Personalized seating solutions for truck drivers

Reducing musculoskeletal disorders & discomfort with the use of 3D-printed seat inserts.

PERSONAL INFORMATION

Boris Steenhuis
5057612
Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology
25/06/2025

SUPERVISORS

Y. Song (Chair)
M. Özdemir (Mentor)
A. Anwar-Hameed (Company Coach)
Perfect Fit Upholsteries

TU Delft

ABSTRACT

Musculoskeletal disorders (MSDs) are a persistent occupational hazard among professional drivers, particularly truck drivers, due to prolonged static postures, whole-body vibrations, and poor seat ergonomics. These issues contribute to discomfort, sick leave, and long-term health deterioration. This study aimed to develop, prototype, and evaluate a personalized seating solution that addresses these risks through the use of 3D scanning and 3D printing technologies.

Over a 20-week research period, custom seat inserts were created using anthropometric data and vacuum cushion imprints, which were digitally modeled and 3D-printed using flexible TPE filament. The inserts were both fitted in and tested in a simulated truck cabin with 17 participants, using a combination of pressure mapping and short-term comfort questionnaires.

Quantitative results showed a 39.2% reduction in average pressure, 18.1% reduction in peak pressure, and a 15.1% increase in contact area when using the inserts. Subjective comfort ratings significantly improved in regions under the thighs, buttocks, knees, and neck ($p < 0.05$). Observational data revealed enhanced postural stability and anthropometric fit, though backrest comfort varied due to human error in production tolerances.

These findings demonstrate the feasibility and ergonomic benefits of integrating additive manufacturing into personalized seating interventions for occupational drivers. While short-term results are promising, future research should evaluate long-term effects under real-world driving conditions, including the impact on whole-body vibrations and MSD progression. The study contributes to the growing field of parametric ergonomic design and supports the application of human-centered additive manufacturing in the transportation and seating industries.

PREFACE

There are a few people I want to thank for their support and contribution to this thesis. Anne, for always being my number one fan, despite all of the early mornings and late night ramblings she had to endure because of me. Without your constant affirmations and unrelenting support, I don't know where I would be.

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TABLE OF CONTENTS

TABLE OF CONTENTS

1. Introduction

1.1 CONTEXT & BACKGROUND

Musculoskeletal disorders (MSDs) are a widespread occupational health issue among professional drivers, with prevalence rates reaching up to 80% depending on the vehicle and profession. Lower back pain, neck pain, and shoulder pain are especially common, largely due to prolonged driving hours and years of cumulative strain. Studies highlight that both light and heavy vehicle drivers face similar risks, pointing to systemic ergonomic issues in addition to vehicle size. Poor seat design and especially mismatches between driver body types and vehicle seating, forces drivers into static, uncomfortable postures. Contributing factors include inadequate support to the legs and back, limited adjustability, and wear and tear to seats over time.

Whole-body vibration (WBV) further worsens MSDs by causing spinal compression and tissue damage, often exceeding international safety thresholds. Seat suspension systems, although intended to reduce WBV, often transmit the majority of vibrations due to design flaws or wear over time. Additionally, standard seat designs often overlook population specific anthropometric data, leading to poor pressure distribution and discomfort, particularly for heavier drivers. Addressing MSDs in drivers requires an integrated approach involving ergonomic redesign, personalized seating, and facilitating ergonomically sound posture.

1.2 PROBLEM STATEMENT

Currently, there are no scientifically researched products in place that facilitate a reduction or prevention of MSD's among occupational drivers. This leads to long term health issues among drivers and results in regular sickness and MSD related absence leave, accounting for up to 30% of annual sick days in certain sectors.

1.3 RESEARCH OBJECTIVE

To design, produce and evaluate a personalized, 3D-printed product that addresses, reduces and/or removes one or multiple causes of MSD's among occupational drivers.

1.4 RESEARCH QUESTIONS

1. Can 3D-printed seat inserts improve seating comfort for truck drivers?

2. Can custom seating reduce ergonomic risk factors associated with MSDs?

1.5 SCOPE & LIMITATIONS

The scope of this study is limited to static testing, including pressure distribution analysis and short-term comfort rating procedures. These methods were selected to assess the immediate effects of custom 3D-printed seat inserts on seated comfort, with a specific focus on truck drivers. While the primary target group is long-haul truck drivers, the findings are expected to hold relevance for other professional driving populations who experience prolonged sitting under similar conditions.

It is important to note that this thesis does not evaluate the influence of the inserts on whole-body vibrations, which are a known contributor to musculoskeletal disorders in vehicular occupations. Accurately measuring such vibrations would require testing under dynamic, real-world driving conditions. Due to the logistical, ethical, and safety challenges associated with conducting on-road trials, this component was excluded from the research scope.

1.6 THESIS STRUCTURE

This thesis is structured to systematically explore the development and evaluation of custom 3D-printed seat inserts designed to improve comfort and reduce musculoskeletal disorders (MSDs) among truck drivers. The report begins with a literature review, which addresses three key areas of background knowledge.

First, it examines how MSDs develop in the context of occupational driving, highlighting the biomechanical, physiological, and postural factors that contribute to long-term discomfort and injury. Second, it reviews how comfort is conceptualized, achieved, and measured. Drawing on both subjective and objective evaluation methods in place to accomplish these goals. Finally, it establishes the relevance of additive manufacturing, specifically 3D-printing, as a promising method for creating ergonomic, customized seating solutions tailored to individual body shapes.

The methodology section describes the research and experimental framework applied throughout the project. It outlines the overall structure of the experiment, which consisted of two primary phases. The first phase involved the collection of anthropometric data through a driver fitting process, ensuring that seat contours could be customized. The second phase involved objective pressure mapping and subjective short-term comfort assessments, enabling a comparative evaluation between standard and modified seating configurations.

Following this, the design and development chapter details the iterative creation process of the seat inserts. This includes the fitting procedures, 3D-scanning of participants, and digital modeling using Rhino and Grasshopper. The chapter also elaborates on the production phase, focusing on the practical aspects of 3D-printing, as well as considerations related to the application of upholstery to ensure realistic seating scenarios.

The experiment and analysis chapter outlines the experimental setup in detail, including a presentation of the actual 3D-printed inserts used during testing. It also provides participant background information and demographic tables, followed by an in-depth analysis of the quantitative and qualitative results obtained through the comfort assessments and pressure distribution measurements.

The thesis concludes with the discussion and reflection, where findings are interpreted in relation to existing literature and project objectives. The implications of the results are considered both for industrial design practice and for the broader field of ergonomics. Finally, the conclusion synthesizes the outcomes, acknowledges limitations, and provides recommendations for future research and development in personalized seating systems.

2. Literature Review

2.1 Prevalence and Causes of Musculoskeletal Disorders in Driving Occupations

Musculoskeletal disorders (MSDs) constitute a significant occupational health issue, especially among professional drivers. According to a systematic review by Joseph et al. (2020), these disorders account for approximately 42% to 58% of all work-related illnesses, underscoring their prevalence and impact. This review of 56 studies encompassing 18,882 participants from across all inhabited continents provides a global overview of the problem. Participants ranged from 20 to 71 years of age, with a mean of 42.8 years, suggesting a widespread effect across both early- and late-career drivers. Across all types of driving professions (public transport, freight, taxi) lower back pain (LBP), neck pain, and shoulder pain emerged as common complaints, with significant implications for occupational safety and driver well-being (Joseph et al., 2020).

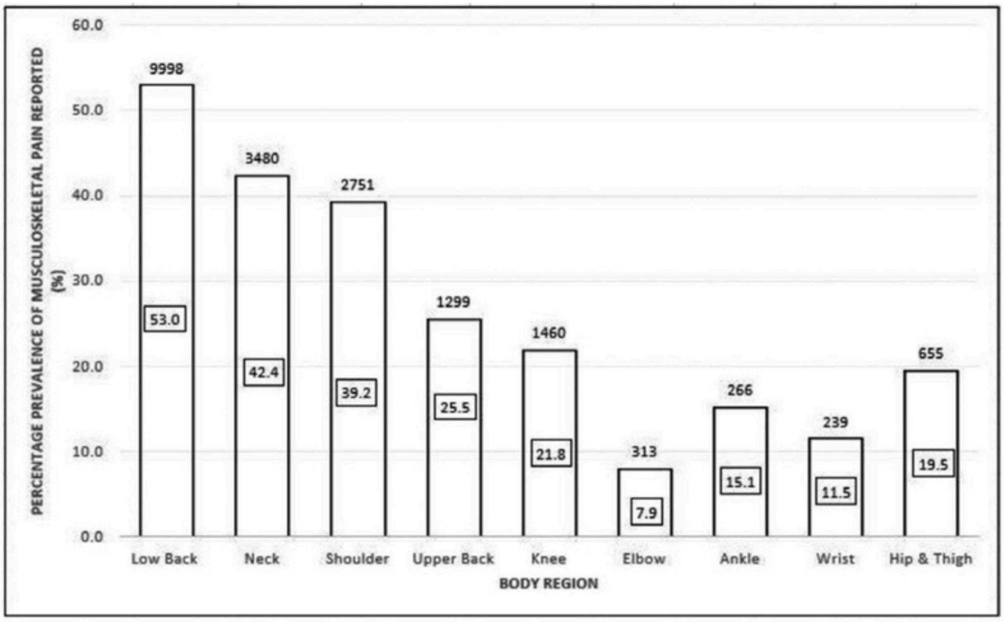

Figure 1: Musculoskeletal pain reported per body region among professional drivers. (Joseph et al., 2020)

The burden of musculoskeletal pain (MSP) varies by vehicle type but remains consistently high across categories. For instance, Rezaei et al. (2024) report that taxi drivers show up to 71% prevalence of MSP, particularly in the lower back, neck, and knees. Among truck drivers, the prevalence is even higher, with Tahernejad et al. (2024) indicating rates exceeding 80%. These studies highlight how long hours of driving, often averaging 9.6 hours per day with over a decade of cumulative experience, contribute to chronic musculoskeletal strain.

Location	N	Prevalence (%)	Mean	SD
Low back	50	72.5	2.9	2.0
Shoulder	38	55.1	2.9	2.5
Neck	35	50.7	2.7	2.4
Knee	29	42.0	2.4	2.5
Wrist/forearm	25	36.2	2.2	2.6
Ankle/feet	22	31.9	1.7	2.3
Leg pain/sciatica	18	26.1	1.4	2.2

Figure 2: Prevalence of musculoskeletal pain in various body regions among professional drivers (Joseph et al., 2020)

In a systematic review spanning from 2006 to 2021, Pickard et al. (2022) found that these patterns held across global studies, indicating that both light and heavy vehicle drivers suffer from similar MSD risks. These findings suggest that the fundamental ergonomic and occupational conditions inherent to these driving professions are more critical than vehicle size or weight.

Table 3 Summary of meta-analysis results related to different body regions

MSDs	Number of studies	Sample size	Prevalence of MSDs	95% CI
Shoulder	9	1090	31.5%	22.25- 40.75%
Neck	10	1348	25.79%	18.15- 33.43%
Lower back	15	2662	23.46%	9.29- 37.64%
Knee	6	705	22.26%	11.37- 33.16%
Ankle	6	658	20.46%	9.77- 31.16%
Wrist	6	620	20.25%	10.13- 30.37%
Upper back	7	1012	18.65%	10.70- 26.61%
Elbow	6	674	11.91%	5.65- 18.17%
Hip	5	744	7.50%	5.15- 9.86%

CI: Confidence Interval; **I^2**: I Squared

Figure 3: Musculoskeletal disorder prevalence by body region, based on meta-analysis (Tahernejad et al., 2024)

Ergonomic risk factors are central to understanding the prevalence of MSDs among professional drivers. Poor seat design (specifically mismatches between the driver's anthropometry and the vehicle's seating configuration) is a recurring issue. Halder et al. (2018), studying Bangladeshi truck drivers, identified critical mismatches in seat height, depth, and pedal position, leading to unnatural, static postures among drivers during their work. These findings were reaffirmed by Cardoso et al. (2019), who demonstrated that traditional truck seats often fail to accommodate the diverse variety of truck driver body types. Additionally, vehicle cabin design issues like steering wheel tightness, poor backrest support, and limited legroom aggravate musculoskeletal strain (Pickard et al., 2022). Such ergonomic deficiencies are particularly pronounced in long-haul truck and bus drivers, who report the highest rates of discomfort and LBP.

Whole-body vibration (WBV) has been identified as a particularly harmful ergonomic hazard in the professional driving context. Kim et al. (2016) observed that truck drivers are frequently exposed to vibration levels exceeding international standards during their work, resulting in spinal compression, tissue damage, and impaired circulation. Podlaha et al.

(2023) found that WBV not only worsens existing musculoskeletal conditions but can also initiate degenerative changes in spinal discs. Seat suspension systems, while designed to absorb vibration, often fall short in practice. According to Gomes and Pereira (2016), standard air suspension seats transmit about 86% of floor vibration to the driver, and only absorb 5% of that force. The ineffectiveness of such systems points to a need for better seat design and maintenance, particularly as seat wear over time is correlated with increased WBV exposure.

Anthropometric mismatches are another central concern when it comes to vehicle seat design. Halder et al. (2018) found that seat designs often do not account for population-specific anthropometric data, leading to elevated peak pressures under the sitting bones (ischial tuberosities) and inadequate thigh support. Such mismatches not only reduce comfort but may also contribute to long-term musculoskeletal disorders. Advanced materials and designs (such as warp-knitted spacer fabrics or cushions with zoned firmness) offer improved comfort and pressure distribution, particularly for heavier drivers who are more prone to bottoming out on soft seat surfaces (Buchman-Pearle et al., 2021). In this context, Cardoso et al. (2019) advocate for seats that combine softness and structural integrity, providing both comfort and biomechanical support.

In summary, musculoskeletal disorders among professional drivers are driven by a confluence of ergonomic shortcomings, inadequate pressure distribution, prolonged exposure to whole-body vibration, and anthropometric mismatches in seat design. The existing literature highlights not only the scope of the issue across different driving sectors but also promising technological and ergonomic interventions. The integration of dynamic seating systems, individualized support, and anthropometric-aware seat design appears critical for reducing the long-term occupational health burden in this population.

2.2 Seating Comfort: Concepts, Measurement, and Influencing Factors

Achieving ergonomic comfort through seating design has long been a multidisciplinary endeavor encompassing engineering, design, and human factors. In recent years, growing attention has been paid to both the subjective and objective dimensions of comfort, revealing the nuanced complexity of the sitting experience. Vink (n.d.) underscores that comfort is a multifaceted construct influenced by physiological, psychological, and environmental factors. His review consolidates decades of empirical insights, emphasizing that while discomfort is closely associated with biomechanical issues such as fatigue, strain, and pain, comfort is more elusive and subjective, linked with feelings of well-being and relaxation. Importantly, Vink introduces a model that covers the process from physical interaction with the seat to internal bodily effects, culminating in perceptual outcomes that determine comfort or discomfort. This model helps designers understand how seating contexts dynamically interact with the human body over time, integrating physical effects such as muscle activity and pressure distribution with psychological expectations and perceptions.

Building on this foundational understanding, Song & Vink (2021) advocate for integrating objective metrics alongside subjective measures to enhance the validity and applicability of comfort research. Their meta-analysis, part of the COMFDEMO project, evaluates over 190 studies on objective comfort assessment methods. They found that while subjective questionnaires remain the gold standard, combining them with physiological and biomechanical indicators (electromyography, pressure mapping, heart rate variability, and galvanic skin response) can yield a richer, real-time understanding of discomfort. Especially relevant for seating contexts, pressure distribution emerges as a key factor in both predicting and alleviating discomfort, with optimal designs distributing load evenly to reduce localized pressure points. In addition, temperature, vibration exposure, and air quality also play critical roles in modulating comfort, particularly over extended durations of use.

Varela et al. (2019) investigated the effects of engineered seat movement during simulated driving tasks and found that passive seat movements (fore-aft and cushion-backrest) significantly reduced discomfort in areas such as the buttocks and lower back after prolonged sitting. Their findings emphasize the importance of micro-movements in stimulating circulation and preventing musculoskeletal fatigue, aligning with earlier office ergonomics research advocating for posture variation.

Similarly, Channak et al. (2024) evaluated the effectiveness of two dynamic seat cushions among office workers and found that cushions promoting frequent postural shifts led to increased lumbar muscle activity and reduced spinal discomfort. Notably, cushion designs with lower inflation levels (providing greater instability) were more effective in encouraging movement without impairing task performance. These findings suggest that integrating dynamic elements into seat design can mitigate the negative effects of sedentary behavior, particularly when natural breaks or mobility are constrained by the task environment.

Beyond dynamic movement, personalization of seating configuration has also gained traction. Buchman-Pearle et al. (2021) explored how individual characteristics influence lumbar support preference in automotive seating. Their study revealed that anthropometric features such as height, mass, and spinal curvature significantly predict lumbar flexion, seatback pressure distribution, and selected lumbar support prominence (LSP). While most users maintained their original LSP settings during an hour-long simulation, they naturally adjusted their posture to reduce lumbar flexion and increase back pressure, suggesting a subtle, unconscious adaptation to discomfort. This showcases the need for seating systems that not only accommodate diverse body types but also respond to postural changes over time.

