on the respective discomfort scale.
10. Swap the prototype in accordance to predetermined testing order.
11. Repeat step 1-2 & 4-9 until test subject has evaluated all prototypes.

After all test subjects had evaluated all prototypes the results needed to be summarised. Due to having an upper and lower reference the results from the discomfort scale could be averaged on a per body part and prototype basis. The comfort scale however only has a lower reference and the average comfort is thus not as reliable and will thus be normalised.

To do this, each participant's score for a given concept was divided by the sum of their scores across all three concepts, yielding the proportion of their total points allocated to that concept. These proportions were then summed across all participants to produce a final score for each concept.

Pressure testing

To support the user perceived comfort from the user testing as well as to attempt to identify how pressure distribution correlates to perceived comfort the pressure distribution of each concept was tested. How pressure testing is performed is explained in 3.1.5. The pressure testing was performed on three chairs and these were tested in a rotation. Each concept was tested 6 times. Afterwards the data was processed to provide the average peak pressure, the percentage of load that occurs in different regions as well as visualizations of the pressure distribution.

3.3 Outcomes from first design iteration

This section presents the data derived from the implementation of methods in design iteration 1, described in Section 3.2. The results showcase how the shape of a seat cushion can be parametrised, the initial foam construction concepts generated in order to achieve the "effective shape" of said parameters, as well as the screening of the generated concepts, prototype realisation and final user testing and additional pressure distribution testing.

3.3.1 Ideation

In Figure 3.5, a depiction of how each cross section of the seat can be manipulated is presented. In this image the section numbered 1 represents the area in the front of the seat cushion, i.e. the part closest to the knee. Consequently section 2 represents the middle, 3 the rear and 4 the sides. Cross section A-A is thus the middle profile as viewed from the front and cross section B-B is the side profile.

In order to manipulate the shape of the seat the curve at each cross section can be adjusted. In both cross sections each section of the seat can be raised, lowered or

straight. For example the red line in cross section A-A is lowered in section 1, raised in section 2 and lowered in section 3. If the curve is raised in a given section it gets the notation +1, if it is lowered -1 and 0 if it is straight. Thus, the red line in cross section A-A can be described as $(-1, +1, -1)$. Cross section B-B is described in the same manner, however since it is symmetrical it only needs two notations and the red line can therefore be described as $(-1, +1)$. Therefore, a concept utilising both red curves would be described as $(-1, +1, -1), (-1, +1)$.

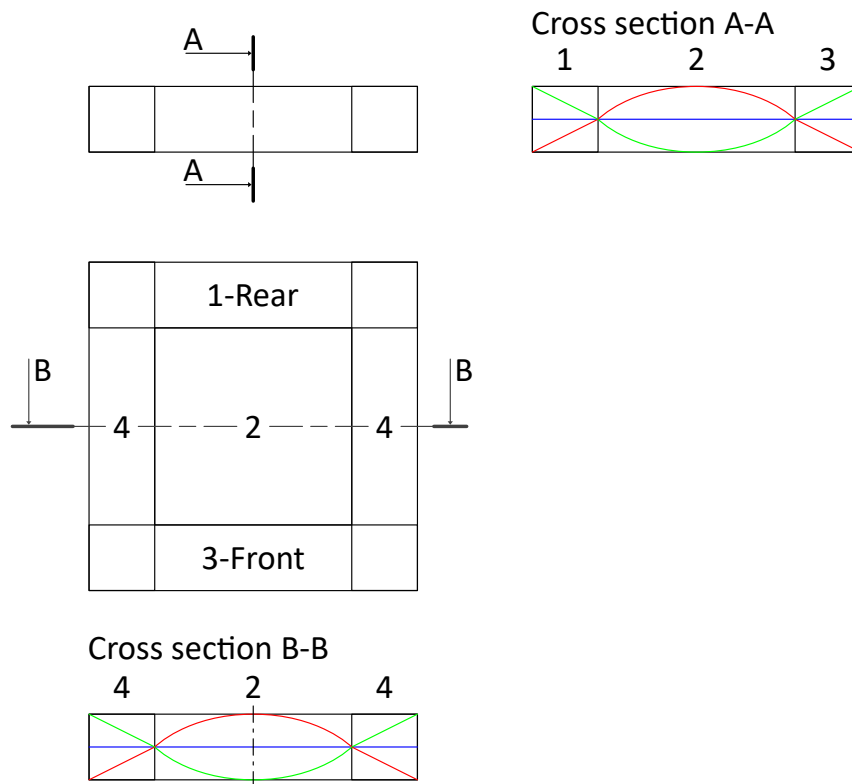
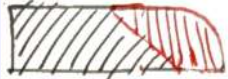
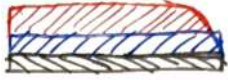
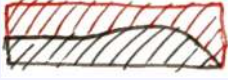
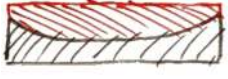
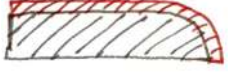
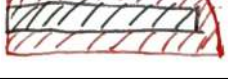


Figure 3.5: Visualization of how the two cross sections can be manipulated to change the shape of the seat.

3.3.2 Initial concepts

In Table 3.2 all twelve of the initial concept can be found. In this table the first column indicates the number that it was given, this is used to identify each concept. The second column provides a short description of the given concept, the third row provides a visual representation of the cross section and the fourth row indicates which profile the image is seen from, i.e. if the cross section is seen from the front or from the side och the seat cushion. In the visual representation of concepts in the third column, the colours refer to how the hardness of foams vary within a given construction; Red means that it is softer, black means that it is harder, and blue means that it is in-between, for any given construction.

Table 3.2: Numbering, description and visualisation of 12 initial concepts.

No.	Description	Image	Profile
1	Homogeneous		Side
2	Homogeneous with waterfall		Side
3	Homogeneous with softer front		Side
4	Vertically increasing hardness		Side
5	Varying cross section		Side
6	Varying cross section		Front
7	Hard top layer		Side
8	Homogeneous with memory foam		Side
9	Soft under front section		Side
10	Soft sections from the front		Front
11	Soft under sciatica and the front		Side
12	Soft sandwich		Side

3.3.3 Initial concept evaluation

The initial concept evaluation was performed utilised a kesselring matrix and a comfort evaluation. The result from both is presented in this section.

Kesselring matrix

The result from the Kesselring matrix can be seen in Figure 3.6. In this figure the percentage indicated is in relation to a theoretical maximum. What score each concept was given for each need can be seen in appendix B.

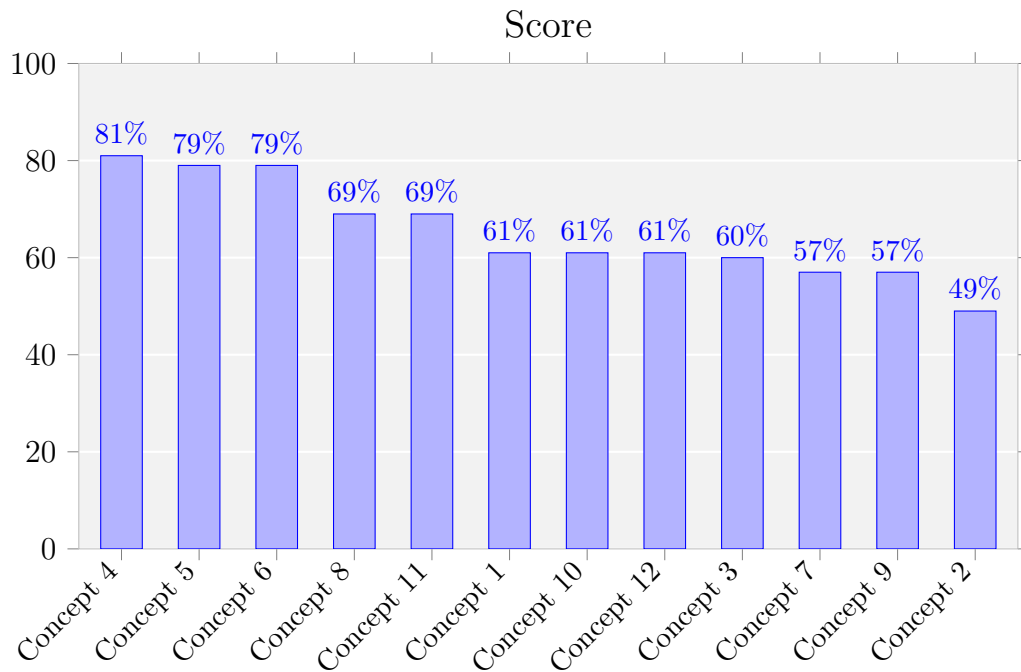


Figure 3.6: Score for each concept in relation to theoretical maximum.

Comfort ranking of low fidelity prototypes

The foams procured for design iteration 1, all had a density of 65g/L and varied in hardness by using different indices. The different foam indices procured can be viewed in Table 3.3.

Table 3.3: The procured foam indices.

Foam	Index
Foam 1	80
Foam 2	85
Foam 3	90
Foam 4	95
Foam 5	100

The resulting ranking from the two groups of concepts can be seen in Tables 3.4 and 3.5, in these tables a lower value means that it was ranked higher. The numbers in the "Construction" column indicate the hardness, where a lower number means it is a softer foam, and higher number means it is a harder foam, for further clarification; see the explanation of foam indices in the foam manufacturing expert interview in Section 2.3.4. Furthermore, the first number in the order of indices, indicates the top layer and the last the bottom layer.

Table 3.4: Ranking of the first group of concepts.

Construction	Ranking
80:80:90	1.5
80:85:80	1.5
80:90:80	3
85:95:85	5
85:85:95	4

Table 3.5: Ranking of the second group of concepts.

Construction	Ranking
80:80:80	1.5
85:85:85	4
80:85:90	3
80:85:80	1.5

3.3.4 Prototypes

Out of the twelve concepts evaluated, three were made into prototypes, these were concepts number 5, 6 and 12 and visualizations of their cross sections can be seen in Figure 3.7. These were selected, due to them scoring well in initial evaluation. Whilst concept 4 scored the highest in the kesselring matrix it was not selected, due to the underlying idea already being present in concepts 5 and 6. Additionally, concepts 10 and 11 were not selected due to their intended upside being similar to concepts 5 and 6. Concepts 8 and 1 were homogeneous, or close to homogeneous, making them uninteresting to test at this stage, and thus concept 12, which also scored well during the ranking of the low fidelity prototypes, was selected as the third concept.



(a) Concept 5 - Side View.



(b) Concept 6 - Front View



(c) Concept 12 - Side View.

Figure 3.7: Side/Front views of the three prototypes, red indicates foam with lower hardness, blue average hardness and grey higher hardness.

3.3.5 Comfort evaluation of prototypes

This section showcases the results from the user evaluation as well as the pressure tests of the final concepts from Design iteration 1. Furthermore, this section also covers the concept selection for the concepts, which will be further developed in Design iteration 2.

User evaluation

Following the comfort evaluations, the data gathered was compiled in a spreadsheet and the comfort results normalised. The resulting data can be viewed in Table 3.6 & 3.7, showcasing that concepts 5 and 6 performed the highest both in terms of maximizing comfort and reducing discomfort. Especially in the thigh and knee region, where concept 12 on average showed a noticeably higher discomfort rating than the other concepts. An important observation from this round of user testing was that test subjects repeatedly tried to compare different prototypes to each other, even though they were explicitly instructed to only compare to the reference provided at the start of each test. How each user rated the respective concepts can be seen in Tables C.1 and C.2 in Appendix C

Table 3.6: Average comfort scores and ranking distribution per concept indicating how many times each concept was ranked 1st, 2nd and 3rd as well as their average ranking.

Concept	Comfort	Ranking			
	Average	1st	2nd	3rd	Average
5	3.61	6	4	2	1.7
6	3.49	5	4	3	1.8
12	3.21	4	4	4	2.0

Table 3.7: Average discomfort scores per concept.

Concept	Average Discomfort		
	Buttocks	Thighs	Knees
5	0.94	0.56	0.17
6	1.00	0.50	0.27
12	1.04	1.06	0.40

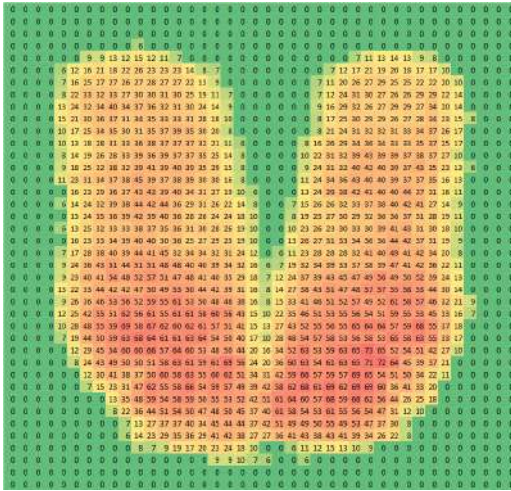
Pressure mapping

The average peak pressure from all six tests and the distribution across different regions for all three concepts can be seen in Table 3.8. The averaged and filtered pressure for each concept can be found in Figure 3.8. These results showed a minor

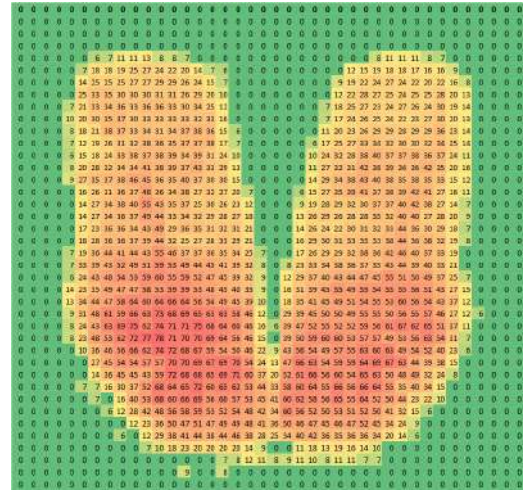
difference in average peak pressure, where concept 12 had a slightly lower peak pressure. The percentage of pressure distributed across the sides and seating bones was identical for all concepts. However, concept 5 showed a slightly larger portion of the pressure being distributed across the front of the seat. Concept 12 distributed a slightly lower amount of pressure in the same region and concept 6 distributed even less pressure in said region. Furthermore, the result from each individual pressure test can be seen in Figure D.1, D.2 and D.3 in Appendix D.

Table 3.8: Average peak pressure and distribution in different regions.

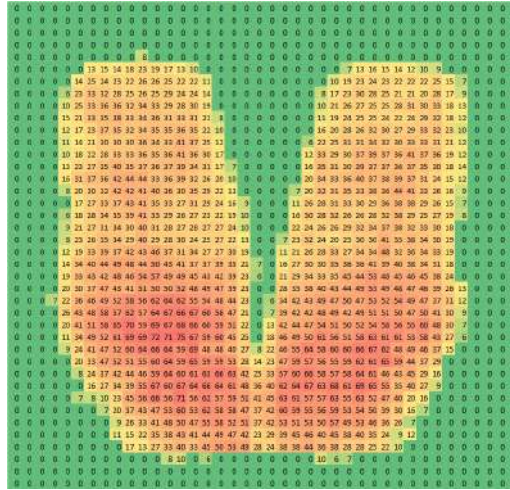
Concept	Average Peak	Sides %	Front %	Sit bones %
5	76	24%	35%	7%
6	76	24%	30%	7%
12	74	24%	33%	7%



(a) Pressure distribution for concept 5.



(b) Pressure distribution for concept 6.



concepts, within the research team. In its current state, the parametrisation can describe a surface well if it maintains a constant curvature throughout the part, from both the front and side view. It becomes more complicated when a surface is defined by several curves throughout the part from either the front or side view, which would require several more cross-sections to describe its geometry somewhat accurately.

3.4.2 Evaluation of initial concepts

From the initial 12 proposed concepts, concepts 4,5 and 6 stood out as the highest performers following the kesseling matrix, where the concepts were theoretically ranked and scrutinised against the previously defined needs shown in Table 3.1. The outcomes from the ranking of low fidelity prototypes, presented in Tables 3.4 & 3.5, further validated the potential of concepts 5,6 and 12, whilst also most notably highlighted, that the foam used for the first iteration of prototypes were all too hard and made comparison between constructions difficult as users tended to only properly interact with the top 2 layers of foam and had a difficult time discerning between constructions when they become too hard. This means that for the second iteration of prototypes, softer foams should be used, with the softest foam from the first iteration (Density: 65g/l and Index: 80) being a good example of what the hardest foam should be like.

3.4.3 User evaluation of prototypes

For the final prototypes of the iteration, concepts 5,6 and 12 were chosen to be manufactured, as they showed the highest potential in the early evaluations. The user evaluation data showed that concepts 5 and 6 slightly outperformed concept 12, both in terms of increasing comfort and reducing discomfort, see Tables 3.6 & 3.7. However, it became clear that it would likely produce more accurate data if concepts with more extreme differences in hardness were tested; because subtle differences appeared to be difficult for users to notice. Interestingly, despite it having been difficult for users to compare the cushions, the data in Table 3.7 still indicate that concepts 5 and 6 appeared to decrease the discomfort in both the thigh and knee region, when compared to concept 12.

3.4.4 Pressure tests

Finally, the pressure distribution tests showed that all concepts distributed pressure very similarly across the cushions. The subtle differences were likely, once again, a consequence of the foam constructions not having extreme enough variations in hardness or containing soft enough foams to function optimally. However, one important detail to note was that the concepts showed a variation of pressure distribution underneath the front part of the seat. This likely has a direct correlation to how thick or thin the uppermost soft layer of foam is, before a harder foam underneath it starts interacting more directly with the person being seated. Effectively this means that the hardness of the interface was successfully altered using the different foam constructions. Consequently, this means that the design of concepts 5 and 6

appeared to function as intended and should therefore be further developed in the second iteration.

4 Design Iteration 2

This chapter builds on the results from design iteration 1 in Chapter 3, and describes the methods used for the second design iteration, as well as the results produced by them. Most importantly, this chapter covers the final prototypes of the project and their subsequent evaluation through user testing.

The chapter is split into four sections, beginning with the methods used and then their following implementation. Afterwards, the outcome from the implementation is presented and the chapter ends with the key findings from this design iteration.

4.1 Methods

This section will not introduce any new methods, as no new methods were used in the second design iteration. However, both the Likert Scale and the User Testing methods presented in Section 3.1 will be re-incorporated with some slight modifications to their implementation. Otherwise, much of the work in this design iteration used an ad hoc approach, without implementing any established methods.

4.2 Implementation of the second design iteration

This section describes the predominantly ad-hoc methodology used in order to produce and evaluate the final prototypes of the project. Unlike the methodology of the first design iteration, described in Section 3.2, this ad-hoc approach was taken in order to more efficiently navigate the challenges that were encountered when handling a more sophisticated manufacturing method. The purpose of this iteration was to determine whether a more sophisticated foam construction, designed to redistribute pressure away from or to certain sections of the seating, is more or less comfortable than that of a homogeneous foam cushion.

4.2.1 Final concept design

Data from the results of Design iteration 1 was analysed and discussed in depth to determine a concept to move forward with. User testing results and sentiments were considered alongside the results from the pressure distribution tests in order to generate and select a final concept. Once the final concept had been selected it was refined in an iterative manner until it was ready for prototype manufacturing.

Parametrisation of complex seat pan shape

As discussed in Section 3.4 the previously developed parametrisation did not provide enough information in order to describe a more complex surface with enough accuracy. In order to describe the more complex shape that was planned to be developed in the second design iteration, the parametrisation tool thus needed to be updated to provide more information. This was done by adding more cross sections where additional information about the surface shape could be added.

4.2.2 Surface modelling

Using the discrete parametrisation of seat pan shapes described in Section 4.3.1, the parameters were translated into CV points in the CAID software *Autodesk Alias* and iterated on, in order to achieve a manufacturable shape which aligned with the design intention of the final concept.

4.2.3 Tooling design

In order to injection mould the foam, and extract a shaped foam block, tooling that could enclose the negative space for the foam to expand into was needed. A cutting surface was also made in *Autodesk Alias* in order to split the foam into the desired shapes. Each foam shape was converted into a .STEP file format and imported into *CATIA V5* for solid modelling operations. The final tooling was then designed using Boolean operations, which created the negative space between two tool halves. Details were further added to the tooling and improved based on consultation with the manufacturing company and finally approved before tooling manufacturing began.

4.2.4 Tooling manufacturing

Due to economical and time constraints, the tooling was manufactured using 3D printing. Each tool half was printed in four parts due to size constraints presented by the 3D-printers. Furthermore, each half was designed as a shell with thin outer walls, and vertical ribs were added to provide additional stiffness and divide the geometry into sections. Once printed, the hollow sections were filled with fine grained sand in order to solidify the mould. The sand was packed using a vibrating element, and the holes were plugged with a laser cut wooden piece, and finally sealed with hot glue. Four quarter sections for each tooling block were glued together through wet-layup with polyester resin and glued onto a 18 mm thick MDF-board for increased stiffness. Finally, each tool's A-surface was coated with 2 layers of polyester resin, before being sanded, polished and sealed with a chemical surface sealant.

4.2.5 Prototype manufacturing

Once the tools were manufactured they were sent to the factory, where the foam was manufactured. At the factory, each foam was manufactured in multiple different hardnesses and densities. This was done, in order to ensure that there was a large enough variety of hardnesses to create the desired foam constructions.

Once the foams had been manufactured, three prototypes were created. Out of these, one was homogeneous and the other two had a softer top foam in relation to the bottom foam. In order for these three concepts to be comparable, it was vital that their average density was similar. Thus, the average density of all possible combinations of top and bottom halves were calculated, as well as how large the difference in density is between the top and bottom foam for each respective combination. Then, all possible trios of combinations that have a similar average

density, and where one of the combinations has a homogeneous density, were identified. These trios were then tested by the authors in order to quickly gain a grasp of which combinations would be the most suitable. In combination with the difference in density between the non-homogeneous combinations, together with the results from the tests, the most suitable trio was selected and permanently combined into prototypes that were suitable for repeated evaluation.

In order to ensure proper glue adhesion between the foam halves, the surfaces where the foams will make contact with each other were sanded. In Figure 4.1, a piece of foam with a clear split line can be seen where the right side had been sanded and the left side was yet to be sanded. Due to the edges of each piece of foam being quite hard, the corners were chamfered to ensure that this did not impact the comfort, images showing the before and after of this step can be seen in Figure 4.2. Once the foam pieces had been prepared, they were permanently glued together, in order to be used for the prototype evaluation. As in the first iteration, a modified version of an old Refine chair was used to test each prototype cushion.



Figure 4.1: Foam where the right side of the surface has been surface and has a rugged finish and the left side has not been sanded and has a slippery finish.



(a) Foam half before chamfer.



(b) Foam half after chamfer.

Figure 4.2: Foam halves before and after the edge being chamfered.

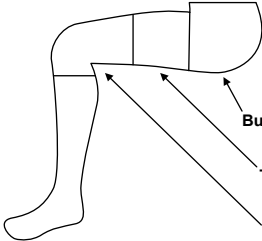
4.2.6 Prototype evaluation

The user evaluation of this iteration's prototypes was performed in a similar way as for the first iteration, which was presented in Section 3.2.5, but with some key modifications. One modification is that users were, unlike in the first round of user testing, explicitly asked to compare the ratings of each prototype to each other, instead of being asked to avoid doing so. Thereby the users were expected to provide more accurate data from their experiences, compared to that of the first user evaluation. The other modification made, was the addition of another Likert scale, on which the user was asked to rate their perceived hardness for each concept. As mentioned in Section 4.2.5, the prototypes should have similar densities and thus hardness, in order for them to be comparable. This new Likert scale thus validated whether or not the prototypes were perceived to have similar hardness. Hence, the new scale provided data that could be used to investigate whether there exists a correlation between perceived comfort and hardness. The updated evaluation form used can be seen in Figure 4.3.

Perceived Comfort

1	2	3	4	5
Very slightly or not at all	a little	moderately	quite a bit	extremely

Perceived Discomfort



	low discomfort				high discomfort
Buttocks					
Thighs					
Knees					

Perceived Cushion Hardness

1	2	3	4	5	6	7
Very soft	Soft	Somewhat soft	Medium	Somewhat hard	Hard	Very hard

Figure 4.3: Comfort/Discomfort/Hardness evaluation form.

Unfortunately the prototypes in this stage were not tested for pressure distribution, as it was neither feasible time-wise, nor economically.

4.3 Outcomes from second design iteration

This section covers the results derived using the methods described in Section 4.2. The section is divided in three main parts, being final concept design, final prototype

manufacturing and finally, final prototype evaluation.

4.3.1 Final concept design

The results from the user testing in the first iteration showed an insignificant difference in comfort between concepts 5 and 6, however, these concepts scored noticeably higher than concept 12 (see Table 3.6 & 3.7). The results from the pressure testing showed no noticeable differences between the concepts, aside from a slight variability in pressure in the thigh region (see Table 3.8 and Figure 3.8). Considering these results, a decision was made to combine the ideas behind concepts 5 and 6, resulting in a cushion, that is split in two parts; one softer top portion and one harder bottom portion.

Parametrisation

In order to describe the surface used to split the top and bottom half using the parametrisation proposed in Section 3.3.1 additional information needed to be added to the model. A new modified version with additional cross sections can be seen in figure 4.4. This model works in the same way as the one presented in Section 3.3.1 but includes additional cross sections and thus more information that can describe the shape of the surface.

For this model the shape of the surface can be described in the same manner as before. However, for this version the points in cross section A1 intersect with the first points in the B cross sections and the same being true for the A2 cross sections and the second point in the B cross sections. Thus the shape of a surface can be described using a 3x2 matrix such as the one presented in Figure 4.5.