Postural studies in automotive contexts further confirm the relevance of seat design in comfort outcomes. Smith et al. (2015) compared discomfort ratings between elevated and conventional driving postures under exposure to whole-body vibration. While both postures showed progressive discomfort over time, the conventional posture resulted in higher ratings of lower back and shoulder discomfort after 50 minutes. The elevated posture, although unconventional, allowed for potentially more favorable biomechanical loading, suggesting that alternative, well-supported configurations, can reduce strain in prolonged sitting tasks.

Collectively, these advancements portray a compelling trajectory for seating design that merges biomechanical intelligence with sensory and psychological sensitivity. Whether through dynamic adjustment, user-specific contouring, or posture changes, the future improvement of seating lies in its ability to anticipate or adapt to human needs, transforming comfort into an active, embodied experience.

2.3 3D Printing in Ergonomic Seating: Opportunities for Personalized Design

Truck drivers are routinely exposed to a convergence of ergonomic risk factors such as prolonged unhealthy posture, whole-body vibrations, anthropometric mismatches, and inadequate pressure distribution that contribute to the development of musculoskeletal disorders. Traditional seating systems often fail to accommodate individual body morphology, leading to discomfort, fatigue, and long-term health complications. To address these challenges, this thesis employs 3D printing technology to develop customized seat inserts based on individual body contour data and their corresponding truck seat shape and surfaces.

Recent advances in human data-driven parametric design have shown promising results in personalizing seating systems. According to Zhang et al. (2025), integrating detailed anthropometric and postural data into the design process enables the creation of seating surfaces that more accurately conform to each user's unique anatomy. This alignment reduces pressure hotspots, improves load distribution, and allows for postural alignment. All of these being key factors in minimizing MSD risk.

Pagliari et al. (2023) further demonstrated the ergonomic benefits of using 3D scanning and additive manufacturing in cushion design for backrests in the context of daily office workers. Their findings support the idea that personalized inserts, derived from accurate body shape data, can significantly enhance user comfort by reducing peak pressures and accommodating natural and healthy postures. These insights are especially relevant for professional drivers, whose comfort and health are closely tied to sustained seating performance, especially under vibration and load during driving activities.

Moreover, 3D printing allows for iterative and user-centered development that is both cost-efficient and adaptable. Ahmad et al. (2022) showed how additive manufacturing could be effectively applied to create user-friendly, customized seating in the context of wheelchair design. The same principles of flexibility, scalability, and anatomical accuracy are transferable to truck seating, enabling personalized interventions without the constraints of traditional manufacturing processes like production time and development costs.

In this context, 3D-printed inserts or cushions function as a targeted ergonomic solution. They can improve pressure distribution, increase spinal and pelvic support, and may passively dampen WBV by material choice combined with maximizing the contact area between driver and seat. These effects are expected to reduce physical discomfort and mitigate the long-term risk of MSDs. Thus, the integration of 3D scanning and printing technologies is not only innovative but also aligned with emerging best practices in seating ergonomics and personalized design.

3. Design & Development

To preface, this design thesis was done as part of an internship at Perfect Fit Upholsteries, where prior product design knowledge was provided as a foundation to start the development of the seat inserts. Based on insights shared directly by peers, certain design choices were already made based on earlier experimentation. This includes the following:

1. 3D-printing using a gyroid infill pattern, due to the fact that this was perceived as most comfortable and an appropriate balance between flexibility and seat stiffness

2. 3D-printing with a 2 millimeter nozzle diameter, motivated by the level of detail required for a seat shape compared with the amount of printing time required per item.

3. The choice of using certain vacuum bags to measure and fit users' bodies for a custom seat insert, since this had already been applied to their current process for producing personalized rowing seats.

4. The use of the "Scaniverse" app to make scans of the vacuum bags after a fitting is also part of the working practices at the company, both for the personalized rowing seats as for digital fabrication of accurate upholsteries.

5. The usage of Rhinoceros 3D & Grasshopper for digital was determined by the current workflows of peers at the company. These were used for modelling and creating the seat inserts, due to the fact that it is currently the norm at the company. It is deemed as an appropriate tool for working with meshes and surfaces similar to the scans used for the seat inserts.

6. The choice for TPE (TF40QD-LCNT) filament was made based on the fact that this was already in use for the rowing seats and other seat prototypes. Additionally, this was available in abundance for multiple concepts to be printed and tested.

3.1 CONCEPT DEVELOPMENT

In the initial stages of concept development, multiple versions of seat inserts were explored and reviewed with the help of occupational drivers. Included below is a selection of the most relevant ideation and brainstorming results of this phase, with every concept or iteration contributing their own insights. These insights led to conclusions and knowledge about what is feasible in production and what is desirable for the user. Additionally, it informed design choices concerning use and size. Where certain concepts might have been more easily produced, their size and awkward handling were major drawbacks.

3.1.1 Small One Part Insert

The first concept fully worked out and printed was a singular seat insert. Created based off of the seat scan and body shapes from a collaborating occupational driver, this concept aimed to fit within the seam lines of their company car. Although this design was shaped fairly well against the body shape, the sizing correction from 3D-scan to the mesh in Rhino was off by a significant amount. This led to this concept not fitting the user, because the size was off by around 20%. This did result in an immediate correction in the scaling factor used in later insert development.

Two versions of this concept were produced: one with a consistent infill of 20% throughout the entire seat insert and one with certain areas having their infill lowered. The aim of this was to create certain softer spots and making other regions more rigid. Unfortunately, this did not have the intended effect. The varied infill version had multiple drawbacks. The lower infill areas (5-10%) became unstable and empty, while the outer bounds (20-25% infill) felt harsh and uncomfortable.

Moreover, this led to distinct lines within the 3D-printed structure that did not merge and compromised the structural integrity of the insert. The solid 20% infill was more comfortable and did not have these distinct lines, but still was deemed too hard and too stiff.

Figure 4: Small One Part insert concept shown from multiple angles

3.1.2 Small Two Part insert

Figure 5: Small Two Part concept shown with infill percentages and split up

The second concept developed was a direct derivative of the Small One-Part insert, with one key modification: the design was divided into two separate components. A seat pan insert and a backrest insert, split precisely at the seam where these two parts meet in the underlying seat structure. This modification was intended to explore the practical implications of a modular insert design, particularly in terms of ease of placement, improved adaptability, and enhanced fit. By separating the two elements, the concept aimed to allow greater flexibility in application, especially for fitting different types of seating such as commercial vehicle seats and standard office chairs.

This iteration retained the same geometric scaling used in the original one-part version, which unfortunately meant that it too turned out undersized, due to the previously uncorrected scaling error. However, this version incorporated improved infill configurations, resulting in a noticeably better distribution of softness and rigidity across both components. As a result, the comfort level of this version was considered superior to that of the previous concept, despite the continued size issues.

Furthermore, the split design offered clear advantages in structural flexibility and versatility. It demonstrated a better capacity to conform to various seat geometries without compromising the integrity or shape of the 3D-printed inserts. The flat contact surfaces created by the separation also simplified the alignment process during placement, allowing for the two inserts to be easily positioned in the correct orientation relative to one another.

3.1.3 Yoga Mat Concept

This concept was developed with portability and ease of use as its primary design goals. Inspired by the idea of a yoga mat, the design focused on allowing users to easily carry the seat insert to and from their vehicle without added bulk or complexity. The insert featured a simple rectangular form and was printed with a constant 15% infill density. This consistent structure enabled the part to be produced efficiently, laid flat on the print bed, and without the need for additional support material. However, this approach also meant that the insert had to conform to the inner seam boundaries of the seat, thereby defining a strict limit for how far the insert could extend horizontally across the seat surface.

Although the upper surface differed slightly from earlier concepts, this design was intentionally less intrusive, aiming to provide targeted comfort while avoiding interference with existing seat features. Its extended length offered a functional benefit: it provided additional support beneath the knees and thighs, particularly valuable for taller drivers who often experience a lack of under-thigh support in standard car seats. By bridging this gap, the insert enhanced lower limb support without requiring modifications to the seat.

During testing, the collaborating driver described the insert as “comfortable and seamless in its placement,” suggesting that it blended well with the existing seat. However, the same participant also noted that it “lacked support on the side supports of the seat.” While the slim, inner-seam-conforming profile allowed for a snug fit within the vehicle seat, it came at the cost of lateral support. As a result, the concept neglected the outer thigh regions, which can be critical for stabilizing the driver’s posture during prolonged driving sessions. This trade-off highlighted the challenge of balancing portability, fit, and ergonomic support in minimal insert designs.

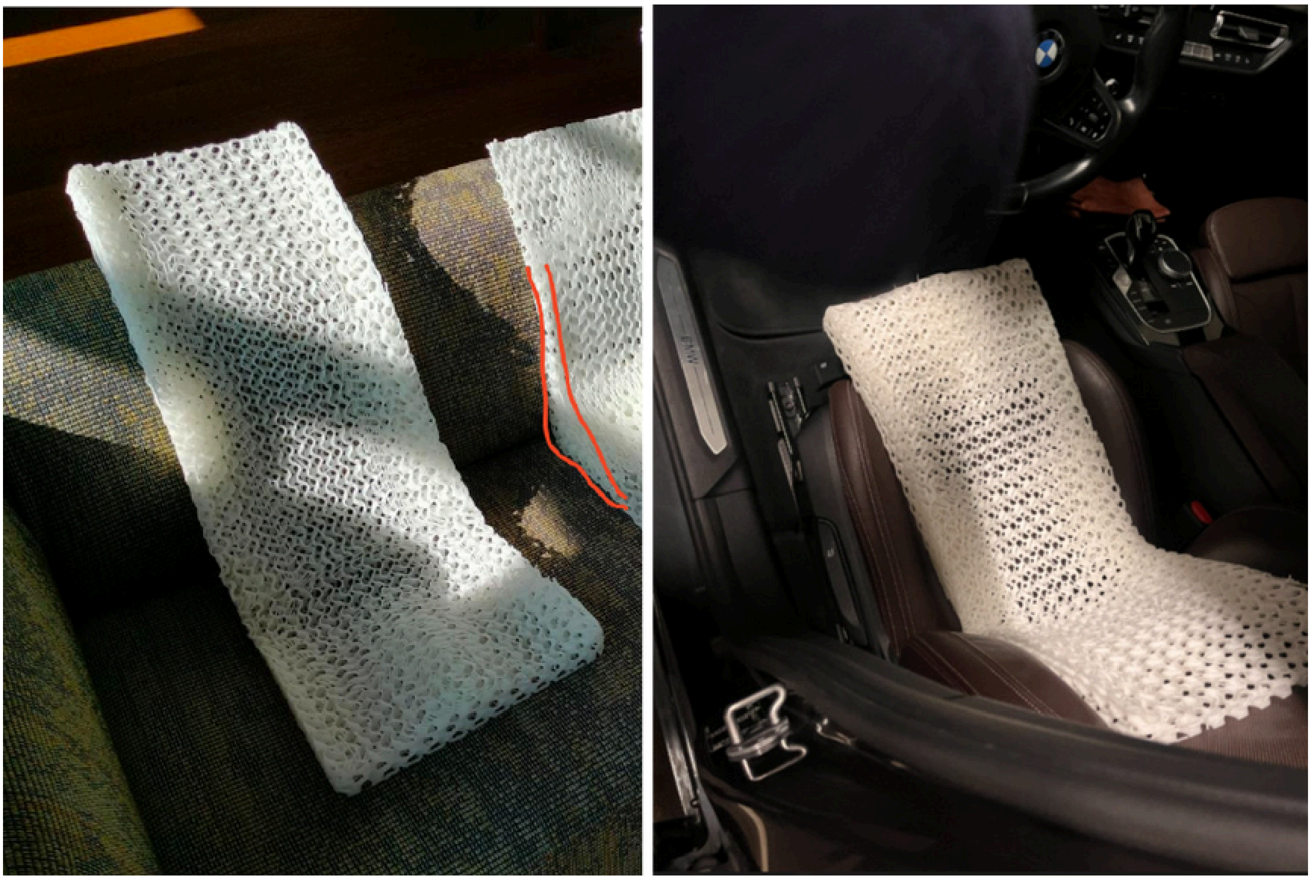

Figure 6: Yoga Mat concept shown on regular couch and put into car seat

3.1.4 Solid Fit Curvature

As a reimagined iteration of the Yoga Mat concept, a single-piece insert was designed with the goal of addressing the limitations observed in testing. This version featured a broader backrest and a wider seat pan, aiming to enhance both comfort and coverage. By increasing these dimensions, the design sought to provide improved cushioning in the contact area between the driver's thighs and the side supports of the vehicle seat. Similarly, the extended backrest was intended to accommodate a greater portion of the upper body, offering more comprehensive support.

In adapting the design, a significant change was made to the print orientation. Due to the increased thickness of the insert, the concept was no longer capable of being rolled up, which eliminated the need for printing it flat on the bed as with the previous iteration. To maintain a support-free print process, the insert was oriented on its side, which had implications for the surface, texture and mechanical properties of the backrest. While the seat pan still featured an open-structured gyroid infill pattern, the backrest now had a contact surface composed primarily of layered print walls. This created a distinct difference in feel and flexibility between the lower and upper sections of the insert.

When tested with the collaborating occupational driver, the concept was described as "almost a warm bath to sink into," referring its enhanced size, increased width, and generous thickness. These attributes contributed to a sensation of enveloping comfort. However, these same qualities also introduced practical drawbacks. The rigidity of the solid structure, combined with its lack of flexibility, made it awkward to maneuver into the contours of the seat. Its bulkiness reduced adaptability and hindered seat integration, especially in vehicle interiors where precise alignment and compliance with existing seat forms are critical.

Figure 7: The Solid Fit concept set against a window to show its open structure

3.1.5 XL Two Part Inserts

This concept was created as a hybrid between the earlier Two Part insert and the Solid Fit iteration, combining key features of both approaches. It aimed to balance the modular adaptability of a split design with the continuous support and structural integrity of a unified form. When evaluated by the collaborating occupational driver, this concept was described as “the most comfortable by a landslide” compared to all previous prototypes tested. Several aspects of the design were specifically mentioned for this significant improvement in comfort. These included the softened side regions of the seat pan, which provided enhanced lateral support for the thighs; the refined shape of the backrest, which better conformed to the user’s spine and upper torso; and the increased overall thickness, which resulted in a more cushioned and forgiving seating experience.

Despite its strong performance in subjective comfort assessments, this version had critical drawbacks in terms of size and feasibility. The insert was substantially larger than any of the earlier concepts, both in volume and outlines. When placed within the vehicle’s interior, it occupied an excessive amount of space, ultimately interfering with essential driver movement and potentially compromising safety. This practical limitation prompted a strategic shift in the design direction: while the comfort-enhancing features of the concept were validated, the excessive material use and bulk called for a more compact and efficient variant.

Figure 8: The XL Two Part concept being tested with an oocupational driver

3.1.6 Foldable Backrest

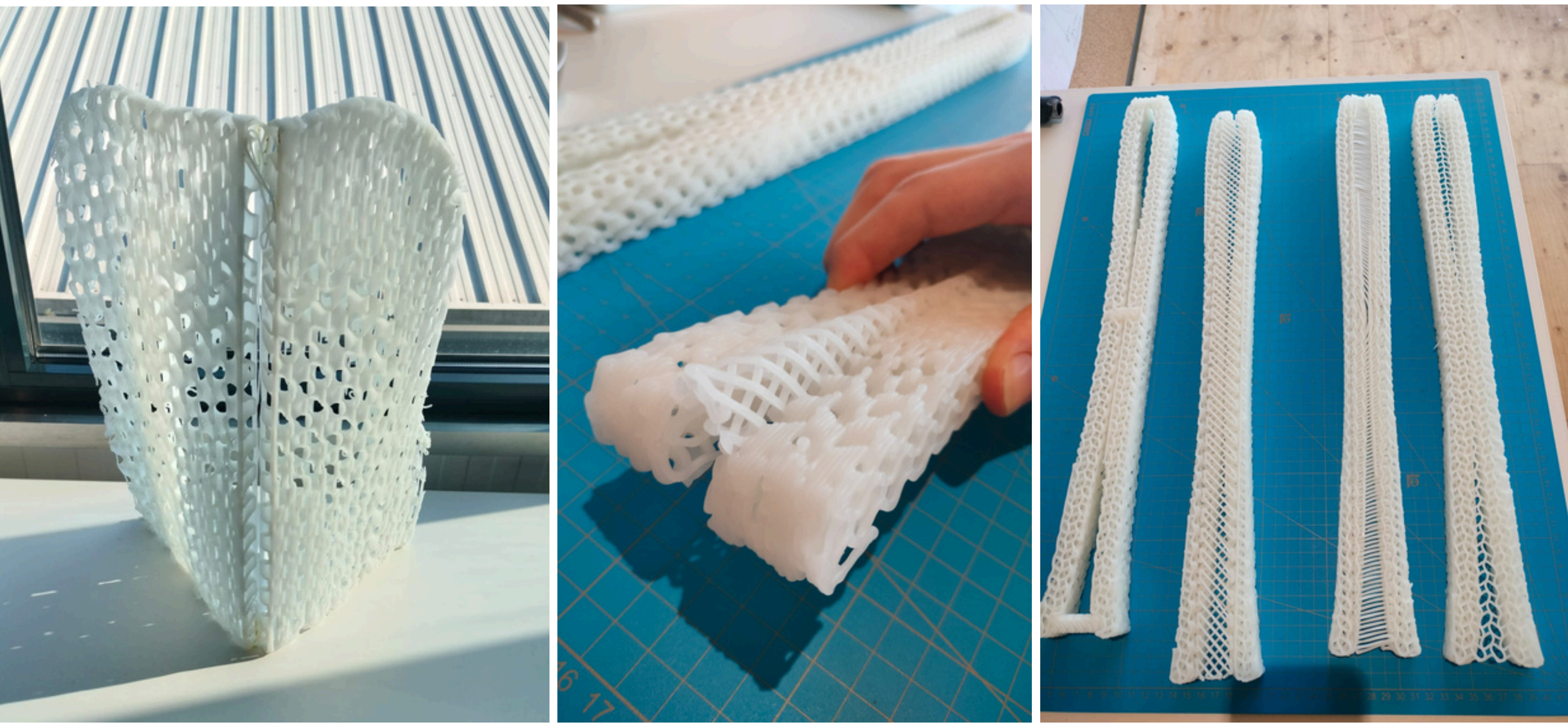

Figure 9: a Foldable Backrest with its proof of concept test prints connected through different infills

Another concept explored was a foldable backrest insert, developed in response to the challenges associated with printing doubly curved backrest shapes using flexible material. Traditional support structures proved difficult to remove cleanly and often posed a risk of damaging the final print. This design aimed to eliminate the need for such supports, reduce overall print time, and investigate the comfort potential of a thinner, more flexible backrest.

While the concept was technically functional, it introduced a critical drawback: the central seam line, where both halves of the print were joined, created an uncomfortable pressure point along the user's spine. For a symmetrical design, the connection naturally formed at the midpoint, resulting in a pronounced and rigid layer line that compromised comfort. Additionally, the reduced thickness of the backrest failed to provide adequate support, leading to the decision to discontinue this direction.

Nonetheless, the experiment demonstrated that bendable seams within 3D-printed structures may offer promise for applications where flexibility and compactness are key. This particular design could be folded over itself for easy storage and was significantly faster to produce than other backrest prototypes. Its efficiency stemmed from a minimal construction: only 2–3 print layers using gyroid infill, with a maximum width of approximately 5 centimeters along its length.

As shown in the figure above, different infill patterns were used to create proof of concept test prints, to evaluate what pattern would facilitate bending and reshaping the best. Gyroid, Cubic and Coincentric patterns where used with an additional print with 3 straight sections. Of these four, the gyroid pattern was selected as best infill setting.

3.1.7 Car Seat Cutouts

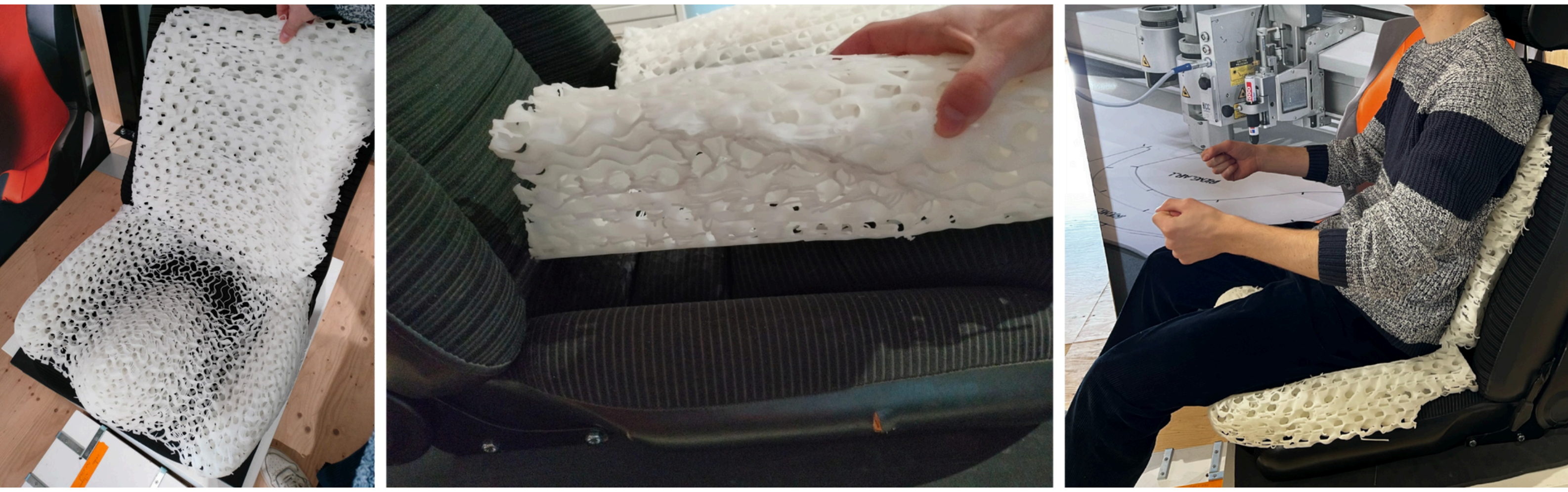

Figure 10: Different angles of the Seat Cutouts concept placed on an old van seat

This iteration of the seat insert was developed with the goal of reducing the overall footprint of the Two Part system and improving its integration into existing vehicle interiors. One of the key changes introduced in this version was the strategic repositioning of the separation point between the seat pan and backrest components. In contrast to earlier prototypes, where the split occurred in areas that were more exposed or in direct contact with the user's body, this design relocated the division into the naturally hollow section of the truck seat. The recessed area between the seat pan and the backrest is typically not in constant contact with the user during sitting and, as such, provided an optimal location to conceal the connection between the two components without compromising comfort.

In addition to the revised seam location, the overall geometry of the insert was slimmed down to ensure a better fit within the precise contours of the vehicle seat. These dimensional adjustments were made to allow the inserts to sit flush within the seat's existing boundaries, minimizing any protrusion or misalignment. Together, these modifications aimed not only to improve the physical compatibility of the insert with various seat types, but also to visually and functionally conceal the split line, thereby enhancing the perception of the insert as a single, cohesive product.

A further improvement was implemented on the underside of the seat pan component. Specifically, a cut-out was introduced in the rear lateral section to accommodate the raised side supports found on many truck seats. In previous designs, these supports had the unintended effect of pressing against the insert, causing it to deform or bend inward. By introducing a contoured recess that allows the insert to fall naturally over the side supports, this issue was resolved. The cut-out not only improves the structural integration of the insert into the seat, but also serves a practical alignment function, helping the user position the insert accurately and consistently each time it is used.

3.1.8 Lowered Backrest

Figure 11:The concept being tested in a Volvo Globetrotter XXL, with the truck driver it was tailored to

The last and final iteration before the design that was decided on for testing, explored the possibility of lowering the backrest. From tests with earlier backrests and the foldable concept, it was found that the backrest does not have to come up all the way to the shoulders. Occupational drivers' feedback either found the higher backrest "too intrusive" and "claustrophobic" or had felt "discomfort from the thicker parts pushing against shoulders and upper back".

This concept achieved similar results with a lower backrest, also allowing for shorter printing times and a more focussed approach to lumbar support and matching the backrest to the users waist where needed. An additional advantage of the lower backrest was the fact that it could taper off into seams throughout the backrest of a truck seat. As pictured, the prototype reviewed with a truck driver aligns with the middle parting line of the backrest. This being both an intuitive place for the product to have its outer boundary and the user to align their product to. Yet, still high enough to properly provide support for the lumbar, yet not coming up to the aforementioned areas of the body that felt discomfort.

3.2 (DIGITAL) WORKFLOW ITERATIONS

3.2.1 Fitting Process

At the start of the process of getting a person a personalized seat insert, is the capture of their own, unique shapes and sizes in something that resembles a mold. To accurately capture the body shape of a person, vacuum bags are used. These can be deflated while a person is in a static position, to shape itself around the outer contours of their body, slowly conforming to the weight, size and curves of their current posture.

This process had to initially be explored for the optimal use and best practices, so a choice could be made between two different kinds of vacuum bags at the disposal of this project. Pictured here are these two options, a blue variant and a green variant. The blue has the advantage of being lighter and slightly more stiff, but had to be in/deflated by hand with a bike pump. This makes the process of deflating it with a person sitting in it quite clumsy, limits the range and might distort the position of the cushion during.

Additionally its smaller size meant that not the entirety of the human shape would be covered around the sides. This makes it easier to handle and transport, but the green variant has the advantage of its height and weight to slowly and smoothly let the person sink into the deflated seating area. Its less rigid, inflated state initially makes it slightly wobbly at the start of the procedure, but this effect fades out over time.

Finally, the green variant allows a connection to a small compressor, using tubes and a pedal to consistently regulate air flow electronically. This makes the process more controlled and does not interfere with the position and minimizes outside distortion of the process while deflating.

Figure 12: The initial fitting setup at the company

Next to selecting the right equipment and procedure, the context and placement of these vacuum bags was also reviewed. With the later experiment in mind, a realistic and representational environment for truck seating would be emulated. This meant that the fittings for body shapes to create the 3D-printed inserts, would also have to be accurate and match this environment. Moreover, they should be taken while the participant is in a healthy and realistic driving posture.

For this, multiple methods were explored to find the best way of proceeding and taking fittings. Initially, it was thought that doing these fittings inside a normal passenger car would be as close to reality as possible. Since this was closest to the real driving environment and posture of the intended user, it would stay as close to the normal driving activity achievable to recreate.

First of all, the blue vacuum bags had to be used in this case, since the green vacuum bags would not fit inside most passenger car seats without completely obstructing the driver from getting in. Then, the car seat had to be moved down and back as far as they could, to allow the driver to even enter the car. This already was quite uncomfortable, due to limited space between the vacuum bags on the chair and the steering wheel, making the driver feel cramped.

Once the driver sat down behind the wheel, they could slightly adjust their car seat to a position that was most comfortable to them. Once this had happened and the driver indicated that they were in the most comfortable position, the blue vacuum bags had to be deflated by hand, with a bike pump used from the second row of seats in the car. This would yield good results, but the procedure was inconvenient and uncomfortable for the driver being fitted. It also did not allow for all of the seat configurations to be put in place, since the added thickness from the fitting bags meant that the seat pan was higher and the backrest came more forward. For taller drivers, this obstructed them from getting into their desired comfortable position, therefore not reflecting the body and seat shapes needed for a comfortable seat insert.

Figure 13: A trial fitting performed on a colleague using the blue vacuum bags

Due to these difficulties during the fitting procedure in the car itself, the possibility of doing a fitting outside of a car interior was explored, to see if the results could be sufficiently accurate for making seat inserts. A simple representation was made with an old truck seat and set at an appropriate height, allowing for a seating option with enough space to properly move around. The extra space allowed for the use of the green vacuum bags instead of the blue variant, providing a larger surface area to contact the person being fitted and using a compressor for in/deflation instead of the bike pump. These factors both increase the handling of the procedure, by making it easier to harden or soften the bags and providing a bigger volume for the participant to sink into when the vacuum bags are being deflated. This articulates not just the general outline of their body shapes, but also captures its depth, providing a more accurate image of the person's body. The extra space around the chair

also gives the person performing the fitting the ability to move around the participant and tweak and adjust certain details if needed. For example, pushing the sides up of the vacuum bag on the seat pan, to make sure they touch the participant.

Figure 14: from source above

This configuration allowed for a big improvement in the accessibility and movement options, but is not as realistic due to the missing car environment. Therefore, factors that would usually obstruct the driver when seated behind the wheel are not accounted for. This factors into the posture that they assume during the fitting, resulting in a body shape that would not be plausible in the reality of driving a truck. Based on this, the decision was made to create a buck that resembles a truck cabin as closely as possible. This would allow for realistic representation of the boundaries and experience of being seated in a truck, while also allowing for the person performing the fitting to access the vacuum bags or other devices if needed. The specifics of this truck cabin setup can be found in chapter 5: "Experiment".

3.2.2 Scanning Procedure

For scanning the resulting body shapes of the fitting procedure, two different tools were tried and evaluated. At the company, multiple tools are currently used to collect 3D models from scans. A handheld scanner and two different apps were readily available for use in this research. The scanner being the Creality Ferret SE and the apps being Scaniverse and KIRI. The KIRI app requires a LIDAR sensor in the phone, which was not available at the time of research. Due to this, only Scaniverse and the handheld scanner have been tested.

The initial first choice fell upon the Ferret scanner, since this handheld device is specifically made for 3D scanning as opposed to a smartphone app. The first trials with this device yielded highly accurate scans with minimal added background noise or artifacts. However,

the time to make a singular scan could take up to 30-40 minutes with multiple moments of restarting and finding a reference point. After this long process, the scans also have to be post processed in the CrealityScan software. This in turn added about an hour of additional time from start to finish, including the fact that both the processes are demanding in terms of hardware of the connected laptop or computer.

The results of these testing scans are pictured here, where it is visible that after careful scanning and post processing, a highly accurate and even color mapped 3D-model emerges. Upon seeing the results of this experimentation with the CrealityScan software and the Ferret SE, it was decided that the time spent on a singular seat with this workflow would be too long for scanning all participants' body shapes in the experiment later on.

However, the accuracy and color mapping feature of this scanner can be useful in cases, for instance the use of visual markers on the seat for later reference during modelling or finding seams that can function as outer bounds for 3D-printed inserts.

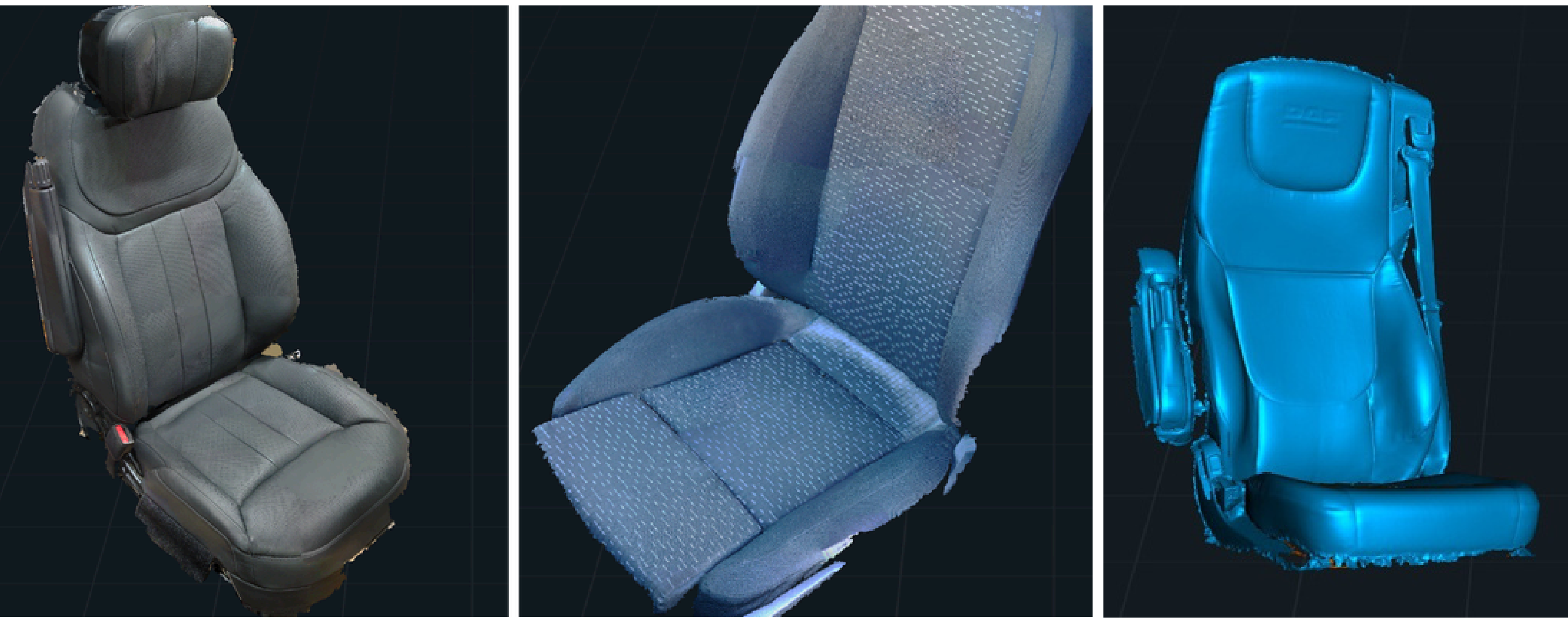

Figure 15: Scans of different car seats, made with the Creality Ferret SE

The recommended programme to use alongside the Ferret scanner, CrealityScan, does a good job of creating solid and accurate meshes from the gathered data during scans. Color mapping allows for tracking scanning (masking tape, print/color on car seat) However, as mentioned before, it is demanding on the hardware running it and can be slow at times due to this. Therefore it is deemed fitting for making one highly detailed scan of the car seat that can then be used across multiple inserts, to have a sound basis and starting point, for example making inserts for a specific chair across a fleet of the same cars or trucks. This procedure was also used in the later production of seat inserts to be tested.
As pictured here, the level of detail on the truck seat later used in the experiment was high enough to capture various intricate details of the chair, an example being the name of the brand recessed in the headrest even being picked up.