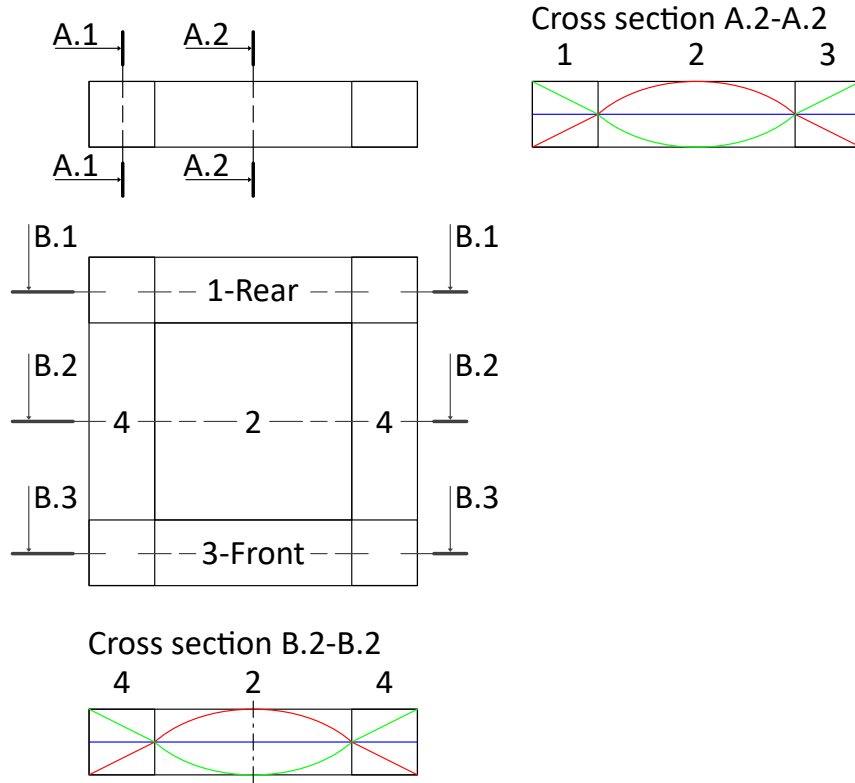


Figure 4.4: Visualization of how the five cross sections can be manipulated to change the shape of a surface.

This description of each section of the splitting surface used, described according to the parameters can be viewed in Figure 4.6. Additionally a CAD representation of this splitting surface can be viewed in Figure 4.7.

$$\begin{array}{cc} & \begin{array}{cc} \text{A.1} & \text{A.2} \end{array} \\ \begin{array}{c} \text{B.1} \\ \text{B.2} \\ \text{B.3} \end{array} & \begin{bmatrix} a & b \\ c & d \\ e & f \end{bmatrix} \end{array}$$

Figure 4.5: Matrix used to describe shape of a surface.

$$\begin{array}{cc} & \begin{array}{cc} \text{A.1} & \text{A.2} \end{array} \\ \begin{array}{c} \text{B.1} \\ \text{B.2} \\ \text{B.3} \end{array} & \begin{bmatrix} 0 & -1 \\ +1 & +1 \\ -1 & -1 \end{bmatrix} \end{array}$$

Figure 4.6: Parameter based description of used splitting surface.

CAD & CAID models

An isometric view of the cutting surface splitting the top and bottom foams can be seen in Figure 4.7, note that the figure uses max curvature radius values to measure and describe the curvature of the surface. The closer the colour of a surface is to the left of the scale, the more concave it is and the closer the colour is to the right of the scale, the more convex it is.

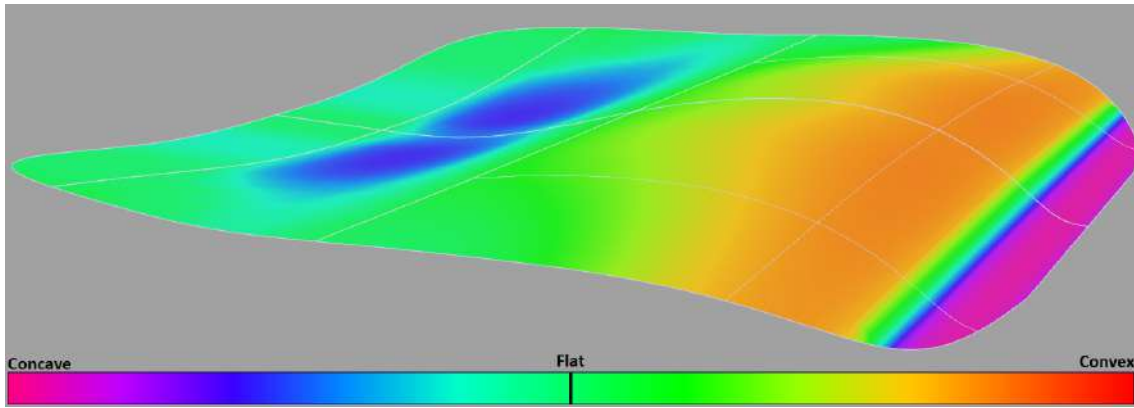


Figure 4.7: Isometric view of cutting surface.

Figure 4.8 shows how the resulting density will vary when using a foam with a lower density on the top layer and a higher density in the bottom layer. To create these visualizations Equation 2.2 presented in Section 2.3.1 was used to get the average density for a given point on the surface. For this example a density of 50.3 g/l is used for the top layer and a density of 69.4 g/l for the bottom layer. Furthermore, renders of the top and bottom foams can be seen in Figures 4.9 and 4.10

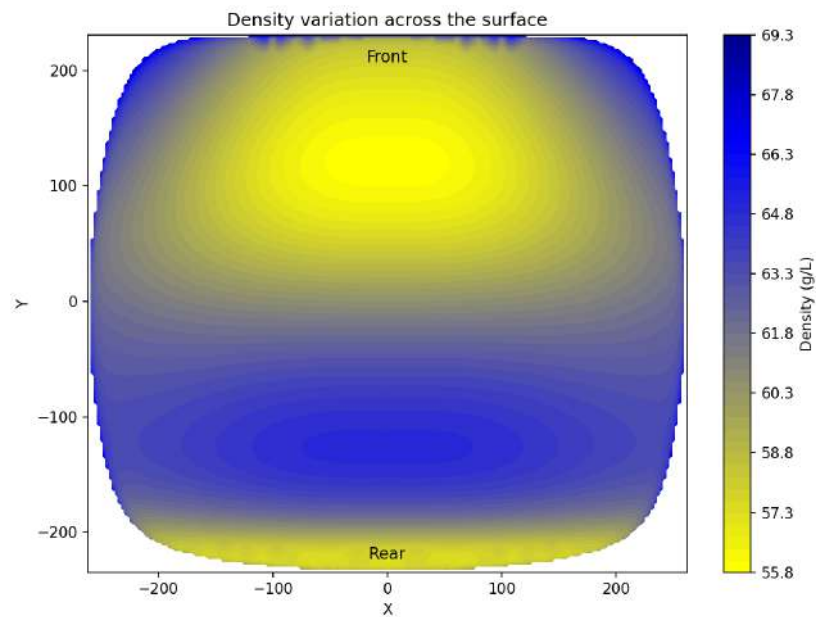


Figure 4.8: Visualization of how the density varies over the surface with the yellow colour indicating a lower density and the blue colour indicating a higher density.



(a) Render of bottom half of foam.

(b) Render of top half of foam.

Figure 4.9: Renders of top and bottom half of foam respectively.



Figure 4.10: Render of top and bottom half of foam.

4.3.2 Final prototype manufacturing

This section covers the manufacturing of the final prototype, split into two main stages being, Mould manufacturing and Cushion manufacturing.

Mould manufacturing

Due to the cushion being split into two halves two mould tools needed to be manufactured. These tools are in turn split into a bottom and top half with the bottom half containing the cavity for the foam and the top acting as a lid. Furthermore, to ensure that the halves are placed correctly in relation to each other positioning pins were added to the bottom and corresponding positioning holes to the top. Lastly a parting line gap was added to minimise the risk that defects in the mating surface caused gaps, where air could leak out uncontrollably. How the positioning pins & holes, mating surface and parting line gap was designed can be seen in Figure 4.11.

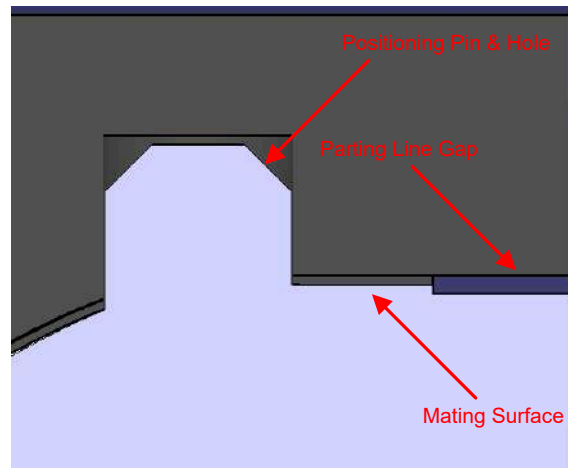
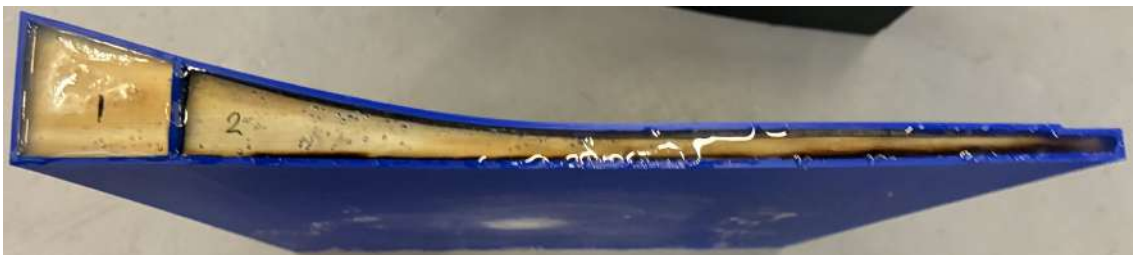


Figure 4.11: Design of positioning pins & holes, mating surface and parting line gap.

The 3D-printed mould parts after being filled with sand can be seen in Figure 4.12a and in Figure 4.12b an example of a mould part plugged with a wooden cap and sealed with hot glue can be seen.



(a) Mould after cavities have been filled with sand.



(b) Mould after the wooden cap and hot glue seal.

Figure 4.12: Moulds before and after being sealed with hot glue.

An image of one of the clamping setups used when gluing sections together can be seen in Figure 4.13a and two of the tools halves after the final polishing can be seen in Figure 4.13b.



(a) Example of clamping setup when gluing two sections to finish one of the tool halves.



(b) Two of the tool halves after being polished.

Figure 4.13: Two of the steps performed during the preparation of the tool halves.

Cushion manufacturing

The foam pieces were manufactured and extracted from the set-up as showcased in Figure 4.14, with the resulting stacks of manufactured foam shown in Figure 4.15. Aside from a slight surface defect on the top tool of the top foam mould, due to overheating of one of the tool surfaces which in turn caused warping, all foams were manufactured without any notable defects.



(a) Foam after curing.



(b) Foam after being de-moulded and flipped.

Figure 4.14: Two steps of the foam manufacturing process.



Figure 4.15: The stack of foam manufactured used for the final prototypes.

In total 7 different densities of foam were manufactured. These foams are categorised by their different densities as "Tx" and "Bx", with "T" meaning top foam half, "B" meaning bottom foam half and "x" being representative of their order by density from lowest to highest for each half, in Table 4.1.

Table 4.1: Foam densities for the top and bottom halves respectively.

Foam	Density (g/l)
T1	50.3
T2	54.9
T3	59.5
B1	53.4
B2	58.7
B3	64.0
B4	69.4

In Table 4.2, all feasible combinations that would result in a negligible difference in average density between top and bottom foam can be seen. These combinations represent the possible constructions for a homogeneous foam, with the "Density Diff (%)" column serving as a representation of how much harder the bottom foam is compared to the top foam, or how much softer it is in the case of negative percentages.

Table 4.2: The possible combinations that were the closest to homogeneous.

Combination	Average Density (g/l)	Density Diff (%)
(T2, B1)	54.0	-3%
(T3, B2)	59.0	-1%
(T1, B1)	52.0	6%
(T2, B2)	57.0	7%

As Table 4.2 shows, the combinations of (T2, B1) and (T3, B2) provide the closest possible construction to a homogeneous foam, with the given circumstances. The different constructions that would result in a nearly identical average density in comparison to the two homogeneous combinations mentioned above, are presented in Table 4.3. Just as in Table 4.2, the right most column of Table 4.3 shows the resulting difference in density of the two halves in the same way as in the previous table, however, this time relating to the specified constructions in the "Possible Constructions" column.

Table 4.3: Possible suitable constructions for each homogeneous combination.

Homogeneous Construction	Possible Constructions	Average Densities (g/L)	Density Diffs (%)
(T2, B1) (density = 54.0)	(T2, B2 ; T1, B2)	(57.0 ; 55.0)	(7% ; 17%)
(T3, B2) (density = 59.0)	(T2, B2 ; T1, B3) (T2, B3 ; T1, B4)	(57.0 ; 58.0) (60.0 ; 61.0)	(7% ; 27%) (17% ; 38%)

Table 4.3 shows, that using the homogeneous construction (T3, B2) would allow for the two most "extreme" concepts, (T2, B3) and (T1, B4), whilst also having the most representative construction for a homogeneous foam as seen in Table 4.2. Whilst simultaneously having the most similar average densities, tied with the possible constructions (T2, B2) and (T1, B3). The three constructions (T3, B2); (T2, B3); (T1, B4) were chosen to be used for the the final prototypes, to be tested in the final prototype evaluation. The concept using (T1, B4) for its construction was named Concept 1, the concept using (T2, B3) was named Concept 2, and finally the concept using (T3, B2) was named Concept 3.

Figure 4.16 shows the seat base which was modified to hold the foam cushions and allow for them to be easily switched out. Additionally Figure 4.17a shows one of the final prototypes positioned on the seat base, without the cloth which would cover it during the Final prototype evaluation. Finally, Figure 4.17b shows a picture of the final prototype with a cover, which is the final state of the final prototype for this project.

**Figure 4.16:** The modified seat base that held the final prototypes.



(a) The chair and prototype without the cloth cover.



(b) The chair and prototype with the cloth cover.

Figure 4.17: The final prototypes positioned onto the seat base, with and without the cloth cover.

4.3.3 Final prototype evaluation

The complete results from this round of prototype evaluation can be seen in appendix E. There, how each user rated each concept based on comfort, discomfort and perceived hardness can be seen. In total there were 15 participants in the survey and a summary of the results relating to comfort can be seen in Table 4.4. The columns "1st", "2nd" and "3rd", show the amount of times each concept was ranked first, second and third by the fifteen participants. Similarly the Average column provides the average ranking of each concept by all test subjects.

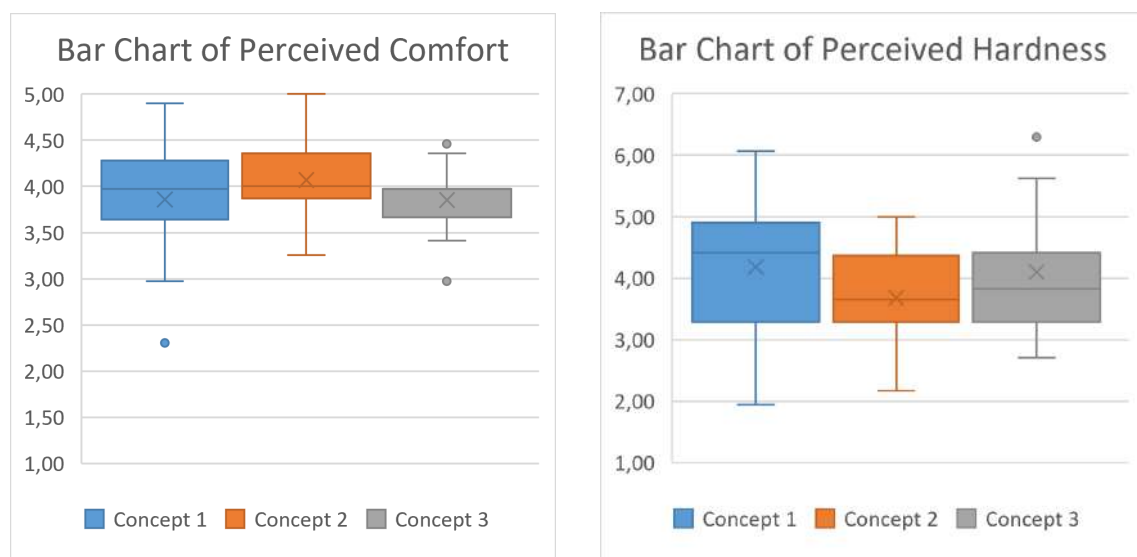
Table 4.4: Average comfort scores and ranking distribution per concept indicating how many times each concept was ranked 1st, 2nd and 3rd as well as their average rank.

Concept	Comfort	Ranking			
	Average	1st	2nd	3rd	Average
1	3.86	5	5	5	2.0
2	4.07	8	5	2	1.6
3	3.85	3	7	5	2.1

In Table 4.5, the results of the user evaluation relating to their perceived discomfort and hardness has been summarised. The average discomfort shows the users average perceived discomfort in the three different areas, being buttocks, thighs and knees. Here a 1 on the scale is no discomfort and a 5 is high discomfort/pain in the given area. Furthermore the column describing the perceived hardness, shows the average value given by each test subject, ranging from 1-Very soft to 7-Very hard. How the perceived comfort and hardness is spread can be seen in Figure 4.18.

Table 4.5: Average discomfort scores and perceived hardness per concept.

Concept	Average Discomfort			Perceived Hardness
	Buttocks	Thighs	Knees	
1	1.89	1.70	1.32	4.18
2	1.70	1.72	1.35	3.68
3	1.89	1.58	1.31	4.10



(a) Bar chart depicting the spread of the perceived comfort.

(b) Bar chart depicting the spread of the perceived hardness.

Figure 4.18: Bar charts depicting the spread of the perceived hardness and comfort for the three concepts.

4.4 Key findings from design iteration 2

This section covers the most important findings from design iteration 2. The findings are categorised in 5 parts; Final concept design, Parametrisation, Mating surface design, Tooling & mould performance and Prototypes & user evaluation. The purpose of this section is to provide a conclusion to design iteration 2 and to highlight the most significant outcomes.

4.4.1 Final concept design

Concepts 5 and 6 were combined in order to leverage their respective strengths for the final concept, resulting in a two part foam construction with an engineered mating surface. The intention of the concept was to achieve a slight concave effective shape underneath the buttocks, incorporating concept 6's construction at the rear, whilst the design of concept 5 provides a gradual rise of hardness underneath the thighs in the middle portion, and finally end with a soft front portion in order to reduce potential pressure on the backside of the knees.

4.4.2 Parametrisation

The parametrisation method had to be slightly adjusted to incorporate at least one more cross section in order to accurately describe the geometry of the splitting surface for the final concept. With a third cross section, more complex geometries could be communicated between project group members without the need for CAD tools. This method allowed for a more controlled and intentional design process of the final concept, which is described by its parameters in Figure 4.6.

4.4.3 Mating surface design

The final surface used to split the foam into its two constituents is shown in Figure 4.7 in Section 4.3.1. The foam should, according to equation 2.2 proposed in Section 2.3.1, vary in hardness across its surface with a linear correlation to the change in average density in any given vertical line going through a point on the surface. A representation of this variation in density and therefore, its variation in hardness, shown in Figure 4.8, verified that the splitting surface should according to this theory vary in hardness as intended, being softer underneath the buttocks, harder underneath the thighs and once again softer towards the back of the knees.

4.4.4 Tooling & mould performance

The tooling ended up being 3D printed and filled with sand to provide additional strength. Finally the moulds were glued together and covered using polyester resin, for a strong bond and to improve the tool surfaces. The moulds held up well through most casts, however, due to the tool's low temperature resistance, a slight surface defect was caused on the top foam pieces as a result from a tooling surface warping under the high heat applied during the foam manufacturing.

4.4.5 Prototypes & user evaluation

As shown in Table 4.1, 7 different foam hardnesses were obtained from the casting process, all using index 80, but with varying densities in order to vary their hardness, instead of using one density and varying the indices, as in design iteration 1. In this iteration, a more extreme range of foams was used in order to achieve more noticeable differences between the prototypes. As shown in Table 4.2 and Table 4.3, in Section 4.3.2, all prototypes had a negligible difference in average density, this

whilst concept 1 and 3 had large differences in density between the top and bottom halves.

The final prototype evaluation results, shown in Table 4.4 and Table 4.5, showed that the homogeneous construction (Concept 3), performed the worst by almost all metrics, apart from the average discomfort on the underside of the thighs. For the rankings and average comfort, concept 2 outperformed both other concepts, being ranked last only twice. Notably, even though Concept 1 and Concept 3 had almost identical average comfort scores, Concept 1 was ranked first more consistently than concept 3. Thus, some users found high levels of comfort in the concept, whilst others found the opposite, which indicates that concept 1 is most comfortable for a specific user type. Concept 2 was on average perceived to be the softest, even though its top layer was neither the softest used, nor the construction with the lowest average density, as can be seen in Table 4.1 and Table 4.2 respectively. However, despite concept 1 having the softest top layer it was perceived to be about as hard as concept 3 which had the hardest top layer. This indicates that the softer foam in concept 1 bottoms out and starts acting rigidly. Thus, it is instead the harder bottom foam that dictates the construction's deformation behaviour.

5 Summarized results

This section presents a summary of the projects results starting with the results from the pre-study and then moving on to the results from the first and second design iterations. The complete outcomes and key takeaways from the pre study, the first design iteration and the second design iteration can be seen in Sections 2.3 & 2.4; 3.3 & 3.4; 4.3 & 4.4 respectively.

5.1 Pre-study results

A user needs list for a gaming seat cushion, derived from data gathered from literature, patent research, competitor review audits, user studies and expert interviews, describes crucial design parameters when designing a gaming chair. The needs list is comprised of 4 separate lists, each relating to specific aspects of a gaming chairs design, these are:

1. Table 2.10 describing user needs relating to physical comfort
2. Table 2.11 describing needs relating to seating posture
3. Table 2.12 describing needs relating to product lifespan and quality
4. Table 2.13 describing needs relating to aesthetic aspects of the product

5.2 Design iteration 1 results

Originally 12 concepts were generated through ideation using the method of brain-drawing. These twelve original concepts are showcased in Figure 3.2. Out of the original 12 concepts, three of them were chosen to be manufactured for the first iteration of prototypes.

The 3 concepts ultimately chosen, being concepts 5,6 and 12 showcased in Figure 3.7, were picked through a screening process using a kesselring matrix which used the needs list from the pre-study in order to compile a weighted needs list used to rank the concepts. Additionally a user test on low fidelity prototypes of the most promising concepts was used to further validate the rankings from the kesselring matrix. The weighted needs list used for the kesselring matrix can be viewed in Table 3.1, with the scoring results showcased in Figure 3.6. Furthermore the results from the comfort ranking of the low fidelity prototypes can be viewed in Tables 3.4 & 3.5.

Finally, concepts 5, 6 and 12, were realized as prototypes and tested through both user tests and pressure tests. The user evaluation results, shown in Tables 3.6 & 3.7, revealed that concepts 5 and 6 performed the best in terms of increasing comfort and reducing discomfort in the thigh and knee regions. Concept 5 also indicated through the results from the pressure tests, shown in Table 3.8 and in Figure 3.8, that it successfully redistributed pressure onto the thighs, as the design intended. Furthermore the pressure tests also revealed that the constructions were indeed effective in manipulating the hardness of the cushion across its interface with the user.

5.3 Design iteration 2 results

By combining the designs of Concepts 5 and 6, a final concept was designed, with the intention of the foam being cast in two separate parts, splitting the cushion horizontally. By engineering the mating surface between the resulting top and bottom foams, the design intended to re-distribute pressure from the buttocks and ischial bones to the thighs, reduce potential pressure on the backside of the knees and create a somewhat concave shape around the buttocks and effectively "hug" the user. The resulting mating surface, with a visualization of its variation in curvature can be seen in Figure 4.7.

In order to manufacture the foams through casting, tooling had to be designed. To produce fast and cost effective tooling for a low number of casting cycles, the tooling was 3D-printed and filled with sand to provide additional strength. The resulting moulds held up well through manufacturing with only minor defects on the top foam parts, proving the method works well for small batch sizes and prototyping. The manufacturing process can be viewed in detail, in Section 4.3.2.

In total 3 different prototypes were created, all with a similar average density, but with varying density differences between the top and bottom foam halves. The three different concepts had the following density differences between the top and bottom foams: Concept 1 had a 38% denser bottom foam representing the most extreme concept, Concept 2 had a 17% denser bottom foam being a scaled down version of Concept 1, and finally Concept 3 had a 1% softer bottom foam representing a homogeneous construction.

The user evaluation results shown in Tables 4.4 & 4.5, showed that Concept 2 ranked the highest in terms of average comfort as well as in reducing the average discomfort at the buttocks. Additionally Concept 2 was on average rated by users, as the foam with the lowest perceived hardness. Concept 1 had the second highest average comfort score, closely followed by Concept 3. Concept 3 ranked the lowest by most metrics, except for reducing the average discomfort in the thighs and knees region, as being ranked in the middle for the perceived hardness. In terms of average comfort, both Concept 1 and 2, which used the engineered mating surface by incorporating noticeably different foam hardnesses, outperformed the homogeneous representation of Concept 3.

6 Discussion

This chapter discusses the methods used in the report and how they were implemented, the results societal, ethical and ecological implications as well as some recommendation for future work and how AI was used.

6.1 used methods and their implementation

In this section the used methods and how they were implemented is discussed. It begins by discussing how the pre study was executed and then moves on to the design of the concepts and prototypes. In the end some aspects of the comfort evaluation is discussed and the section ends with what would have been done differently if the project would have been executed again.

In order to achieve the best result this project was carried out as a combination of research and development. Whilst the evaluations provided insights about comfort, pressure distribution, and foam behaviour; the iterative approach enabled these findings to be used as a basis for design decisions, in order to improve the next iteration of prototypes.

6.1.1 Pre-study

During the beginning of the project it was recommended to investigate the theory behind the construction and manufacturing of mattresses to see if that information could be beneficial within this project. However, this was not done due to it not seeming that beneficial at the time and other sources of data more directly linked to seating comfort were instead investigated. In hindsight, mattress construction would have been interesting to investigate but it would have resulted in the pre study taking up more time or some other area of research being neglected.

The method used to gather information, both from research papers and expert within their respective fields was exploratory and served to provide the authors with a good grasp of the already existing knowledge within the given research area. With this being said, the methodology used was not exhaustive and there is a risk that some sources that could have provided useful information were missed.