Scaniverse

After exploring the capabilities and limitations of the Creality device and its associated software, the other 3D-scanning option of the Scaniverse app was used to compare performances. Only needing a phone and a camera, this scanning procedure requires a lot less upfront preparation and devices to properly execute it. A LIDAR sensor can be used, but is not required of the phone to start 3D-scanning.

The resulting scans are less accurate than those made with the Ferret, but precise enough to capture body shapes left in the vacuum bags. Moreover, using the phone camera is easier to use and very fast compared to the Creality device. For instance, a single scan made with the Scaniverse app takes 1-5 minutes, depending on lighting and complexity. Additional post-processing is done within the application as well, taking a couple minutes depending on the hardware of the phone.
With these two options side by side, the choice was made to use both for their respective strong suits in the experiment. First, taking the time to make a highly detailed scan of the truck seat that would be used for all participants, to ensure that this basis for all future seat inserts was robust and thorough. Then, utilizing the Scaniverse app for its quickness to handle the high number of body scans required to capture all of the participants' imprints in the vacuum bags.

Figure 16: Scanning with the Scaniverse app and its results

3.2.3 Modelling

Next, the collected 3D-scans and their associated meshes had to be processed to create models that could be 3D-printed and later evaluated in the experiment. For this, the Rhinoceros 3D software combined with Grasshopper (full script in Appendix G) was used to create printable models. Meant to clean up and improve the meshes from these scans and transform them into workable objects, that then can interface with each other and create a well fitting insert.

After doing initial clean up of the mesh by removing the background and other artifacts that might have been picked up by the scanner on accident, this mesh is put through the "QuadRemesh" function. This converts the base mesh to one with an optimized topology, with less vertices and using rectangles instead of polygons. This not only cleans up the mesh, but makes it substantially easier to process for the software, speeding up the modelling process down the line. This process applied to both the mesh of the body shape, as well as the mesh of the truck seat.

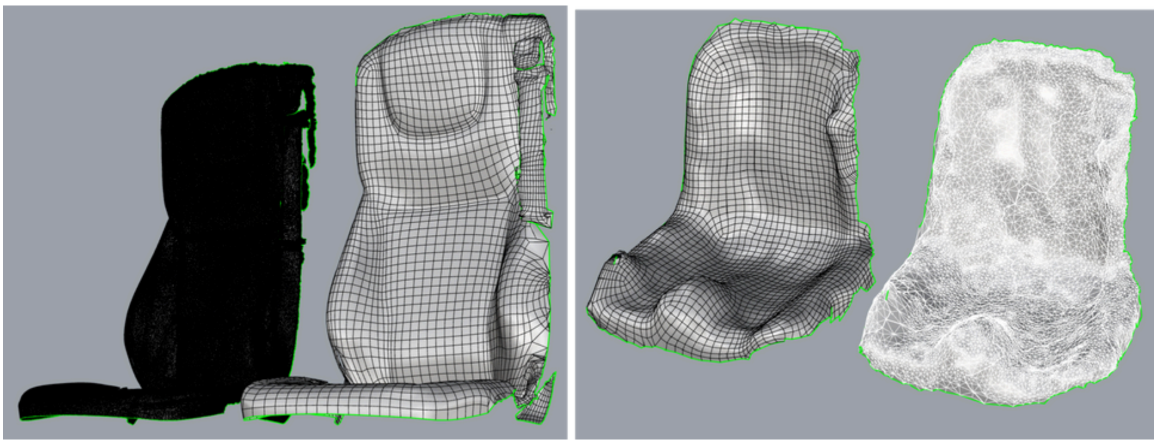

Figure 17: Optimized meshes of the truck seat (left) and body shape (right)

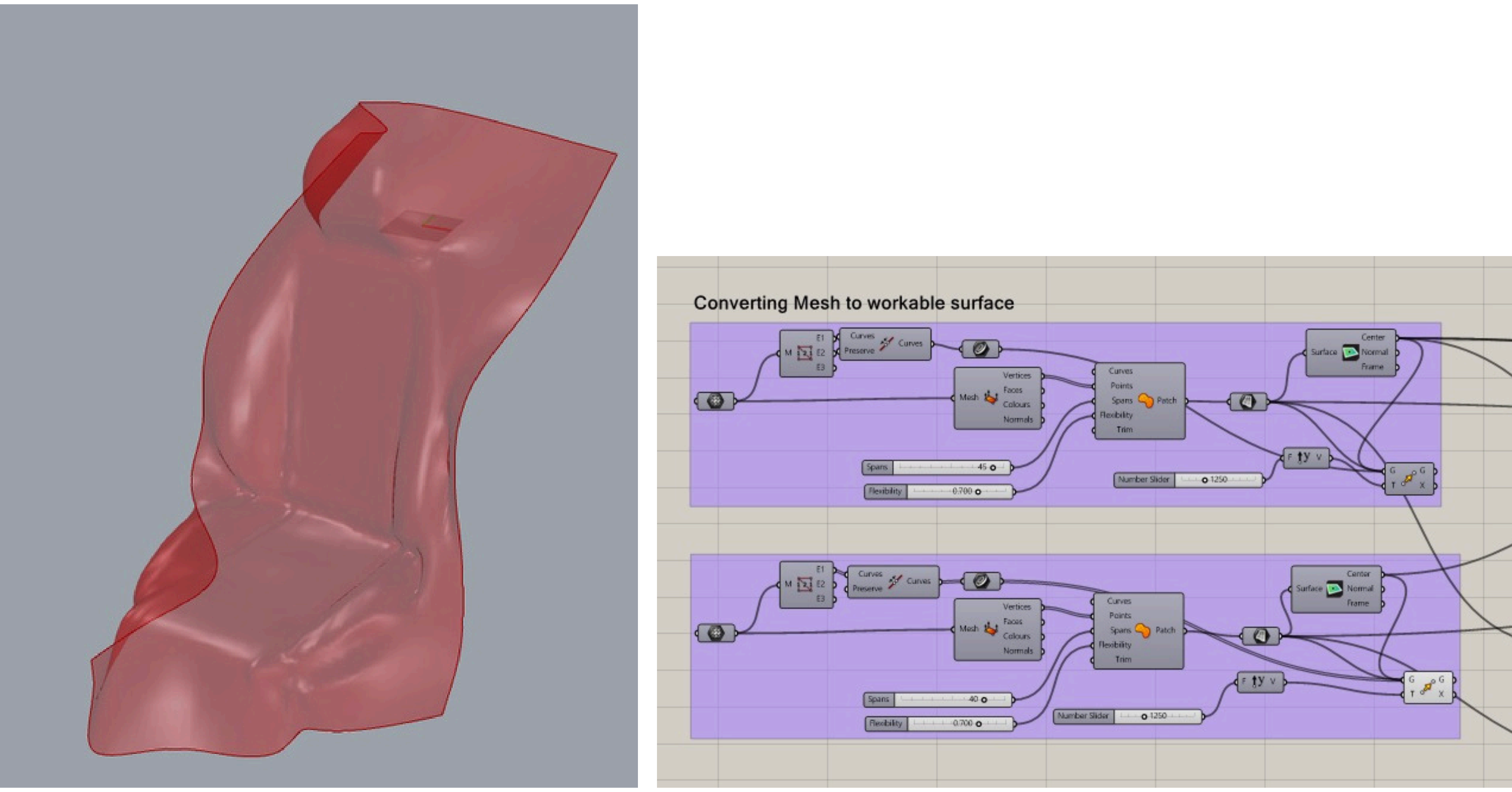

Figure 18: The process and result of the “Patch” command in Grasshopper

To further aid in a smooth and detailed modelling process, the mesh is then converted to a surface using the “Patch” function. The amount of “Spans” and “Flexibility” of this surface is determined by the complexity of the mesh shapes and quality. These allow for the surface to either strictly follow the initial mesh, or to smooth out certain sections that might have gotten convoluted during the scanning procedure. By combining this with a “Curve” consisting of all of the outer (naked) edges of the input mesh, the surface can be automatically confined to these borders, otherwise expanding further beyond them. Again, this goes for both the truck seat and the body shape.

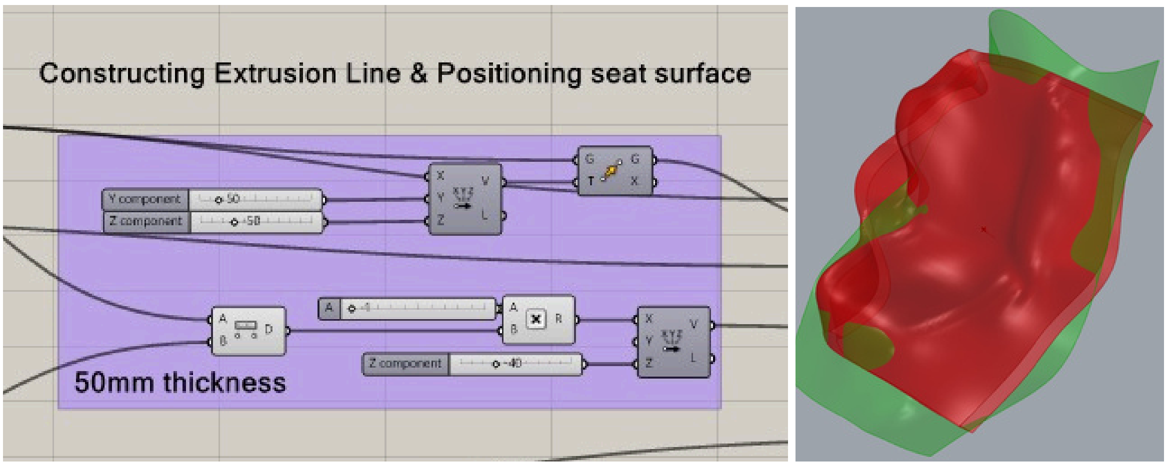

Figure 19: Allignment of the two surfaces

Then, the resulting surfaces of both the truck seat and the body shapes are moved on top of one another. They are aligned through a processing block that creates a movement vector based on the measured distance between the midpoints of both of these surfaces. This vector is then applied to one of the surfaces, modified with an adjustable slider that determines the distance between the surfaces. This distance is, in reality, the thickness that the seat insert would have when printed. The result is pictured, with the green surfaces being the truck seat and the red surface being the body shape of one of the participants.

Note, this does not always function completely as intended. Since the midpoint of complex surfaces such as these can be misaligned due to a number of reasons (asymmetry, Patch-function, artifacts,etc.), the resulting position after alignment will sometimes need slight adjustments. Height and rotational adjustments are most common, due to the extra height of the truck seat compared to the back shape and differences in incline caused by the vacuum bags.

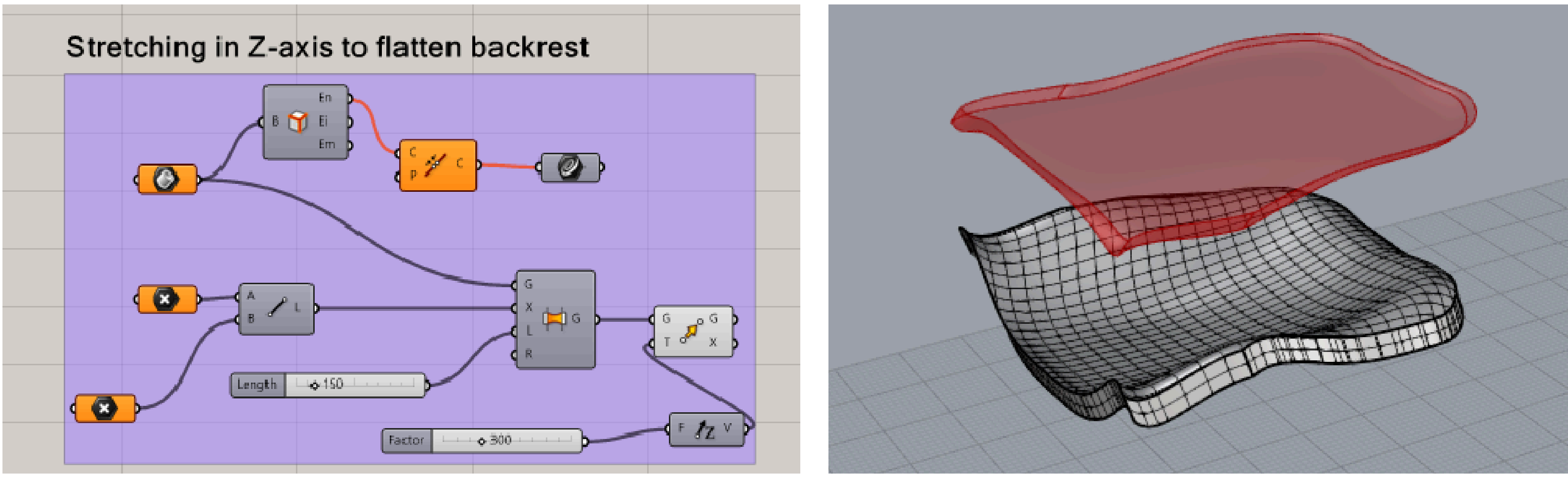

Figure 20: The “Flatten” moduel to correct overaccentuated inserts

Optionally, there is a “Flatten” function added in this workflow as a correctional measure for seat or backrest shapes that are over articulated. In some cases, the person being fitted leaves an imprint that is moderately exaggerated. This is then translated and processed throughout the previous steps in Grasshopper, resulting in a seat insert that overstates its extremities (e.g. a very high support between the legs).

This function is there to offer an effective way of correcting these abnormalities if they show up, while retaining most of the original body shape. Only requiring a line between two points, the function can be easily executed. Whether this is in the default X, Y or Z axis by aligning these points with the “Align and Distribute” function in Rhino, or a specific angle, all the user has to provide is the points that indicate the direction. Moreover, the amount of flattening applied to the seat is also adjustable with the “Length” slider attached. This allows for detailed control over the resulting, corrected shape.

Usually, this function is only applied after manual construction of the seat inserts in Rhino. It is advised to first properly produce a closed polysurface for both the seat pan as well as the backrest. This is due to the fact that it is also possible to negate these abnormalities during that process as well, without modifying the initial body shapes. Which in turn, stays as close to reality as possible in that way.

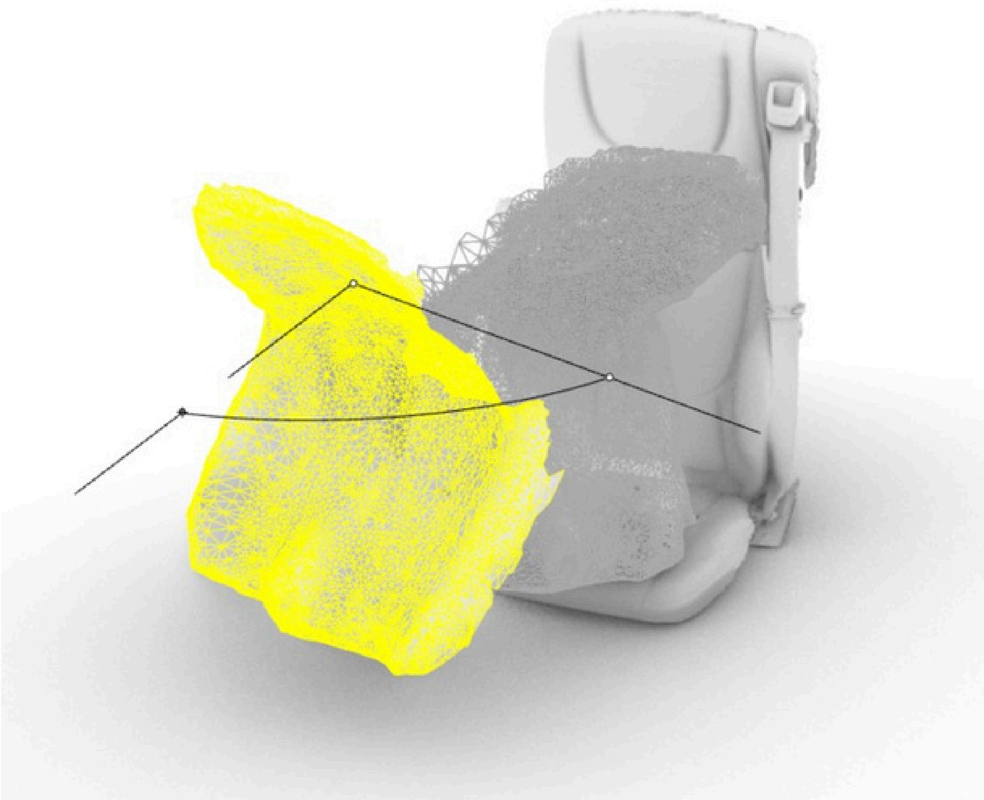

Figure 21: Readjusting meshes that are misaligned on initial import

prior to linking any scan meshes to “Mesh” components so scripts or functions can be executed in Grasshopper, they are first manually repositioned as well as possible. This allows for alignment scripts to run properly later on in the process. Commonly, the Z-axis of the seat scan and the body shapes scan differ in orientation, prompting the need for this correction at the start of the modelling process.

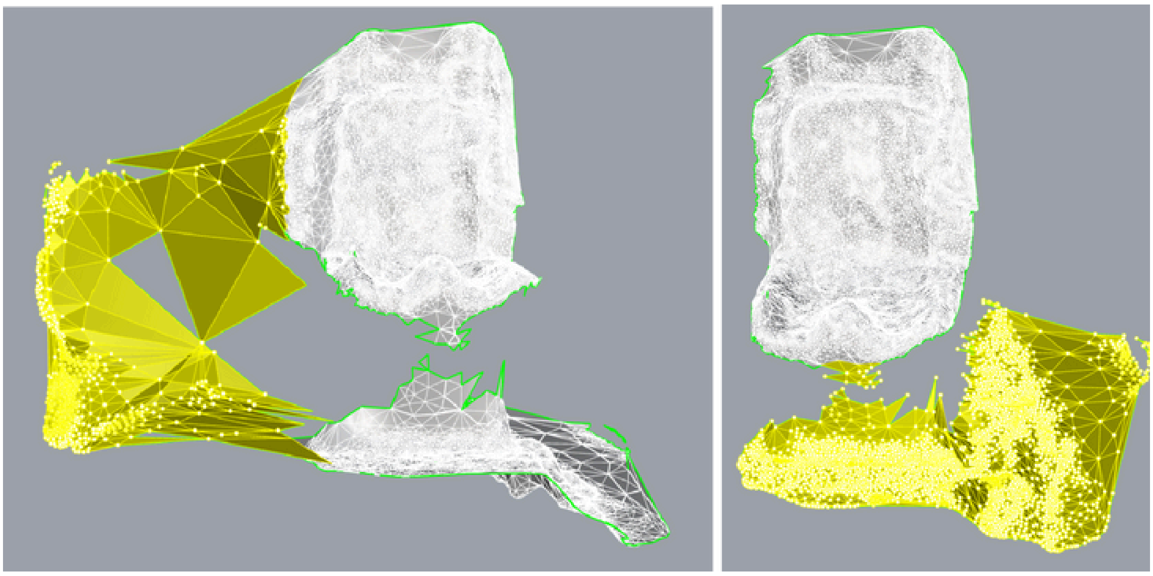

Figure 22: Deleting excess parts from scan mesh

After this alignment, excessive parts of the mesh need to be deleted. More often than not, the scans made using the Scaniverse app catch parts of the environment in which the vacuum bags are positioned. When imported into Rhino, the majority of this mesh can be deleted, since it is not relevant or needed.

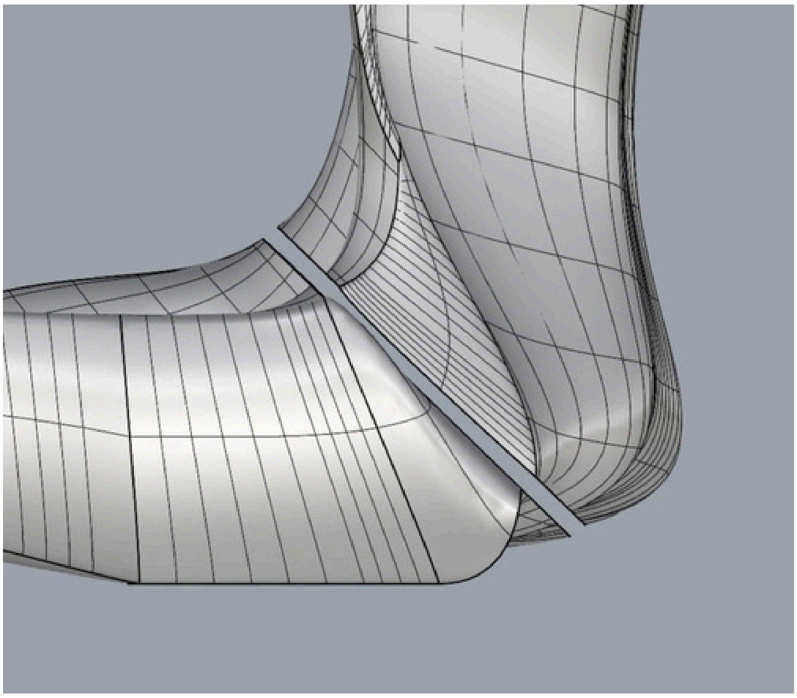

Figure 23: The cut made to seperate seat and backrest

After running the scripts in Rhino, a 45 degree “Split” is made through the bend that connects the lower seat and the backrest of the body shape, and its parallel seat surface. It is meant to reach the point furthest back in both shapes, to facilitate the proper insertion in the truck seat. This is done manually, since each set of seat inserts is highly personal and unique, thus requiring specific attention for this point. Afterwards, the lower seat surfaces (leg imprint and seat pan) and the backrest surfaces (back imprint and seat backrest) are moved apart in their respective couples.

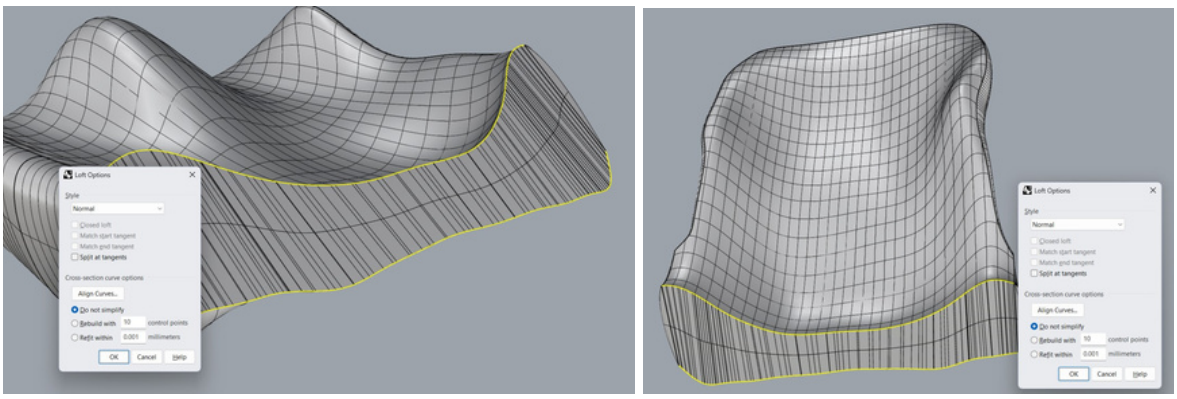

Figure 24: Closing the straight section between the surfaces of body shape and seat

Then, the process of "closing" the shape starts. Meaning, connecting the surfaces into a closed polysurfaces for both a seat and a backrest. To start, a "Loft" is made between the top and bottom surfaces where the 45 degree "Split" was made. This is a straight plane in both parts, allowing the inserts to sit on top of each other in the truck seat.

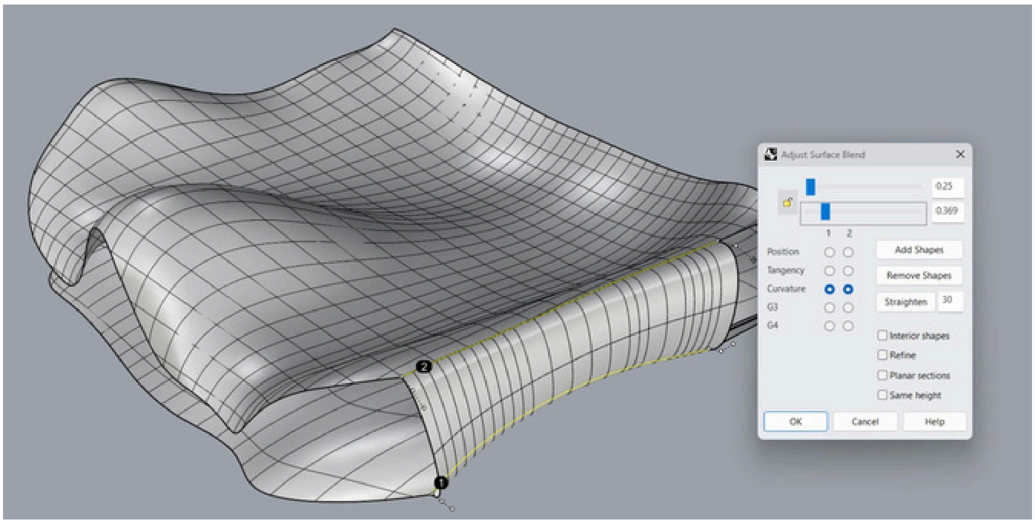

Figure 25: Building out the seat shape along its edges

From here, the process becomes more intricate, requiring control over specific parts of the connecting surface between the edges of both the surfaces. For this, the "BlendSrf" command is used. The adjustable sliders combined with the options of aligning based on Tangency, Curvature or Position per edge, allows for complete control over the resulting shape. The best starting point for this, is most often the longest parallel edges found on the sides of both the backrest and seat part. These edges run along the majority of the length, nearly parallel and without intersection or overlapping curvatures. Creating a solid foundation based off of these sides helps the construction of the other surfaces that connect and close the entire part.

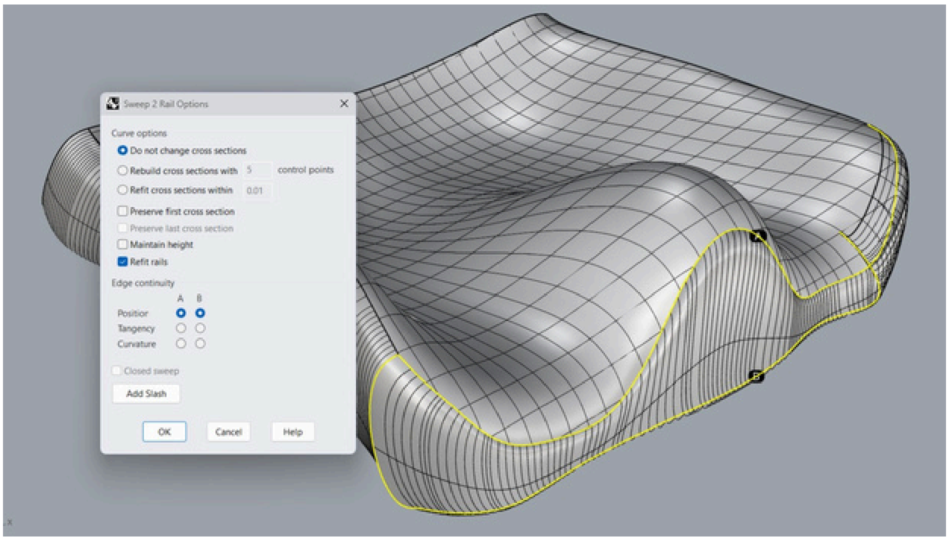

Figure 26: Covering the front of the seat, using curvatures from the sides

If the other edges of coupled surfaces are simple and unproblematic, the initial starting connection surface can be continued to connected edges using the "Sweep2" command. Using the edges as a path to continue on, it adapts the curvature of the selected side. This keeps the sides of the insert part consistent throughout the entire contour, maintaining curvature, height and width as far as possible.

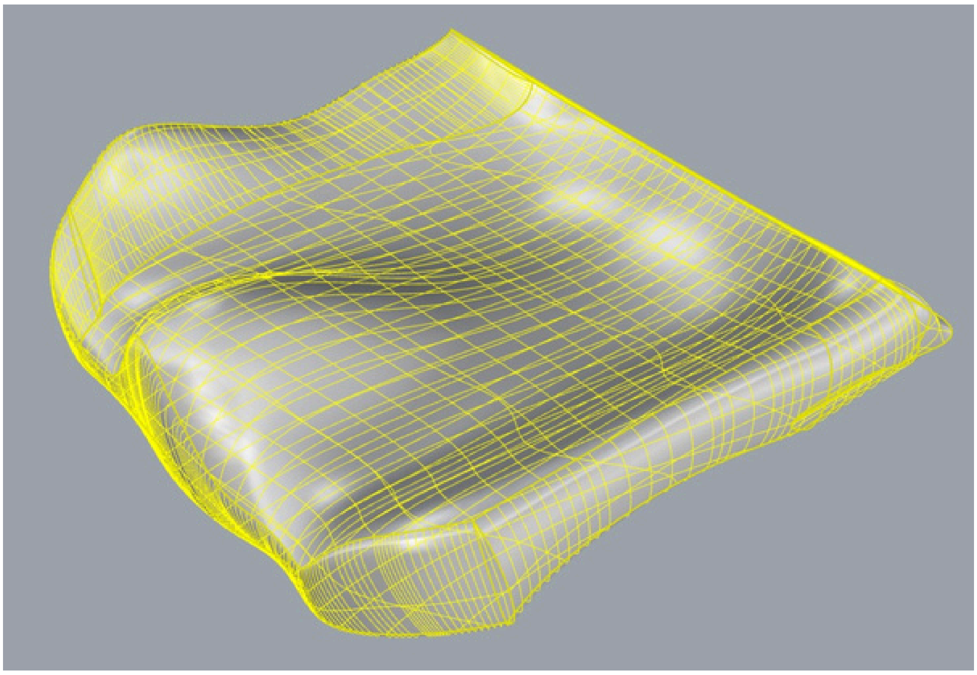

Figure 27: Joining all surfaces together to create one singular shape

After both the surfaces for the seat and backrest are all fully connected, select all of the surface for one part of the insert and use the “Join" command to combine them all into one singular closed polysurface. Then, repeat this for the second part of the inserts as well.

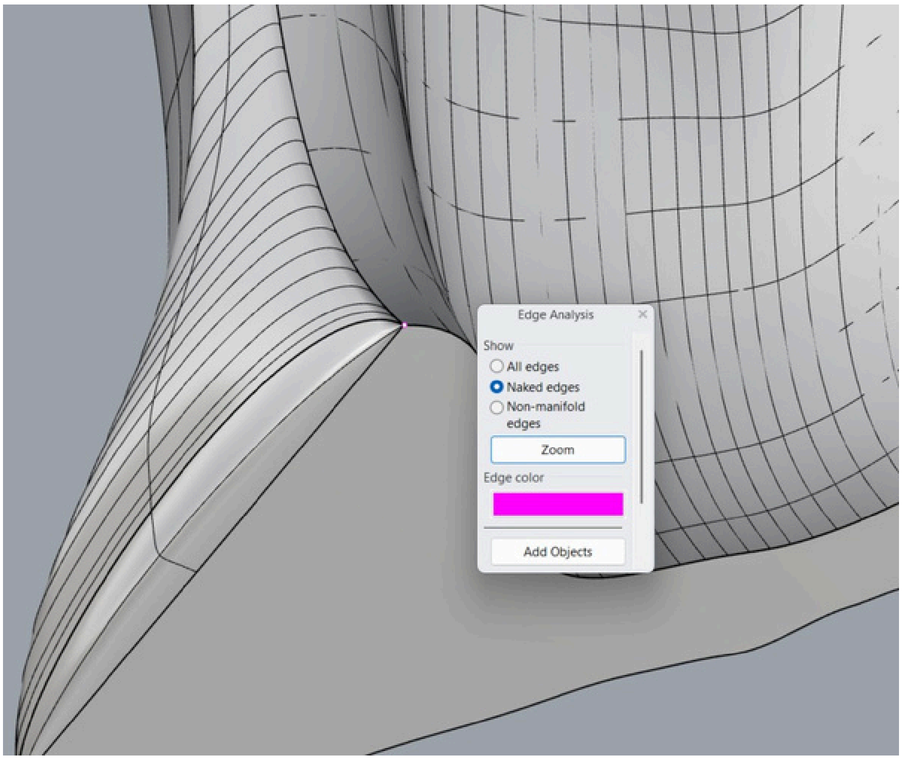

Figure 28: Final check for possible openings or missed holes

As a safeguard, it is advised to select the joined parts and check if they are selected as an open or closed polysurface. An open object will not translate to a working STL file for 3D-printing. If it is found as an open polysurface, the “ShowEdges” command can be used to find where any possible openings might still be stuck in the object. With quick troubleshooting lofts, most of the holes or openings that are left can be fixed. Finally, both the seat and backrest can be exported individually as an STL file ready to be sliced in the Prusa Slicer.

PRUSASLICER

In Prusa, the current template settings for printing have been determined through previous testing. A 15% infill with the gyroid pattern is most comfortable for the seat, where the backrest is best at a lower number of 13% infill, also with a gyroid printing pattern.

For stability, the seat part is given a printing modifier that covers the first 5 layers. This modifier sets the amount of perimeters for these layers to 1, to create a solid outer border at the start of the print. This is meant to join together to open spaces between the gyroid lines in the base layers, improving its strength and acting as a solid boundary line for the rest of the print. It is kept only to the first few layers to prevent the seat becoming too stiff or hard and becoming less comfortable for the user to sit in.

The seat and backrest are printed separately, due to the size and restrictions of the print bed not allowing for them to be printed at the same time. Additionally, this would further complicate the process, since the different infill settings and perimeter requirements would mean a multitude of modifiers needed to achieve everything in one printing session.

The backrest is printed on its back, in a horizontal orientation. Due to the fact that different printing orientations and settings have shown that this minimizes printing times. Earlier optimization attempts saw the vertical orientation as the most efficient, since it requires the least amount of supports to be printed. However, due to the limits in terms of speed for this specific printer, more supports and less verticality resulted in a faster print time.