The perceptual mapping in Section 2.3.3 only included 14 participants from two very different groups. The limited amount of participants and their backgrounds constitutes a risk that the result does not represent the actual target customer. Furthermore, it could have been interesting to investigate other word scales such as "comfortable-uncomfortable", especially since Makris (2026) showed that comfort is influenced by a users expectations of a product even before they are seated.

The needs list presented in Section 2.3.5 was created in a relatively subjective manner with the purpose of quickly getting a usable needs list. This most definitely impacted the result and using a method such as the *KJ-Method* could have provided a more robust and objective result but it would have required more time to be committed to the creation of the needs list.

6.1.2 Design of concepts & prototypes

During the initial design phase only a very limited amount of twelve concepts were developed. This most likely means that some promising concepts were not discovered and that the entirety of the solution space was not evaluated. Methods such as a *Morphological Matrix* could have aided in identifying additional possible solutions but would have taken a considerable amount of time to execute. Thus it was assumed that the twelve already generated concepts likely included the best solutions and the risk that some potentially interesting solutions were missed was accepted.

Unfortunately, the foam used for the first iteration of prototypes was quite a bit harder than desired. This occurred due to a lack of knowledge of what foam hardness that would have been suitable. Due to this the first prototypes turned out harder than initially planned which not only impacted how comfortable they were but also how effectively the different concepts could redistribute the pressure which impacted the result from the pressure mapping.

The prototypes were for both iterations mounted to a *Fractal Design Refine* chair. Thus the comfort of the prototypes have been evaluated in combination with this very specific backrest which most likely impacted the results. There is therefore a chance that the prototypes were tested with another backrest that the results would have turned out differently.

6.1.3 Comfort evaluation

The comfort evaluation for both iterations has a number of factors that most likely impacted the results. For both the tests the participants were allowed to adjust the chair based on their preferred settings in order to ensure that they were as comfortable as possible. This resulted in different seating positions between participants which might have impacted the results. However, it was deemed as necessary since the participants varied in height and anthropometric measurements and the settings for one individual could likely have been uncomfortable for another.

Furthermore, the comfort evaluation included a limited amount of participants, 12 and 15 for the first and second design iteration respectively. Furthermore, the participants were largely male, though demographic variables were not officially recorded during studies. The reason for not recording demographic data was that the sample size of participants was deemed to be too small to be able to draw any conclusions regarding the effects of a participant's sex.

No data on the participants' anthropometric measurements, such as their length, knee height, femur length, or weight, were gathered. It would have been interesting to gather such information to see if there was a correlation between an individual's anthropometric measurement and their preferred concept. However, once again, even if such information had been gathered, the sample size was very small and thus any identified correlations would not have been statistically significant.

During the comfort evaluation the participants were instructed to be seated upon each concept for 5 minutes. Comfort is usually reduced over time and thus the early perceived comfort is indicative of which concept that would be the most comfortable

after a longer seating duration. However, there is a possibility that the comfort of the concepts declines at different rates and that the concept that is the most comfortable after five minutes would not be the most comfortable after one hour. Thus, it is not certain that the result presented is indicative of which concept that would be the most comfortable for longer seating durations.

6.1.4 Areas of improvement

As always, there are many things throughout the project that could have been done differently. This section describes the aspects which the authors would have prioritised to change; if given the chance to execute the project again.

As mentioned previously the participants in both studies was limited and not representative of the larger population. Thus, it would have been highly beneficial to dedicate more time for the comfort evaluation so that the sample size could have been increased. Furthermore, ensuring that the participants were representative of the larger population by at the very least having half be women and the other half men would have provided a more robust result.

It would have been very useful to perform comfort evaluations where the participant would have been seated for a longer duration, perhaps for 45 minutes to an hour as this would most likely have been more representative of the actual use case. If the sample size for the shorter test were larger these longer ones could have been performed with fewer participants and thus not required an unrealistic amount of time committed. It would have been very interesting to see whether or not the concept that was the most comfortable after 5 minutes would also be the most comfortable after a longer duration.

The results from the pressure mapping in Section 3.3.5 showed little to no difference between the three concepts. In hindsight it would most likely have proved more beneficial to perform pressure tests on the second iteration of prototypes instead of the first iteration prototypes.

In order to perform a more elaborate comfort evaluation, it would have required more time. Since the project had a start and an end date, some other part of the project would have had to be cut or given less time. Whilst everything done throughout the project in one way or another aided in progress towards the final results, there are some parts where time could have been saved.

The first one being to focus on the foam construction earlier on. The project early on very open and thus a lot of different solutions that could improve comfort were considered such as mechanisms for extending the seat depth and pneumatic systems that could redistribute pressure. Whilst these could have been interesting, if the focus was shifted towards foam construction earlier, time would have been saved that could have been used for the aforementioned improvements.

Once the goal was set on investigating foam construction it was originally planned to mould the foam in the first design iteration. However, after a while it was realised that cutting foam blocks would provide a good enough result and would take considerably less time. If this had been the plan from the start, a lot of time

would have been saved during the preparations for the manufacturing of the tooling. Additionally, foam could have been ordered earlier to ensure that it was available when it was needed which would have reduced downtime.

6.2 Societal, ethical and ecological aspects

This section will discuss the societal, ethical and ecological impact of this project.

6.2.1 Societal

The main societal aspect for the result of the project is that as mentioned in Section 6.1.3, the participants in the comfort evaluations were from a subgroup of the larger population of probable users. Thus, if this result is used in isolation to develop a seat cushion, there is a risk that the resulting solution will discriminate against a large group of otherwise potential customers.

Another aspect to consider is that since the goal of the project has been to create a more comfortable seat cushion it could contribute to users spending more time seated. This in turn could result in problems and pain in the hips, lower back and neck that are commonly linked to being seated for long periods.

6.2.2 Ethical

No personal data has been gathered for the entirety of the project and all information related to the project have been stored on either the Chalmers *OneDrive*, locally on personal computers or phones or on paper.

All participants in both comfort evaluation were briefed about both the purpose of the tests and the project as a whole before they started. Their consent to participating was gathered through a written signature. For the first iteration of prototypes, they were also asked if they consented to being filmed from the side while performing the test. This film was taken with the intention of counting how often the participant changed their posture and they were not informed of this prior to consenting as it could have impacted how often they changed their posture. However, they were informed of this after the tests were finished and their consent was completely optional and confirmed by checking an additional box below their signature. These films were stored locally on personal phones and were deleted after they had been analysed.

6.2.3 Ecological

In order to create the prototypes foam was ordered and unfortunately too much was ordered and thus not all of it could be used. Therefore, the prototype creation resulted in a large amount of leftover foam that would have become waste. The foam was offered to be donated to the *FUSE-lab* at *Chalmers* which they gratefully accepted. Thus the foam will not be thrown away and can hopefully be used in other students projects.

During the manufacturing of the prototypes, the use of harmful chemicals was necessary. Though they were used in well ventilated areas, whilst wearing personal protective equipment, and handled responsibly, there is a risk that they inflicted damage to the environment and to the individuals using the chemicals.

The manufacturing method used to create the second round of prototypes required the use of two tools, in order to create the two unique foam halves. Usually, the foam is manufactured in its entirety using only one tool and thus this method would require more material and machining for the now two tools. Furthermore, the foam being in two pieces instead of one will result in it requiring additional steps to be assembled. This could result in more material being used and more emissions, however the amount of foam consumed remains unchanged.

6.3 Recommendation for future work

As mentioned in Section 6.1.3 the participant in the comfort evaluations were predominantly male which as presented in Section 6.2.1 is not only a design limitation but a societal problem. It is thus recommended that the comfort evaluation is complemented with additional tests to ensure that they represent the target audience. Furthermore, as also mentioned in Section 6.1.3 the comfort evaluations only lasted five minutes. It is thus recommended that during these additional tests the participants are seated for a longer duration. In Section 6.1.4 it was mentioned that it would have been more beneficial to perform pressure test on the second iteration prototypes and it is thus also a recommendation for future work to do pressure tests on these prototypes.

The prototypes created in the second design iteration were apart from a slight decline from the front of the seat to the rear of the seat practically completely flat. In a lot of cases the cushions of chairs are not completely flat and it is thus recommended to investigate how the concepts presented can be integrated into and combined with a shaped seat.

Furthermore, it is recommended to investigate if the combination of hardnesses could be customised, to optimise the comfort for different individuals based on e.g., their anthropometric measurements or sex.

Due to the concept cushion consisting of two pieces of foam it would need to be investigated how mass production would be executed. Furthermore, the top and bottom foam half needs to be combined in some manner and it is thus recommended to investigate how this would be incorporated into the production line.

As mentioned in Section 6.1.2 the concepts were evaluated in combination with the backrest of a *Fractal Design Refine* chair. It is thus recommended to investigate if the results remain the same if evaluated in combination with other backrests. Furthermore, it would be interesting to see what design considerations should be taken when designing a backrest in combination with a seat cushion similar to the proposed concepts.

6.4 Use of AI

AI has been of great aid and used extensively when modifying figures, tables and solving other formatting issues in $\text{\LaTeX}$, but has not been used to modify or generate any of the content. The only exceptions to this are that the data gathered from both the perceptual mapping and the competitor review audit, which were fed through an LLM in order to analyse and summarise the consensus of opinions in said data, as mentioned in Section 2.2.3. Additionally, AI was used to generate a draft of the abstract that was thoroughly reviewed and modified, before being implemented into the report. Otherwise AI has not been used to generate any of the text written in the report but has been used for recommendations on rephrasing, translating, and improving clarity. Lastly, AI has been used to generate the code used to visualise most of the plots throughout the report.

7 Conclusion

The project set out to investigate what constitutes a gaming chair seat cushion and how its foam construction can be engineered to improve the comfort which a user experiences whilst seated. The specific research questions and their respective answers are presented below.

How does the gaming market's expectations limit the solution space for a gaming chair seat cushion?

The pre-study revealed that no single design element is absolutely necessary for a gaming chair to be considered in the gaming category, and minor design details, such as colour, covering material and logotype placement, can be tweaked at late stages of the design process, with strong impact to this expression. Therefore the shape and materials used for a gaming chair seat cushion may be manipulated freely without the risk of losing relevance to the target market.

Can foams of different hardnesses be combined into a singular seat cushion in order to create a varying hardness across its surface?

The pressure test results from design iteration 1 confirmed that combining foams of varying hardness inside of a seat cushion, successfully altered the pressure distribution on the seat by a seated user. Consequently, this means that the hardness across the interface of the cushion must have changed in order to achieve this difference in pressure distribution, meaning the answer to the research question is yes.

Can a cushion's pressure distribution properties be manipulated by varying the hardness across its surface?

Yes, the results from both design iterations indicate that pressure distribution and localised comfort can be optimised through specifically engineered foam constructions. The results show that by manipulating the horizontal mating surface between varying hardnesses of foams within a construction, the effective shape that the cushion adopts will be altered, meaning the seated user will experience an altered loading pattern on their interacting body parts, consequently altering the pressure distribution on said body parts.

Can the pressure distribution properties of a seat cushion be manipulated in order to improve the seat comfort, compared to a homogeneous foam cushion?

Yes, the results indicate that users find that a cushion that distributes pressure more evenly across the buttocks and thighs is more comfortable than a classic homogeneous foam without altered pressure distribution properties. Additionally, the results also show a correlation between perceived hardness and comfort, meaning that a user generally tends to perceive a cushion as more comfortable if they believe it to be softer. This further indicates that a horizontally layered foam construction is optimal, as the upper layer can focus on providing a soft sensation, whilst a lower and harder layer provides stability and structure.

Bibliography

Atlassian. (n.d.). *What is perceptual mapping?* <https://www.atlassian.com/work-management/project-management/perceptual-mapping>

Bang, J. H., Lee, C. A., Kim, H. Y., Kim, H. J., & Choi, K. Y. (2017). Optimization of the static properties of seat foam to improve the seating comfort. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 231(14), 1945–1960. <https://doi.org/10.1177/0954407016688782>

Cambridge Dictionary. (n.d.). *Comfort*. <https://dictionary.cambridge.org/dictionary/english/comfort>

de Looze, M. P., Kuijt-Evers, L. F. M., & van Dieen, J. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, 46(10), 985–997. <https://doi.org/10.1080/0014013031000121977>

Dentons. (2026, March). *Patent searching: A guide to key search types and their strategic uses*. <https://www.dentons.com/en/insights/articles/2026/march/10/a-guide-to-patent-searching>

Ebe, K., & Griffin, M. J. (2001). Factors affecting static seat cushion comfort. *Ergonomics*, 44(10), 901–921. <https://doi.org/10.1080/00140130110064685>

Fractal Gaming Group AB. (n.d.). *Fractal announces four new products, including two new product categories*. <https://group.fractal-design.com/press-release/fractal-announces-four-new-products-including-two-new-product-categories/>

Goossens, R., Teeuw, R., & Snijders, C. (2005). Sensitivity for pressure difference on the ischial tuberosity. *Ergonomics*, 48(7), 895–902. <https://doi.org/10.1080/00140130500123647>

Makris, M. (2026). *Beyond the seat: Exploring passengers' ride comfort in cars* (Publication No. 5855) [Doctoral thesis]. Chalmers University of Technology [ISSN 0346-718X]. <https://doi.org/10.63959/chalmers.dt/5855>

Moon, J., Sinha, T. K., Kwak, S. B., Ha, J. U., & Oh, J. S. (2020). Study on seating comfort of polyurethane multilayer seat cushions. *International Journal of Automotive Technology*, 21(5), 1089–1095. <https://doi.org/10.1007/s12239-020-0102-z>

Naddeo, A., Morra, A., & Califano, R. (2024). Human-centered design and manufacturing of a pressure-profile-based pad for better car seat comfort. *Machines*, 12(6), 374. <https://doi.org/10.3390/machines12060374>

PaperSurvey. (2026, April). *Likert scales: Designing rating questions that produce reliable data*. <https://www.papersurvey.io/blog/likert-scales-designing-rating-questions>

Research Institutes of Sweden. (n.d.). *Komfortprovning*. <https://www.ri.se/sv/material-och-bestandighet/textil/expertis/komfortprovning>

Sensors lx210:40.40.02 [V3]. (2016, July). XSensor Technology Corporation.