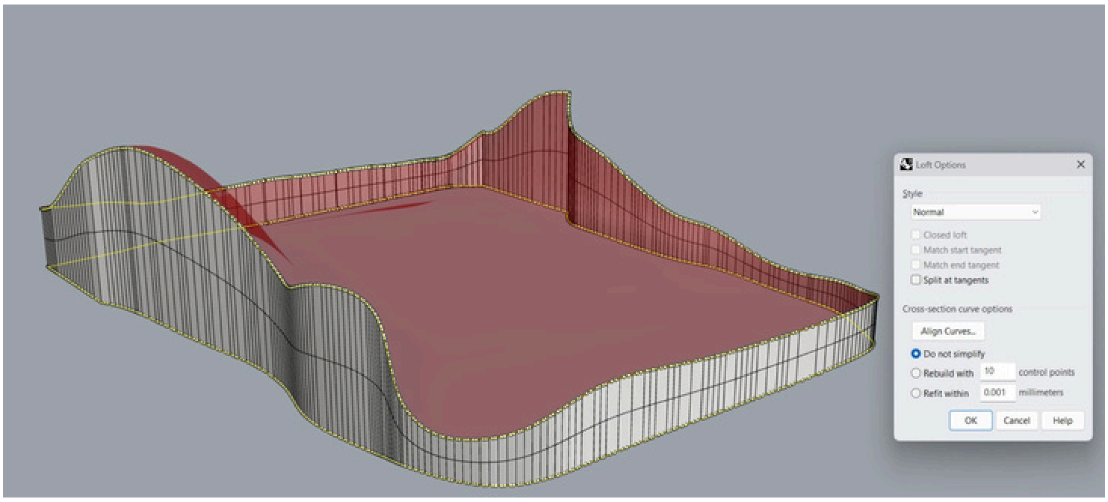

Figure 29: The volume underneath the backrest to the XY-plane in Rhino

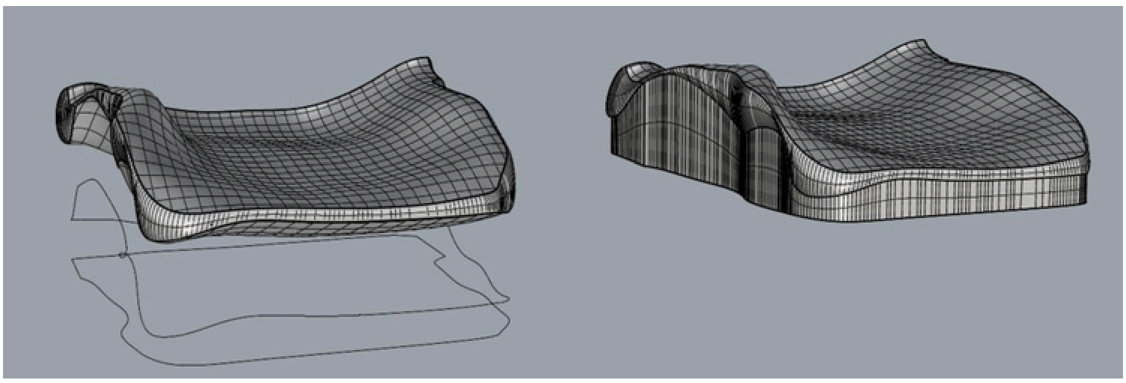

Figure 30: Outline curves real and projected (left) and resulting geometry (right)

Finally, the support structure can be optimized if preferred. Some backrest shapes can be quite challenging to properly print with traditional support, especially a filament such as TPE, due to the strong adhesion between support and regular infill. To combat this, an additional Grasshopper function was created. This function generates a volume between the XY-plane in Rhino and the rear of the backrest, rotated to be horizontal. By capturing this volume, the empty space that is under the backrest, an additional STL file can be generated and put into Prusa. This volume fits perfectly underneath the backrest, since it traces its rear surfaces and edges.

This volume is then given the "Support Cubic" infill pattern, at a 10% infill. This infill gets automatically denser depending on the distance to the nearest top layer (the infill density increases only in the Z-axis). Its primary function is to support the top layers (back of the backrest) by saving as much material as possible, it does so by printing thin strong walls. These walls are substantially easier to remove with a scissor than traditional supports with a higher infill, as well printing significantly faster and using less filament.

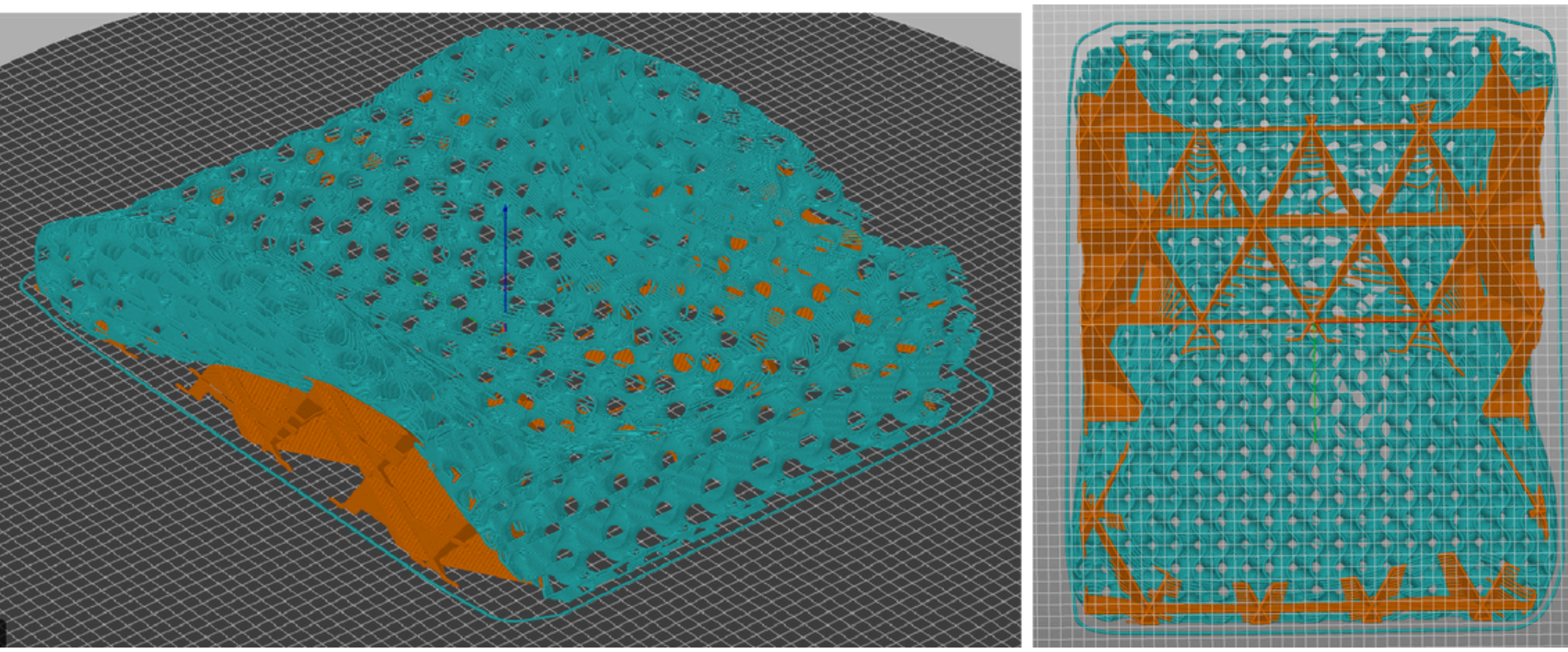

Figure 31: Resulting backrest 3D-print in the PrusaSlicer preview

3.3 FINAL DESIGN

Figure 32: Different aspects of the final design to be tested during the following experiment

The final design of the seat insert system consists of a two-part configuration, composed of a separate seat pan and backrest component. These are split along a 45-degree angle, aligned with the natural hollow region between the seat pan and backrest in a truck seat. This seam is intentionally concealed beneath the seat's upholstery, minimizing visual disruption and preventing direct contact with the user's body. The angled separation not only improves ergonomic fit but also enables the two parts to fold backward onto one another, enhancing portability and simplifying storage when not in use.
As shown on the left in Figure 32, the seat inserts stay withng the borders of the driver seat.

Both components are 3D-printed using TPE filament (TF40QD-LCNT) in pellet form, chosen for its balance of flexibility, durability, and user comfort. The seat pan is printed with 15% infill, while the backrest uses a slightly softer 13% infill, optimizing pressure distribution and surface compliance according to the differing load demands of each region. A gyroid infill pattern is used in both parts, oriented parallel to the user's back and buttocks, so that the open cellular structure faces directly toward the body. This directionality allows the infill to deform naturally under load, improving tactile comfort while maintaining internal stability.

The entire system is dimensionally tailored to fit within the inner boundaries of standard truck seats, with surface refinements made to accommodate seat-side contours and support structures. Cut-outs at critical rear side support locations allow the seat pan to rest over raised upholstery features, avoiding deformation and facilitating accurate placement. Altogether, the design reflects a synthesis of previous prototypes, combining ergonomic support, modular construction, and user-centered flexibility into a robust and adaptable seating solution for professional drivers.

Lastly, the upholstery that is then put around the 3D-printed inserts uses "AirMesh" fabric for the majority of the products' surface that interfaces with the back and buttocks. This fabric has an open structure that allows for better breathability compared to other standard upholstery fabrics. This is to facilitate the ventilation through the open strucure of the 3D-prints, to regulate the temperature and reduce transipiration.

4. Experiment Methodology

This chapter outlines the two-phase research methodology used to develop and evaluate the personalized seat inserts. The first phase consisted of capturing participants' anatomical seating contours through vacuum-fitted cushions and 3D scanning, followed by the digital design and fabrication of custom inserts using additive manufacturing. The second phase evaluated the ergonomic performance of the inserts using both objective pressure mapping and subjective comfort assessments. This dual approach was chosen to reflect the multifactorial nature of seated comfort, incorporating both physiological data and perceptual feedback.

4.1 RESEARCH APPROACH

The experiment conducted to validate the design adopts a quantitative, user-centered approach to verify its comfort. The methodology is structured in two phases: First, capturing the anatomical contour of participants' bodies while seated, using deflatable fitting cushions. Secondly, evaluating the effectiveness of the resulting 3D-printed seat inserts through pressure mapping and subjective short term comfort ratings collected through questionnaires. (Appendices E & F)

The initial phase involves the recording of seated body shapes through 3D scanning of deflated cushions, further nuanced and supported by anthropometric measurements. All this data is then used to design seat inserts specifically tailored to each participant's unique seated posture.

The second phase addresses both the physiological and the psychological factors of comfort. Quantitative pressure distribution data is collected using a high-resolution XSENSOR pressure-mapping system while participants are seated in the regular truck seat with and without their 3D-printed inserts. Additionally, participants are asked to complete short-term comfort questionnaires to capture their perceived comfort experience. This two-part evaluation acknowledges that comfort is not solely a function of physical pressure but is also shaped by subjective perception, an understanding supported by findings from Song & Vink (2021). By combining objective and subjective data sources, the study aims to provide a comprehensive understanding of how customized seating solutions influence seated comfort.

4.2 FITTING PROCEDURE

4.2.1 Experiment Design and Participants

This phase explored the use of deflatable fitting cushions to capture detailed seated body contours, which are intended for the development of customized 3D-printed seat inserts. Participants were individually scheduled, and each session was conducted under the approval of the Human Research Ethics Committee (HREC) and with the appropriate forms prepared and approved (See Appendices B, C and D). Prior to beginning the procedures, participants were briefed on the process and provided written informed consent.

Key anthropometric variables were measured manually using standardized tools, including stature, seated height, hip width, buttock-knee depth, inner-knee depth, and ground-to-knee height. These metrics were essential for validating scan fidelity and understanding variability in comfort outcomes relative to body type. Participants were also asked to report any chronic or recurring musculoskeletal complaints to contextualize comfort ratings.

4.2.2 Test Environment and Setup

To simulate a realistic truck cabin seating experience, a mock-up environment was developed with accurate replication of seat height, backrest angle, and seat pan tilt. The setup included a steering wheel and pedal platform to evoke a familiar posture among participants. (Appendix H) During the fitting session, semi-inflated vacuum cushions were used to capture seated body contours. Participants were instructed to adopt a comfortable and natural posture, after which the vacuum bags were gradually deflated to retain their form. This controlled setup ensured consistency across participants and supported the repeatability of capturing body shapes.

Figure 33: Different stages and details of the testing setup

4.2.3 Fitting Procedure

The fitting procedure followed these steps:

1. The participant was brought into the prepared environment and guided into the seat.
2. They were instructed to find a natural, comfortable posture within the fitting cushions.
3. Once the participant indicated satisfaction with their seated position, the fitting bags were gradually deflated.
4. As the cushions stiffened, minor adjustments were made to ensure close contact with the participant's body (e.g., pressing the bags gently against the back or legs).

Figure 34: A trial run of the fitting procedure

5. After complete deflation and hardening of the cushion shape, the participant was asked to slowly exit the seat by standing up forward. This, to prevent them from disturbing the imprint their body shape made in the fitting bags.

6. The undisturbed seat cushions were immediately scanned using the Scaniverse application on a mobile phone. Scanning was initiated from an upper rear angle and progressed downward to capture the full geometry of the impression.

4.2.4 3D Scanning Procedure

Following the scan of the deflated cushion setup, a second, highly detailed scan was made of the truck seat itself with the use of the handheld Creality Ferret SE scanner. This allowed for subsequent digital modelling to be accurate for all participants' seat inserts. This would be the basis to create an accurate combination of both the body imprint and the seat itself, for later 3D-printing. Both 3D scans were saved in a dedicated folder named with the participant's unique identification number.

The scan of the resulting body shape was then made with the use of the Scaniverse app. Being the quicker option of the two, it was used to facilitate faster fitting sessions to accomodate all of the participants within the allocated time. These scans were processed in the app using the "Surface" feature, checked for artefacts and irregularities to then be saved for later modelling.

4.3 PRESSURE MAPPING

4.3.1 Evaluation Objective

The second phase of testing was designed to assess the functional effectiveness of the 3D-printed seat inserts, which had been developed based on the participant-specific body contour scans. Evaluation focused on two primary outcomes: the distribution of seated pressure and subjective comfort ratings, both of which were compared between the standard truck seat configuration and the same seat fitted with the personalized inserts.

All testing was carried out in a controlled static environment that replicated the spatial and ergonomic characteristics of a truck cabin. The experimental setup consisted of the previously used truck seat mounted in a neutral position aligned with ergonomic best practices. A pressure-mapping system (XSENSOR Technology Corporation) was used to capture detailed measurements of the participants' pressure distribution across the seat surface during use. The participant-specific 3D-printed inserts were carefully positioned within the seat pan and along the backrest, ensuring proper alignment and fit.

To complement the objective pressure data, participants completed a short-form comfort questionnaire administered both before and after the use of the inserts. The questionnaire required participants to rate their comfort across six key body regions on a 7-point Likert-type scale, where 1 indicated very comfortable and 7 indicated very uncomfortable. These combined methods enabled a comprehensive evaluation of both the physiological and perceptual effects of the personalized seating interventions.

4.3.2 Test Procedure

Each evaluation session followed a structured protocol:

1. The participant was welcomed and briefed on the procedure, including their tasks and the use of the pressure-mapping equipment.
2. The participant adjusted the seat to a comfortable position (if needed) and confirmed satisfaction with their posture.
3. While seated in the regular truck seat (without insert), the participant completed the initial comfort questionnaire.
4. The participant then stood up, and the pressure mat was placed on the seat surface, ensuring full coverage without wrinkles or folds.
5. The participant sat down again carefully, maintaining the correct alignment of the mat.
6. Pressure distribution data was captured using the XSENSOR software and saved under the label: "Regular Seat Participant [ID]".
7. The participant then stood up again, and the pressure mat was temporarily removed.
8. The customized 3D-printed insert was placed in the seat and manually aligned with the connection/opening between seat and backrest, to ensure a consistent position.

Figure 35: The truck seat covered with a pressure mat during testing

Figure 36: A participant sitting on their personal seat inserts during the experiment

9. The participant sat down again with the insert in place, made adjustments to the seat configuration if needed, and completed the second comfort questionnaire.

10. The participant then stood up, and the pressure mat was positioned over the insert.

11. After the participant reseated themselves, a second pressure mapping was conducted and saved as: "Insert Participant [ID]".

12. Finally, the participant stood up again, and both the insert and pressure mat were removed.

4.3.3 Data Collection

Two data types were collected during this phase:

- Quantitative Pressure Data: Captured via the XSENSOR system, providing high-resolution pressure maps of the participant's seated interface with and without the insert. These data were used to evaluate differences in contact area, peak pressure, and pressure distribution patterns.

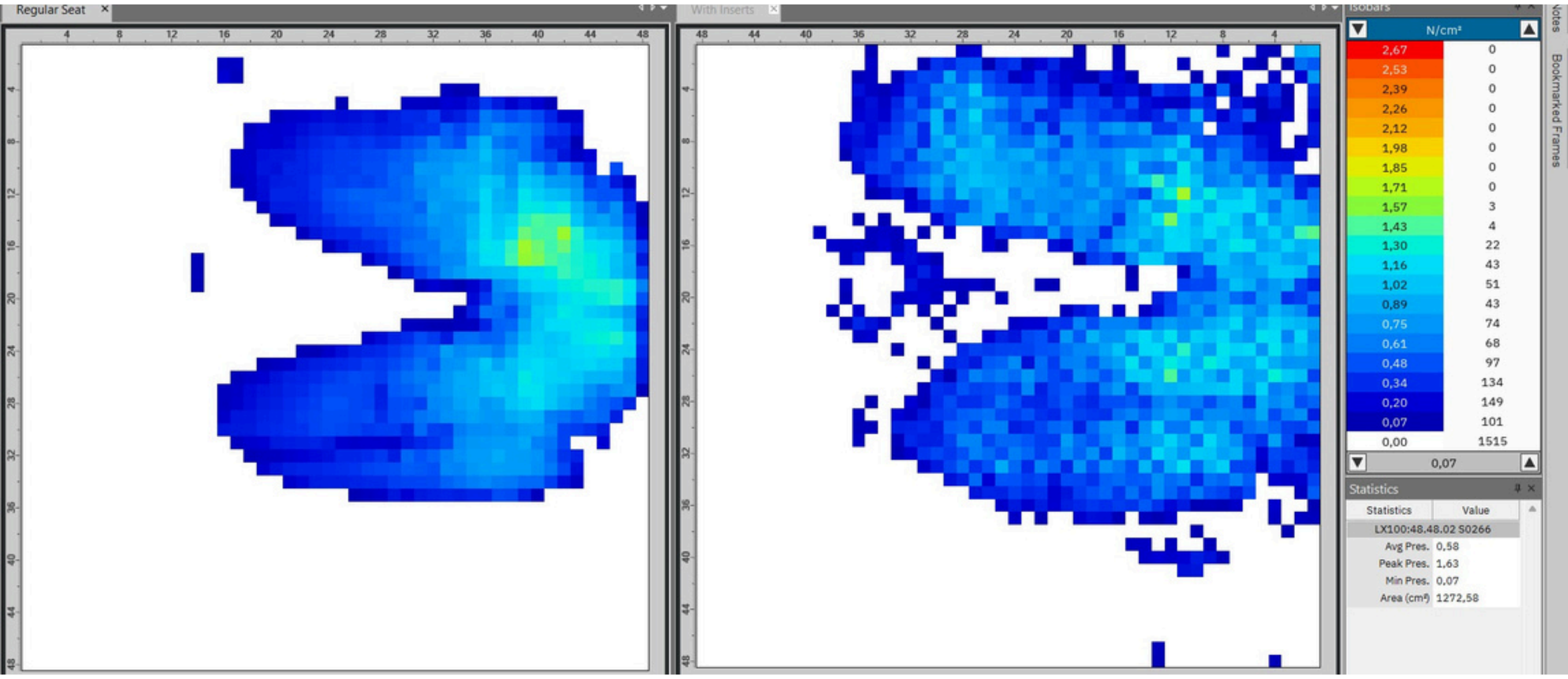

Figure 37: The pressure map comparison of one of the participants

- Comfort Assessment: A structured questionnaire assessed short-term subjective perceptions of comfort across both seating conditions. The results provided insight into the participant's qualitative experience in relation to the pressure data.

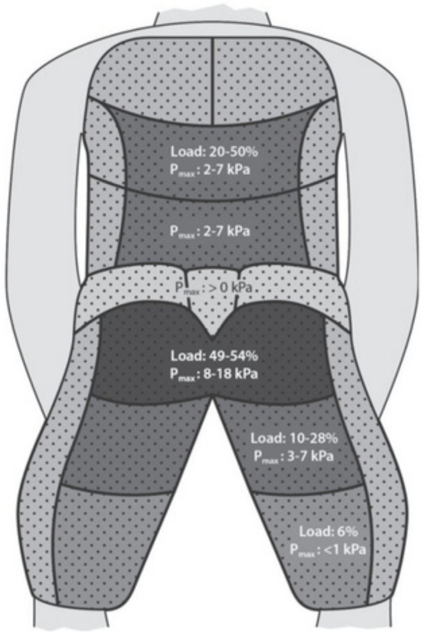

Figure 38: Optimal seated load distribution schematic (Vink & Brauer, 2011)

The questionnaire was constructed to have the areas used in ideal seated load distribution mentioned in Vink, P., & Brauer, K. (2011). This is to do justice to the more sensitive areas under the knees and the lumbar in the back, while also staying in touch with the areas of optimal load distribution as shown in the figure.

4.3.4 Data Collection Methods

Data collection consisted of capturing a comprehensive set of objective and subjective metrics to evaluate the ergonomic effectiveness of the personalized seat inserts. This was achieved through four primary methods: 3D scanning, comfort questionnaires, anthropometric measurements, and pressure mapping. These methods were selected to provide both quantitative and qualitative insights into the interaction between users and the seating intervention.

3D Scanning of Body Shapes and Seat Geometry

The seated body contour of each participant was captured using a two-step scanning process. First, after the vacuum cushions were deflated and the participant exited the seat, the resulting body imprint was scanned using the Scaniverse app on a mobile phone. This method provided sufficiently accurate surface data for modeling personalized inserts while ensuring speed and ease of use across all participants. Second, a high-resolution 3D scan of the reference truck seat was captured using the Creality Ferret SE handheld scanner. This higher-fidelity scan served as the base geometry for aligning all personalized inserts to the physical seat contours and ensured that the digital models maintained compatibility with the actual truck seat used in testing.

All scans were stored in a structured digital archive, labeled according to anonymous participant identifiers, allowing traceability throughout the design and evaluation process.

Comfort Questionnaires

To assess subjective comfort, each participant completed a structured short-term discomfort questionnaire under both conditions: seated in the standard truck seat and in the same seat with their personalized 3D-printed insert installed. Participants were asked to rate their level of discomfort in six anatomically distinct regions: knees, thighs, buttocks, lower back, back and shoulders, and neck. These regions were selected based on the Localized Postural Discomfort (LPD) framework by Vink and Brauer (2011), which identifies key pressure-sensitive areas relevant to prolonged seated tasks.

The original ratings were collected using a 7-point Likert-type scale (1 = very comfortable, 7 = very uncomfortable). For consistency with ergonomic discomfort literature and comparability to prior studies using the LPD method, the data were subsequently normalized to a 10-point scale, where 1 represents minimal discomfort and 10 represents extreme discomfort. This transformation facilitated more intuitive interpretation and improved alignment with standard evaluation metrics in comfort research.

Anthropometric Measurements

Manual anthropometric data were collected prior to testing to characterize the participant sample and support analysis of comfort variations. Measurements included stature, seated height, hip width, buttock–knee length, inner knee depth, and ground-to-knee height. These values were later used to contextualize individual feedback and to explore potential correlations between body morphology and pressure distribution.

Pressure Mapping

Objective pressure data were recorded using an XSENSOR X3 pressure-mapping system, which captured high-resolution distributions of force across the seat interface. Measurements were taken under two conditions per participant: first with the unmodified truck seat, and second with their custom-fitted 3D-printed insert in place. Care was taken to align the pressure mat consistently and to avoid wrinkling or misplacement between conditions. Each measurement was recorded after the participant had adjusted to a relaxed sitting posture, and multiple recordings were averaged to reduce the effect of transient seating artifacts.

4.3.5 Data Analysis Methods

The evaluation of the personalized seat inserts relied on both objective pressure data and subjective comfort assessments, requiring a structured analytical approach. Data collected during testing were subjected to statistical analysis to assess the significance of observed differences between the baseline seat condition and the condition with inserts.

Quantitative Data (Pressure Mapping)

Pressure mapping data were analyzed using paired-sample t-tests to compare three key metrics: average pressure (N/cm^2), peak pressure (N/cm^2), and total contact area (cm^2). These metrics were chosen due to their strong correlation with seated discomfort and their widespread use in seating ergonomics research (Song & Vink, 2021; Buchman-Pearle et al., 2021). Each participant's measurements under the two conditions (regular seat and seat with insert) were averaged across repeated recordings to ensure reliability. Prior to statistical analysis, outliers in peak pressure values were identified and removed using the interquartile range (IQR) method to eliminate artifacts or anomalous spikes unrelated to normal seated behavior.

Qualitative Data (Comfort Ratings)

Subjective discomfort data, derived from participant self-reports, were analyzed to evaluate perceived ergonomic improvements resulting from the personalized seat inserts. Ratings were initially recorded using a 7-point Likert-type scale and later normalized to a 10-point scale in accordance with the LPD questionnaire protocol developed by Vink and Brauer (2011). This conversion allowed alignment with widely used discomfort assessment frameworks in the field of ergonomic seat design.

Paired-sample t-tests were conducted for each of the six body regions to assess statistically significant differences between the regular seat condition and the insert condition. Lower scores indicated greater comfort. Standard deviations and mean differences were calculated to capture both central tendency and inter-participant variability. Although effect sizes were not formally calculated due to the modest sample size, descriptive patterns and confidence intervals were considered during interpretation.

Supplementary Observations

Qualitative observations and participant remarks were used to contextualize the statistical outcomes. For instance, discrepancies between measured pressure relief and perceived comfort were further analyzed with reference to participant anthropometry and recorded quotes, which offered insight into positional instability, sensory feedback, and interactions with existing seat geometry.

Taken together, this mixed-method analysis provided a comprehensive understanding of both the biomechanical and experiential impact of the 3D-printed inserts. The triangulation of sensor data and subjective perception enhanced the internal validity of the findings and enabled a nuanced interpretation of the ergonomic performance of the intervention.

5. Experiment

To accurately capture the body contours of participants and later evaluate comfort of custom seat inserts, a realistic seating environment was essential for the experiment. This thesis therefore included the design and construction of a 1:1 scale, stationary truck seating simulator, developed to closely mimic the spatial and ergonomic characteristics of a Volvo FH Globetrotter XXL cabin, a model widely used for international trucking routes in Europe.

Figure 39: Meeting with collaborating truck driver for cabin dimensions

5.1 DESIGN CHOICES AND REFERENCES

The Volvo FH Globetrotter XXL cabin was selected as the dimensional reference for the simulator, based on interviews with professional drivers and technical documentation from Volvo Trucks Netherlands. This cabin model is widely used in European logistics operations and was thus deemed representative of real-world truck ergonomics. Reference dimensions were obtained through a combination of direct field measurements and specifications provided by the manufacturer. Parameters such as dashboard height, steering wheel reach, and seat dimensions were carefully recorded to ensure fidelity to in-cabin conditions.

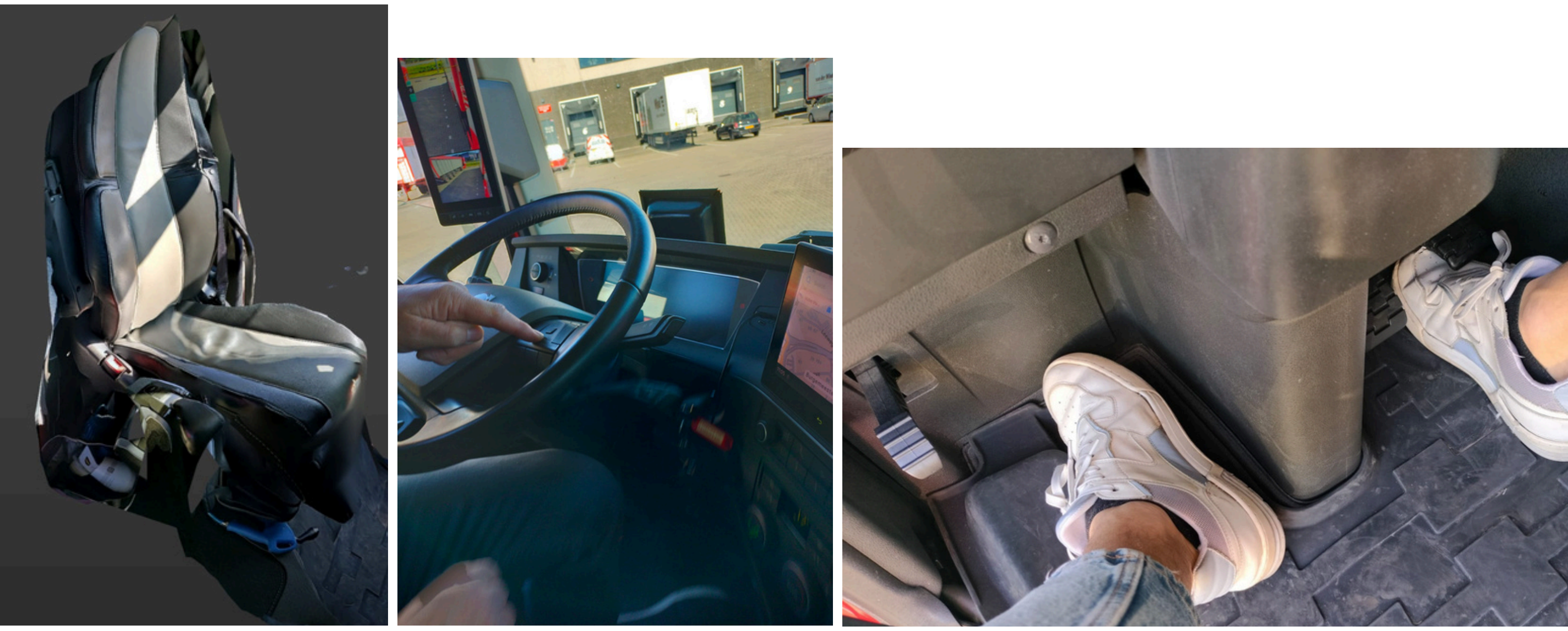

Figure 40: 3D scan of truck seat, steering wheel details and leg space limitations

To ensure the accuracy and contextual relevance of the simulated cabin used in this thesis, its construction was based on in situ dimensional measurements taken directly from the cabin of a truck driver's personal Volvo vehicle. This approach enabled the test environment to closely replicate the spatial constraints and ergonomic characteristics of a real truck interior. Key parameters recorded included a dashboard width of 550 mm, a middle console diagonal of 270 mm, and a seat pan to ground height of 415 mm. Additionally, the vertical distance from the seat pan to the steering wheel middle in normal position was measured at 205 mm, while the seat pan to dashboard distance was 300 mm. The seat pan itself featured a maximum width of 520 mm and a minimum width of 350 mm, with a total depth of 360 mm. The steering column measured 150 mm in width, 560 mm in height, and 250 mm in depth. These measurements served as essential reference points during both the prototyping and experimental phases, ensuring that participants interacted with a layout that reflected authentic driving conditions.

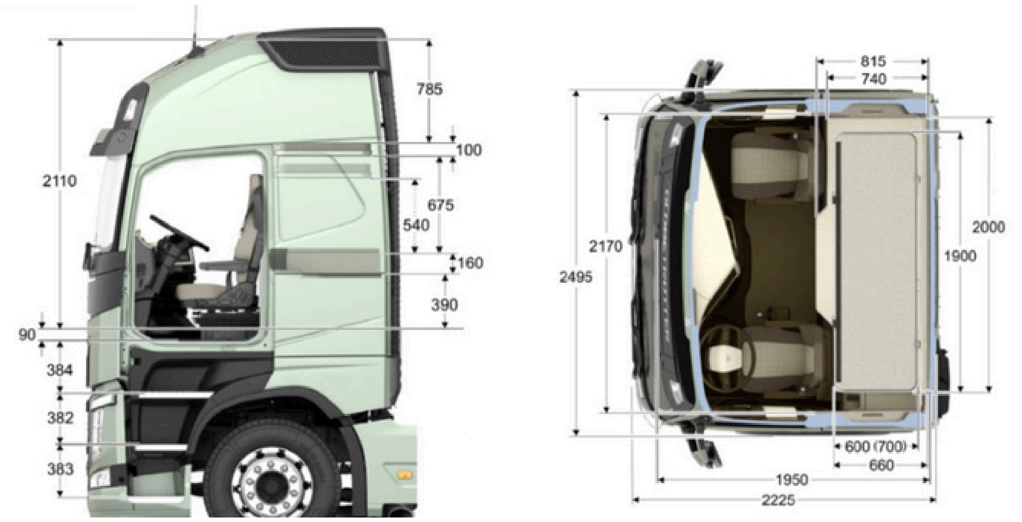

Figure 41: Volvo Globetrotter XXL dimensions

In addition to the measurements taken from the personal vehicle of a professional truck driver, further dimensional and spatial data were sourced from publicly available documentation to improve and validate the simulated cabin environment. Cabin configuration details provided by ClassTrucks (n.d.) were used to better understand the structural layout, dimensions, and types of available Volvo truck cabins. This information complemented the physical measurements by offering broader context on internal and external cabin proportions, helping to define the overall spatial boundaries of the test environment with greater accuracy.

Moreover, product specifications from an OEM-compatible driver's seat, obtained from Drivers-Seats.com (n.d.), were consulted to align the prototype setup with the dimensional standards and adjustability features of commercially available seating. These specifications played a key role in establishing the relative positioning of the seat in relation to surrounding components such as the dashboard and center console. By referencing both manufacturer data and physical measurements, the test setup was designed to closely emulate the ergonomic and spatial constraints found in actual truck cabins, thereby enhancing the validity of the experimental procedures.