Swedish Standards Institute. (2008). Flexible cellular polymeric materials—determination of hardness (indentation technique) [SS-EN ISO 2439:2008]. <https://www.sis.se/en/produkter/rubber-and-plastic-industries/cellular-materials/ss-en-iso-3386-12025/>

Swedish Standards Institute. (2025). Polymeric materials, cellular flexible — determination of stress-strain characteristics in compression — part 1: Low-density materials [SS-EN ISO 3386-1:2025]. <https://www.sis.se/en/produkter/rubber-and-plastic-industries/cellular-materials/iso-3386-12025/>

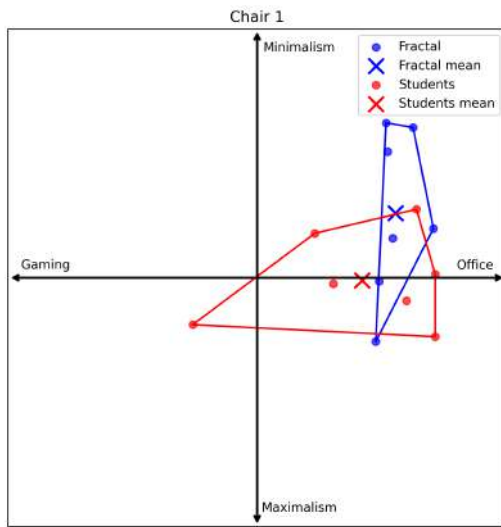
Ulrich, K. T., & Eppinger, S. D. (2016). *Product design and development* (6th Edition). McGraw-Hill Education.

Vink, P., & Lips, D. (2017). Sensitivity of the human back and buttocks: The missing link in comfort seat design. *Applied Ergonomics*, 58, 287–292. <https://doi.org/10.1016/j.apergo.2016.07.004>

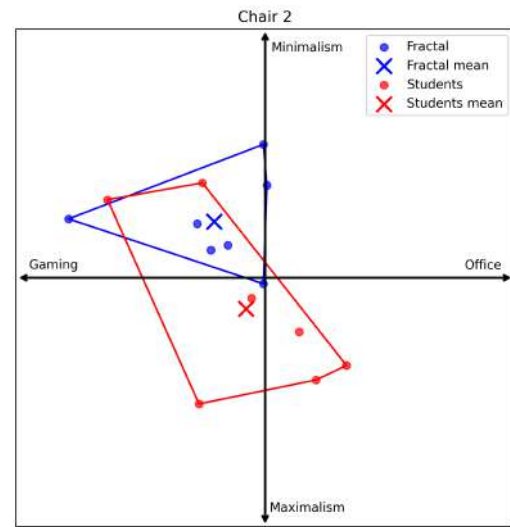
Zemp, R., Taylor, W. R., & Lorenzetti, S. (2015). Are pressure measurements effective in the assessment of office chair comfort/discomfort? a review. *Applied Ergonomics*, 48, 273–282. <https://doi.org/10.1016/j.apergo.2014.12.010>

Zhang, L., Helander, M. G., & Drury, C. G. (1996). Identifying factors of comfort and discomfort in sitting. *Human Factors*, 38(3), 377–389. <https://doi.org/10.1518/001872096778701962>

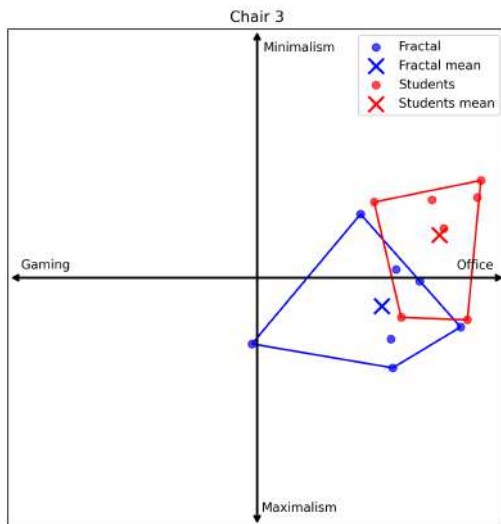
A Plots from perceptual mapping



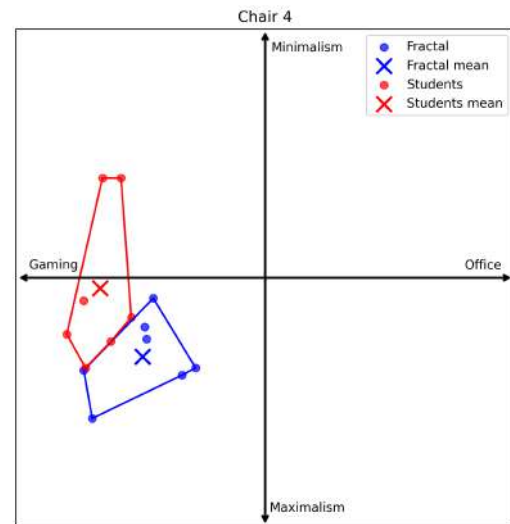
(a) Placement for chair 1.



(b) Placement for chair 2.



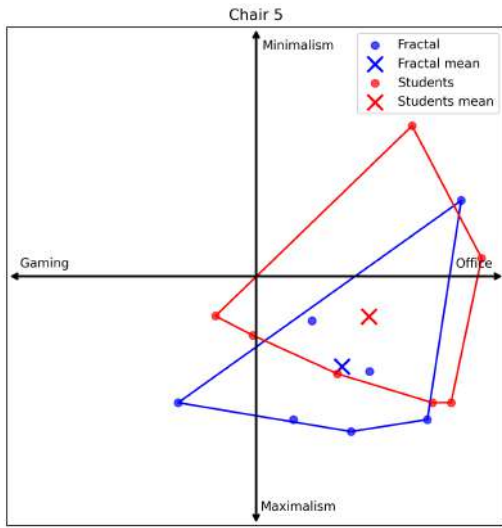
(c) Placement for chair 3.



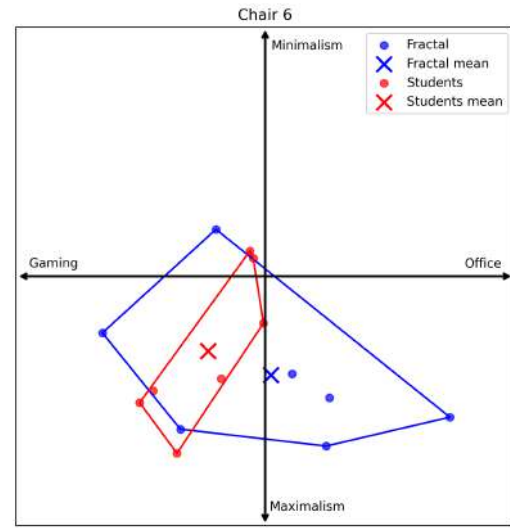
(d) Placement for chair 4.

Figure A.1: Perceptual mapping placements, chairs 1–4.

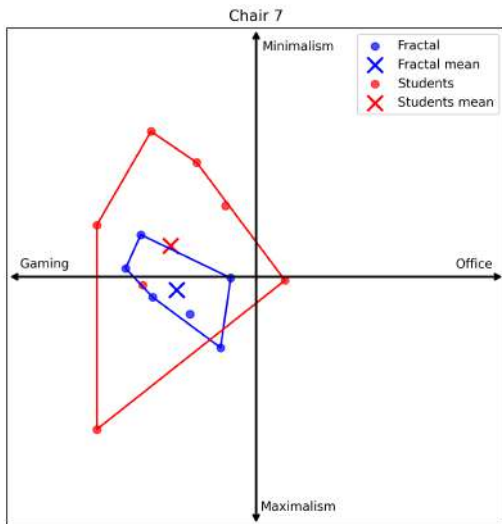
A. Plots from perceptual mapping



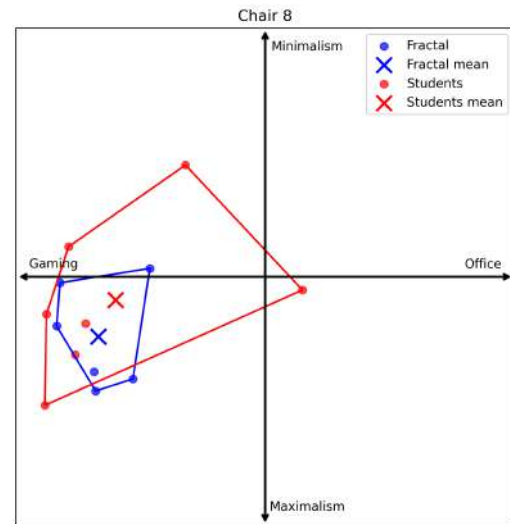
(a) Placement for chair 5.



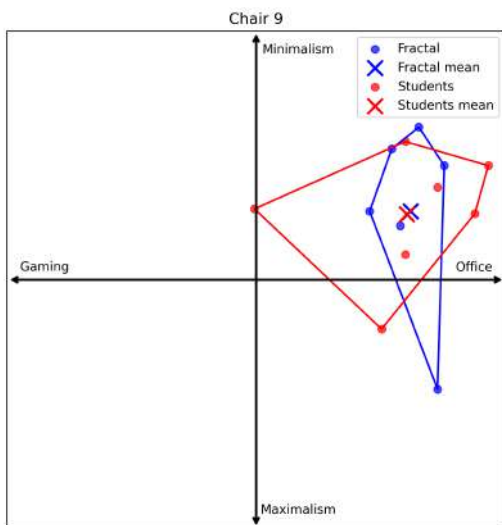
(b) Placement for chair 6.



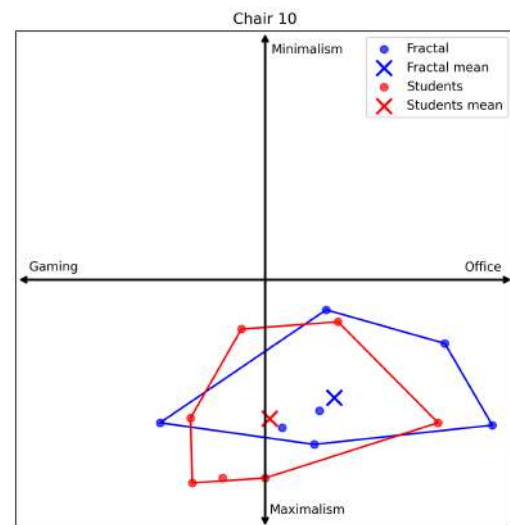
(c) Placement for chair 7.



(d) Placement for chair 8.

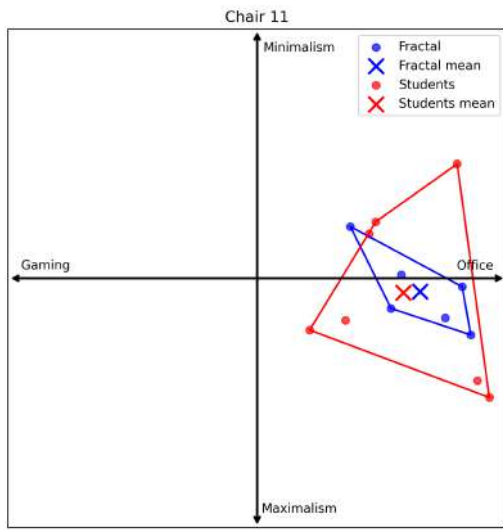


(e) Placement for chair 9.

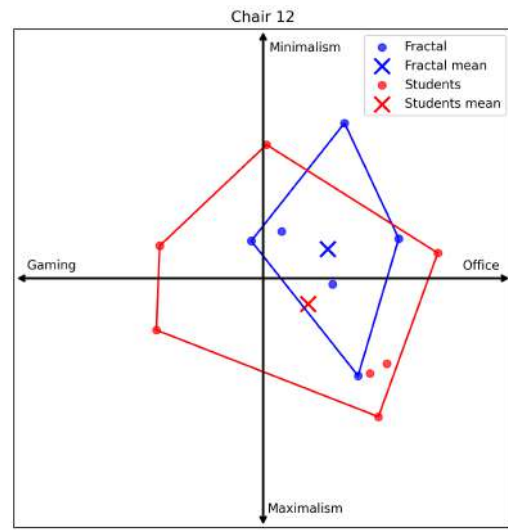


(f) Placement for chair 10.

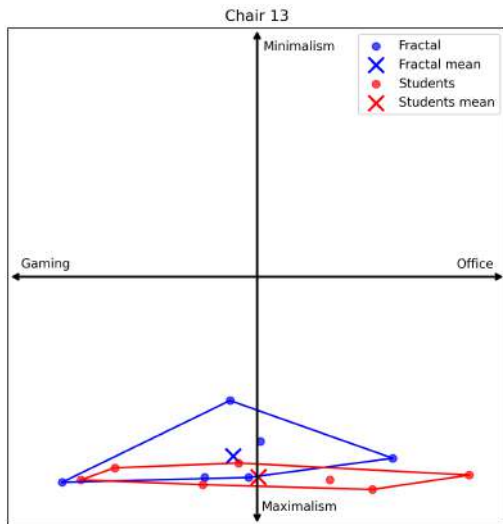
Figure A.2: Perceptual mapping placements, chairs 5–10.



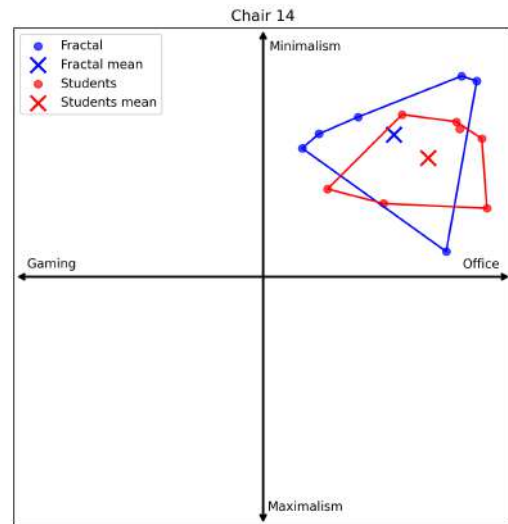
(a) Placement for chair 11.



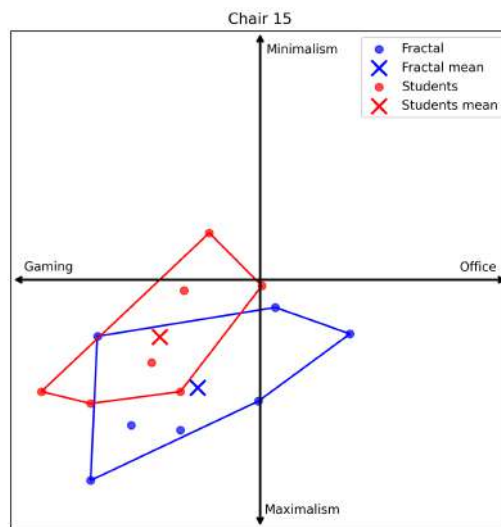
(b) Placement for chair 12.



(c) Placement for chair 13.



(d) Placement for chair 14.



(e) Placement for chair 15.

Figure A.3: Perceptual mapping placements, chairs 11–15.

B Results from Kesselring matrix

Table B.1: Concept scores — Concepts 1 to 4.

No.	Need	C1	C2	C3	C4
1.2	Soft to the touch	3	3	4	5
1.4	Gradual support	2	1	3	5
1.5	Cushion should have a firm hold	3	2	2	4
1.8	Reduce peak pressure	3	1	2	3
1.10	Proper support under thighs	4	1	3	4
1.11	Reduce peak pressure on the back side of the knee	1	5	4	3
2.1	Allow for various seating positions	5	5	4	5
3.2	Stable base	3	3	3	4
		61%	49%	60%	81%

Table B.2: Concept scores — Concepts 5 to 8.

No.	Need	C5	C6	C7	C8
1.2	Soft to the touch	5	5	1	5
1.4	Gradual support	3	4	2	3
1.5	Cushion should have a firm hold	3	5	4	4
1.8	Reduce peak pressure	5	4	2	2
1.10	Proper support under thighs	5	2	4	3
1.11	Reduce peak pressure on the back side of the knee	4	3	2	4
2.1	Allow for various seating positions	3	4	5	4
3.2	Stable base	4	5	2	4
		79%	79%	57%	69%

Table B.3: Concept scores — Concepts 9 to 12.

No.	Need	C9	C10	C11	C12
1.2	Soft to the touch	3	3	3	5
1.4	Gradual support	3	4	3	4
1.5	Cushion should have a firm hold	2	4	3	1
1.8	Reduce peak pressure	3	3	4	2
1.10	Proper support under thighs	3	4	5	3
1.11	Reduce peak pressure on the back side of the knee	3	2	3	5
2.1	Allow for various seating positions	4	1	3	5
3.2	Stable base	2	3	3	1
		57%	61%	69%	61%

C Results from 1st user evaluation

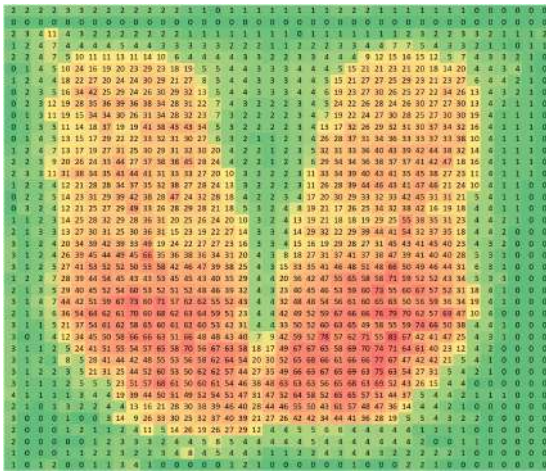
Table C.1: Perceived comfort and discomfort for all users and prototypes, higher is better for comfort, lower is better for buttocks, thighs and knees for users 1-6.

User	Concept	Comfort	Buttocks	Thighs	Knees
1	5	4	1	0.75	0
	6	2.5	2	0.75	0
	12	3	2	1	0
2	5	4	0.5	0.5	0.5
	6	3.5	0.5	0.5	0.5
	12	3.5	0.5	1	0.5
3	5	2	1.5	0.5	0
	6	3	0	0	0
	12	1.5	0.5	2.5	0
4	5	4.5	0.25	0.25	0.25
	6	3.5	1.5	1	1
	12	2.5	1.75	1.75	1.75
5	5	4	0	0	0
	6	4	0	0	0
	12	3	1	0	0
6	5	3.75	0.75	0.5	0.5
	6	3.5	1	1	0.75
	12	4	0.75	0.75	0.75

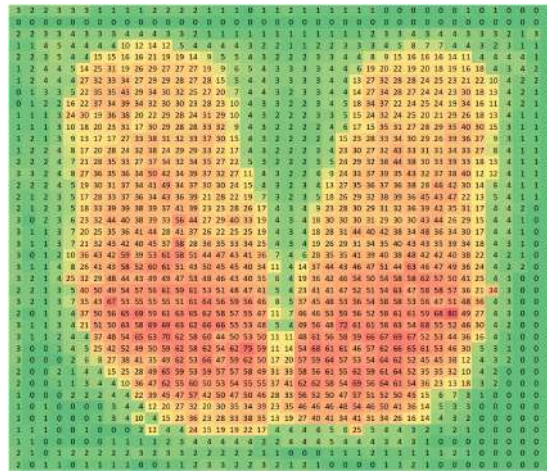
Table C.2: Perceived comfort and discomfort for all users and prototypes, higher is better for comfort, lower is better for buttocks, thighs and knees for users 7-12.

User	Concept	Comfort	Buttocks	Thighs	Knees
7	5	3.9	0	1.25	0
	6	4.25	1	0.25	0
	12	3.25	1	3.25	0
8	5	4.5	1.5	0.5	0
	6	4	2	0.5	0
	12	4.75	0.75	0	0
9	5	2.7	2.75	0.25	0
	6	3.75	1.25	0.25	0
	12	3	2.25	0.75	0
10	5	2.75	2	1.25	0.75
	6	2.9	1.75	0.75	0.75
	12	3.25	1	0.75	0.75
11	5	4.25	0	0	0
	6	4	0	0	0.25
	12	3.75	0	0	0
12	5	3	1	1	0
	6	3	1	1	0
	12	3	1	1	1

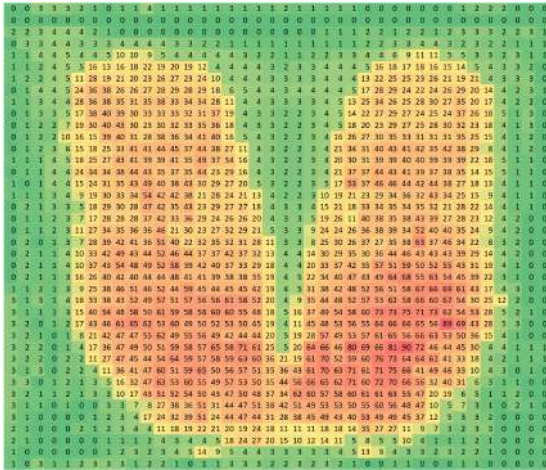
D Pressure Mapping data



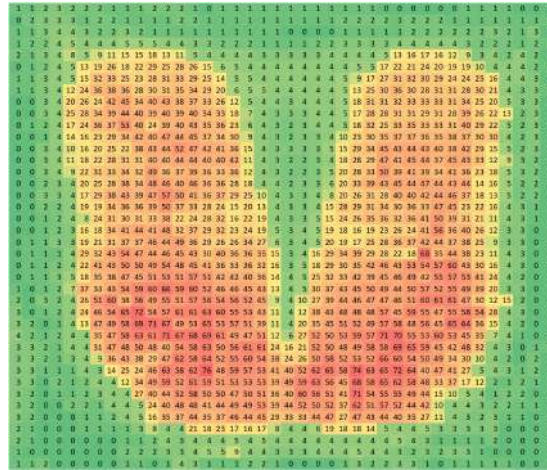
(a) Pressure mapping test 1.



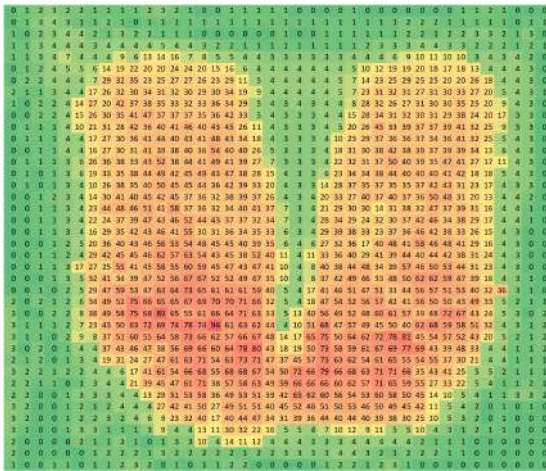
(b) Pressure mapping test 2.



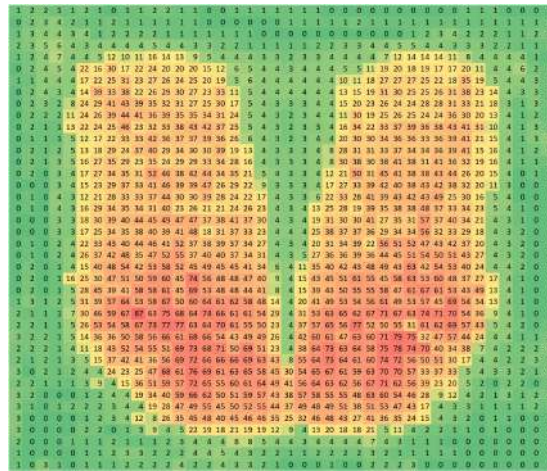
(c) Pressure mapping test 3.



(d) Pressure mapping test 4.



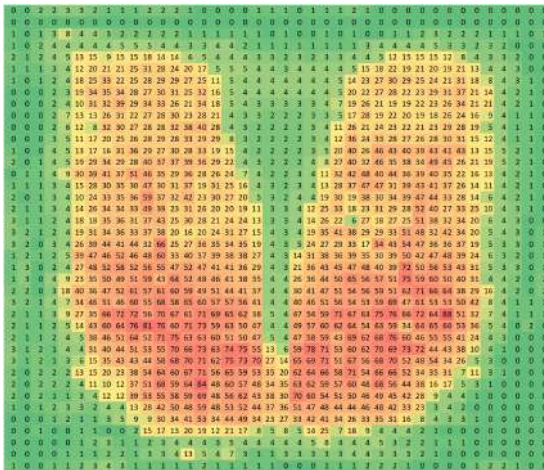
(e) Pressure mapping test 5.



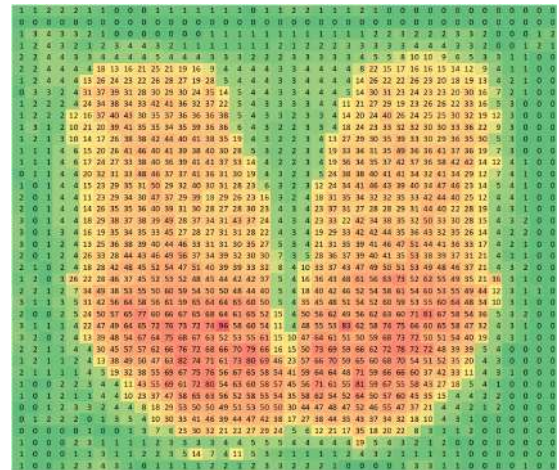
(f) Pressure mapping test 6.

Figure D.1: Pressure mapping tests for concept 5.

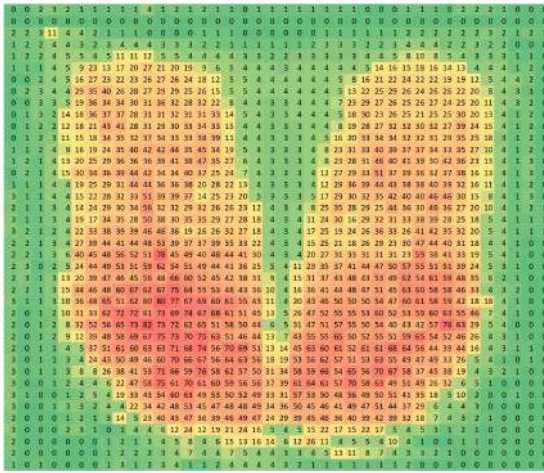
D. Pressure Mapping data



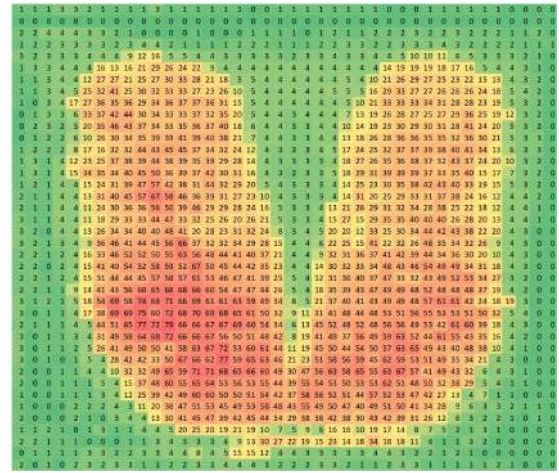
(a) Pressure mapping test 1.



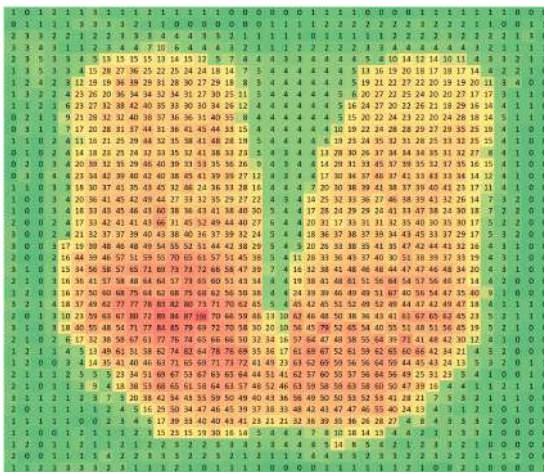
(b) Pressure mapping test 2.



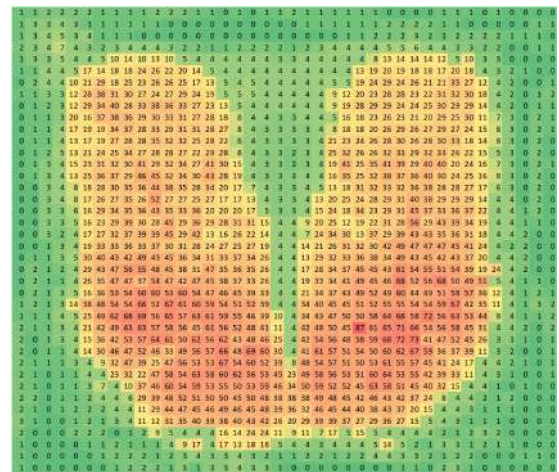
(c) Pressure mapping test 3.



(d) Pressure mapping test 4.



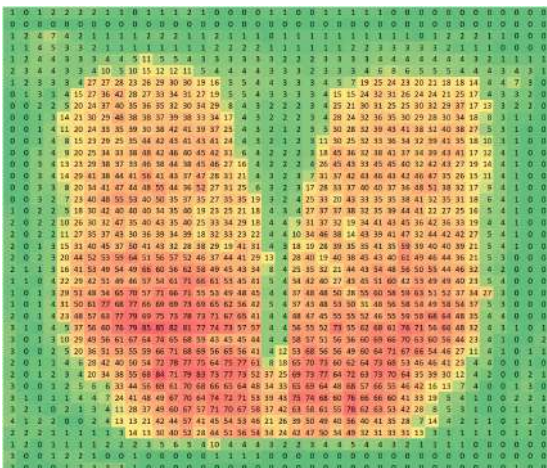
(e) Pressure mapping test 5.



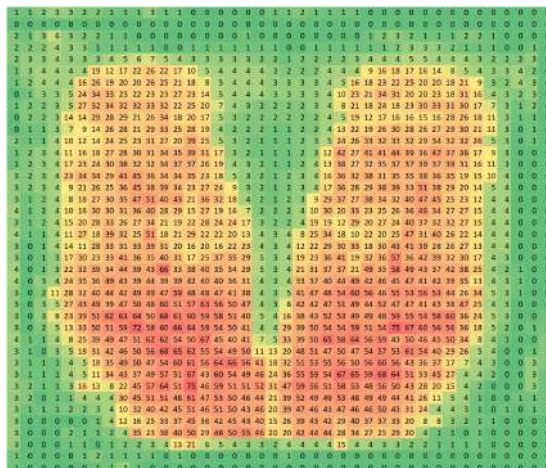
(f) Pressure mapping test 6.

Figure D.2: Pressure mapping tests for concept B.

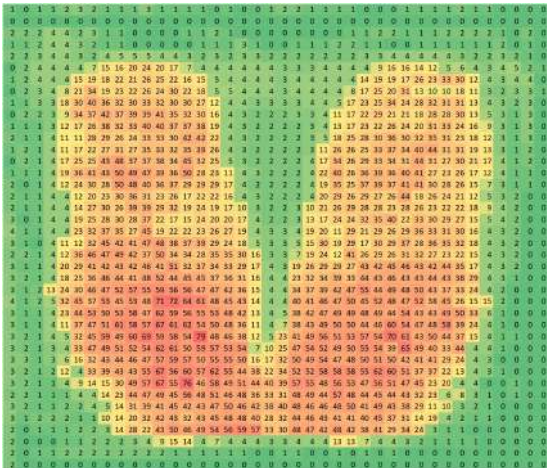
D. Pressure Mapping data



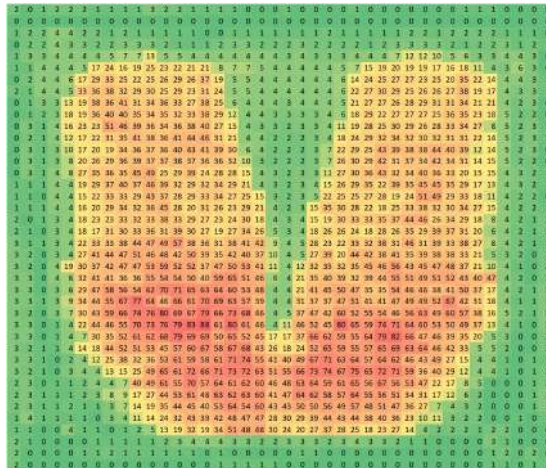
(a) Pressure mapping test 1.



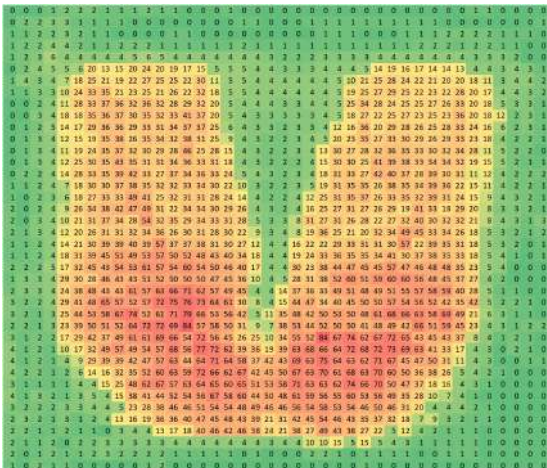
(b) Pressure mapping test 2.



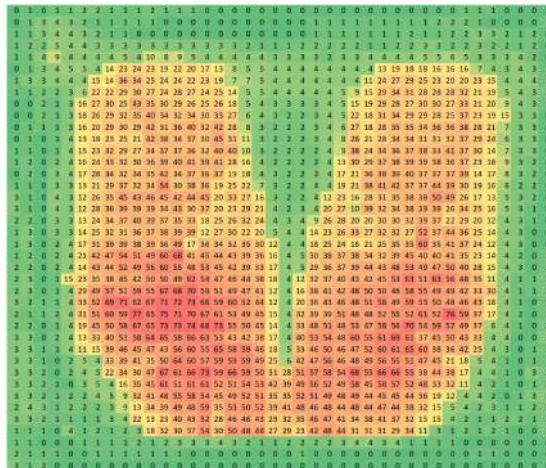
(c) Pressure mapping test 3.



(d) Pressure mapping test 4.



(e) Pressure mapping test 5.



(f) Pressure mapping test 6.

Figure D.3: Pressure mapping tests for concept 12.

E Results from 2nd user evaluation

Table E.1: Comfort scores, normalised values and rankings for all users and concepts, users 1–8.

User	Concept	Comfort	Norm	Rank
1	1	3.95	33.2%	2
	2	4.15	34.9%	1
	3	3.79	31.9%	3
2	1	3.97	36.4%	1
	2	3.97	36.4%	1
	3	2.97	27.2%	3
3	1	2.97	28.9%	3
	2	3.87	37.7%	1
	3	3.44	33.4%	2
4	1	4.28	35.6%	1
	2	4.08	33.9%	2
	3	3.67	30.5%	3
5	1	4.18	32.9%	2
	2	4.51	35.5%	1
	3	4.03	31.7%	3
6	1	3.82	33.1%	2
	2	3.74	32.4%	3
	3	3.97	34.4%	1
7	1	4.38	35.6%	1
	2	3.97	32.2%	2
	3	3.97	32.2%	2
8	1	3.97	29.6%	3
	2	5.00	37.2%	1
	3	4.46	33.2%	2

Table E.2: Comfort scores, normalised values and rankings for all users and concepts, users 9–15.

User	Concept	Comfort	Norm	Rank
9	1	4.64	34.7%	1
	2	4.36	32.6%	2
	3	4.36	32.6%	2
10	1	3.64	31.7%	3
	2	4.00	34.8%	1
	3	3.85	33.5%	2
11	1	4.18	33.2%	2
	2	4.44	35.2%	1
	3	3.97	31.6%	3
12	1	3.69	33.9%	2
	2	3.26	29.9%	3
	3	3.95	36.2%	1
13	1	2.31	23.9%	3
	2	3.36	34.8%	2
	3	3.97	41.2%	1
14	1	2.97	27.7%	3
	2	4.36	40.6%	1
	3	3.41	31.7%	2
15	1	4.90	38.1%	1
	2	3.97	30.9%	2
	3	3.97	30.9%	2

Table E.3: Discomfort scores and perceived hardness for all users and concepts, users 1–8.

User	Concept	Buttocks	Thighs	Knees	Perceived Hardness
1	1	3.39	1.46	1.00	4.23
	2	2.38	1.37	1.00	3.29
	3	2.98	1.55	1.09	3.83
2	1	1.92	1.55	1.00	4.41
	2	1.60	1.55	1.00	4.72
	3	2.43	1.09	1.00	6.29
3	1	2.93	2.01	2.01	5.62
	2	1.97	1.46	1.46	2.84
	3	2.24	1.46	1.46	4.41
4	1	1.00	1.00	1.00	4.90
	2	1.00	1.00	1.14	3.29
	3	1.00	1.00	1.00	3.78
5	1	1.00	1.74	1.00	2.97
	2	1.00	1.51	1.00	2.48
	3	1.37	2.15	1.00	5.62
6	1	2.15	3.34	2.01	3.83
	2	2.29	3.25	2.01	4.05
	3	2.01	2.98	2.01	3.29
7	1	1.00	1.00	1.00	4.41
	2	1.00	1.00	2.01	2.17
	3	1.00	1.00	1.00	3.29
8	1	1.00	1.00	1.00	3.29
	2	1.09	1.55	1.14	4.19
	3	1.37	1.32	1.32	5.62

Table E.4: Discomfort scores and perceived hardness for all users and concepts, users 9–15.

User	Concept	Buttocks	Thighs	Knees	Perceived Hardness
9	1	1.64	1.28	1.18	1.94
	2	2.20	1.87	1.18	3.65
	3	2.56	1.28	1.18	2.71
10	1	1.69	1.18	1.69	4.41
	2	1.28	1.18	1.69	4.14
	3	1.41	1.32	1.69	3.83
11	1	2.01	1.18	1.00	4.86
	2	1.32	1.32	1.00	3.29
	3	2.47	1.32	1.00	4.41
12	1	1.87	2.24	1.14	3.87
	2	1.87	3.76	1.14	3.29
	3	1.51	1.78	1.14	3.29
13	1	3.71	2.20	1.74	5.85
	2	2.75	2.20	1.74	4.41
	3	2.01	1.83	1.74	3.74
14	1	2.01	3.25	2.01	6.07
	2	1.83	1.83	1.78	4.99
	3	3.02	2.66	2.01	4.19
15	1	1.00	1.00	1.00	2.08
	2	1.92	1.00	1.00	4.37
	3	1.00	1.00	1.00	3.24

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