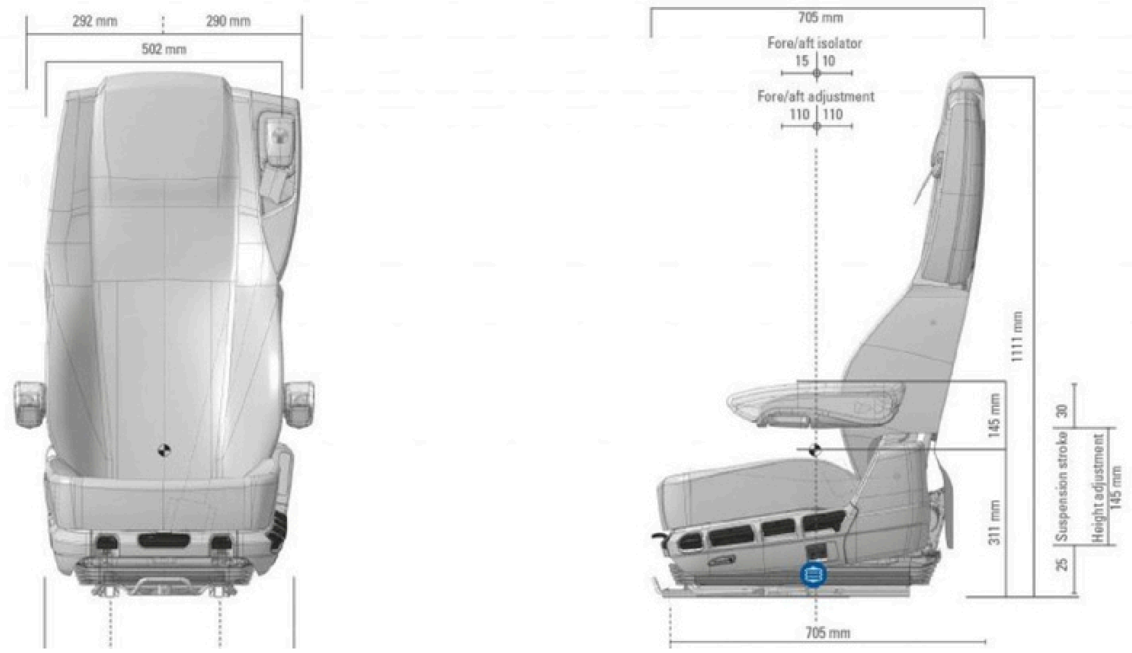

Figure 42: Dimensions of truck seat used in the experiment

These dimensions were used to construct a wooden test platform that replicates the cabin's core ergonomic features like dashboard, steering column, middle column and steering wheel. Particular care was taken to replicate the dashboard positioning, seat-to-steering-wheel distance, and the incline of the steering column to ensure the resulting posture would closely simulate actual, real life driving conditions.

5.2 Construction and Assembly

The simulator was constructed using a modular frame of MDF panels and oak structural beams, mounted on a wooden pallet base to approximate the elevated cabin floor typical of commercial trucks. A commercial second-hand driver's seat, visually and structurally similar to an OEM Volvo FM/FH seat, was mounted onto the platform. Additional features, including a dashboard mock-up, steering wheel, and middle console, were incorporated to restrict posture in a manner similar to an actual truck cabin. These constraints were crucial to elicit natural driver postures during both the vacuum fitting and subsequent pressure mapping sessions, ensuring validity of the captured data.

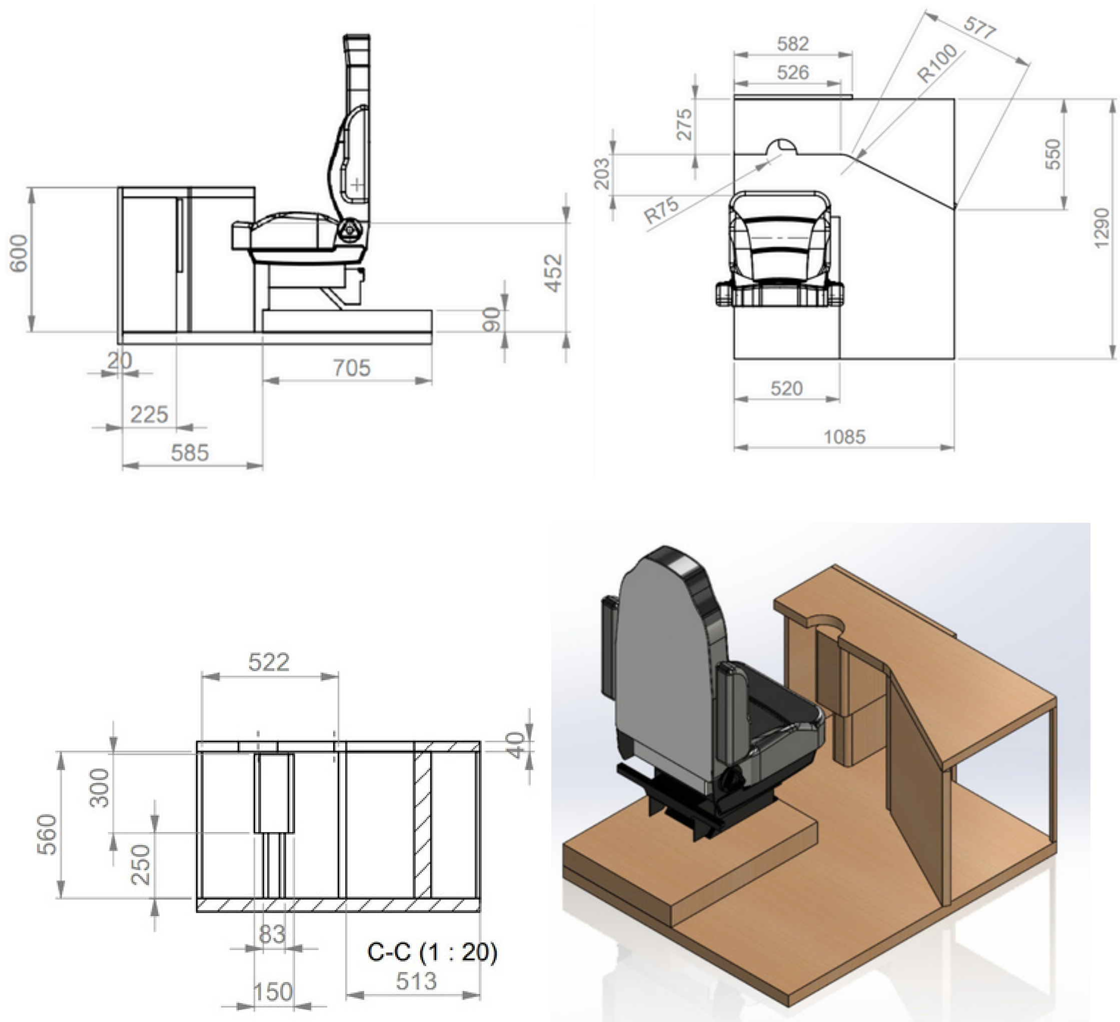

Figure 43: Schematics and isometric view of the test environment to be built (Appendix H)

The seat angle and backrest recline were configured to match the typical driving position for truck drivers: 110° backrest angle and a 5–10° seat pan tilt. A reclined backrest around 110° minimizes lower back strain by allowing the upper body to lean back slightly (Cornell University, n.d.). Similarly, a slight forward tilt of the seat pan around 5°, helps distribute weight more evenly and reduce pressure on the thighs (UCLA Health, n.d.).

Figure 44: The Testing environment completely built

5.3 RELEVANCE TO METHODOLOGY

This physical mock-up served a dual purpose: it ensured standardized and repeatable conditions across all participants, and it allowed for accurate realistic capture of body contours during the fitting phase (via cushion deflation and scanning), as well as valid assessments during the comfort evaluation phase. The effort to match anthropometric, ergonomic, and visual parameters of a real truck cabin is central to the validity of the study, particularly given the postural sensitivity of comfort assessment and the influence of cabin layout on seating behavior (Zhang et al., 2025; Pagliari et al., 2023).

6. Results

6.1 PARTICIPANT ANTHROPOMETRICS

These are the physical measurements done at the start of the experiment, detailing the participants' specific body metrics. No participant had a background in occupational driving, but all were selected based on current truck driver demographics. Sectorinstituut Transport & Logistiek (2021) reports that women made up to 24% of logistics employees (of which 5% specifically truck drivers) with a steady increase over the last 5 years.

The spread of age among participants is wide, but does not completely resemble that of the reported distribution within the workforce. As of 2024, 39% of male truck drivers were 55+, 39% 35-55 years of age and 21% were between 15 and 35 years old. Among females, 50% were between 15 and 35 years of age, with an even split of 25% among both 35- 55 years old and 55+. (Sectorinstituut Transport & Logistiek, 2021)

Participant	Age	Sex	Weight (kg)	Stature (mm)	Hip Width (mm)	Buttock-Knee Depth (mm)	Buttock-Inner Knee Depth (mm)	Seated Height (mm)	Ground to Knee (mm)
1	24	Male	85.4	1924	419	665	587	966	495
2	27	Male	70.7	1758	416	600	512	903	529
3	50	Male	90.9	1827	437	627	542	918	593
4	38	Female	57.5	1733	606	417	492	868	534
5	31	Male	103.3	1901	465	664	541	952	559
6	42	Male	67.5	1728	417	621	526	852	557
7	24	Male	88.5	1912	466	646	519	1017	539
8	30	Male	86.4	1843	424	634	544	964	543
9	34	Male	67.8	1657	374	592	493	854	540
10	60	Female	54.9	1613	408	581	491	844	539
11	46	Male	92.7	1865	414	653	552	945	614
12	34	Female	57.8	1690	400	611	542	869	552
13	26	Female	61.3	1695	400	587	518	920	496
14	57	Male	109.1	1902	438	654	554	933	600
15	57	Female	53.5	1711	377	628	543	819	552
16	30	Female	74.7	1723	466	602	519	872	542
17	54	Male	98.9	1827	436	656	546	915	597

Table 1: Anthropometric measurement data from participants

6.2 SHORT TERM COMFORT QUESTIONNAIRE

Body Region	Mean (Regular Seat)	SD ((Regular Seat)	Mean (Seat Insert)	SD (Seat Insert)	Mean Difference	p-value	Significance
Knees	3.73	1.58	3.00	1.41	-0.73	0.022	Yes
Thighs	3.47	0.83	2.33	1.23	-1.13	0.0024	Yes
Buttocks	3.93	1.28	2.13	0.99	-1.80	0.0013	Yes
Lower Back	3.87	1.51	2.87	1.25	-1.00	0.060	No
Back & shoulders	3.93	1.22	3.60	1.50	-0.33	0.43	No
Neck	5.00	1.41	4.20	1.87	-0.80	0.0046	Yes

Table 2: Results form the perceived comfort questionnaire

A paired sample t-test was conducted to evaluate the impact of customized seat inserts on perceived comfort across various body regions among truck drivers. The analysis revealed statistically significant improvements in comfort ratings for several regions when using the adapted seat inserts compared to the regular seat.

Specifically, significant improvements in perceived comfort were observed under the knees (M_diff = -0.73, p = .022), thighs (M_diff = -1.13, p = .002), and buttocks (M_diff = -1.80, p = .001), with lower mean ratings indicating improved comfort. These regions also exhibited relatively high standard deviations, suggesting some inter-individual variability in responses. Notably, the neck area also showed a significant improvement (M_diff = -0.80, p = .046), further supporting the beneficial ergonomic effect of the seat inserts in upper body support.

In contrast, the differences in comfort ratings for the lower back (M_diff = -1.00, p = .060) and the back and shoulder area (M_diff = -0.33, p = .430) did not reach statistical significance. These results suggest that while the inserts offer tangible comfort benefits in specific contact regions (particularly those in direct pressure zones) their impact on more posture-related discomforts in the back may require additional ergonomic refinements or longer-term adaptation to yield statistically meaningful improvements.

6.3 PRESSURE MAPPING

Metric	Regular Seat	With Inserts	t	p-value	Significance
Average Pressure (N/cm^2)	0.51 ± 0.10	0.31 ± 0.07	8.97	2.0×10^{-7}	Yes (p < 0.001)
Peak Pressure (N/cm^2)	1.71 ± 0.38	1.40 ± 0.46	2.16	0.047	Yes (p < 0.05)
Contact Area (cm^2)	1162.2 ± 135.2	1337.2 ± 198.3	4.16	0.0008	Yes (p < 0.001)

Table 3: Results from the pressure mapping section

Pressure mapping analysis was performed on data collected from 17 participants under both regular seat and seat-with-inserts conditions. For each participant, multiple measurements were averaged per condition. Outliers in peak pressure were removed using the IQR method to account for artifacts. Paired t-tests were used to assess the differences between conditions.

The use of seat inserts resulted in a significant reduction in average pressure (Regular: 0.51 ± 0.10 N/cm^2; Inserts: 0.31 ± 0.07 N/cm^2; $t(15) = 8.97$, $p < 0.001$) and a significant increase in contact area (Regular: 1162.2 ± 135.2 cm^2; Inserts: 1337.2 ± 198.3 cm^2; $t(15) = 4.16$, $p < 0.001$). These results indicate that seat inserts not only decrease the intensity of pressure exerted on the seat surface but also distribute body weight more evenly, covering a larger contact area.

After outlier and noise removal from measurements, peak pressure was also lower with the inserts (Regular: 1.71 ± 0.38 N/cm^2; Inserts: 1.40 ± 0.46 N/cm^2), with the difference reaching statistical significance ($t(15) = 2.16$, $p = 0.047$). However, the reduction in peak pressure showed more variability across participants compared to the other metrics, likely reflecting differences in individual posture and seating dynamics as well as the episodic nature of pressure spikes during measurements.

Interpretation

Overall, these findings demonstrate that 3D-printed seat inserts consistently provide both a measurable and statistically significant benefit in reducing average pressure and increasing contact area for truck drivers. The reduction in peak pressure, while significant, was less robust and more variable, highlighting the importance of both continuous and localized pressure monitoring in ergonomic seat design. These improvements suggest that personalized seat inserts could play an important role in enhancing driver comfort and potentially reducing the risk of pressure-related musculoskeletal issues in long-term driving populations.

6.4 OBSERVATIONS & QUOTES

During the testing procedure, several participants made relevant remarks about their seated comfort or sitting posture. These statements help nuance certain comfort ratings and pressure map results.

First, a majority of the taller participants recalled that the area directly under their knee was not supported by either chair or seat insert. This was caused by the fact that their upper leg was longer than the seat pan, therefore sticking out towards the dashboard. However, shorter participants did have this support under their upper leg, therefore creating a divide in the comfort ratings between taller and shorter participants.

Secondly, multiple participants mentioned that their neck and head were not comfortable against the headrest. When asked what they thought caused this, all of these participants pointed out that the way that the truck seat is shaped directly inconvenienced them. As shown in previous sections, the headrest of the truck seat used has a slight forward incline that is meant to support truck drivers' forward posture when in an elevated position. This specific part of the seat is what the participants mentioned as being uncomfortable during testing.

Third, multiple participants did not find their backrest to be comfortable at all, expressing that "it was too guiding and oppressive". Several participants requested to experience the comfort with only the seat insert (without the backrest), to see if that would alleviate (some of) the discomfort caused by the backrest. When tried, both participants felt more comfortable and "less limited" in their range of motion around the backrest.

Fourth, two participants were surprised by "the stability of posture the seat insert gave them". During testing, one tried to slouch down as far as they were able to, but failed to do so. The other participant mentioned they could not sit in a crooked position, even though they "shifted around in the insert to lean to the left", the resulting posture would "still be a neutral one afterwards".

Additionally, one participant exclaimed that "the difference in comfort between the insert with the pressure mat overtop of the seat insert was noticeable". Indicating that the extra layer of the mat over the 3D-printed structure "smoothed down the feeling of individual lines" within the seat insert.

7. Discussion

7.1 INTERPRETATION OF RESULTS

This thesis evaluated the ergonomic benefits of customized seat inserts for truck drivers by combining objective pressure mapping and subjective comfort ratings across a demographically relevant participant group. The participant sample reflected key characteristics of the current truck driver workforce in terms of body size and proportions, although, as noted, some differences in age distribution were present compared to national statistics (Sectorinstituut Transport & Logistiek, 2021). The inclusion of both male and female participants, as well as a range of anthropometric measurements, supports the generalizability of the findings to the diversity observed in today's logistics sector.

7.1.1 Comfort Perception

The short-term comfort questionnaire provided valuable insight into how seat modifications translate to user experience across multiple body regions. Statistically significant improvements in comfort were found for the knees, thighs, buttocks, and neck, with mean differences consistently favoring the insert condition. These regions correspond closely to the areas of direct pressure interface with the seat pan and bolster, highlighting the critical role of targeted pressure redistribution in enhancing perceived comfort. Notably, qualitative observations from testing revealed that the effectiveness of this support varied with participant anthropometry. Several taller participants remarked that the area under their knees was unsupported due to the seat pan being too short for their upper leg, whereas shorter participants did experience support in this region. This feedback helps explain the observed inter-individual variability in comfort ratings for the thighs and knees and underscores the importance of seat pan length and adjustability in ergonomic seat design.

In contrast, improvements in comfort ratings for the lower back and back/shoulder regions did not reach statistical significance. This may indicate that while the seat inserts effectively mitigate discomfort associated with pressure points, additional ergonomic features—such as enhanced lumbar support or dynamic contouring—may be necessary to address posture-related discomforts in areas less directly influenced by the seat base geometry.

Importantly, participant comments described the backrest as "too guiding and oppressive," and several participants reported increased comfort and freedom of movement when testing the seat insert without the backrest. These findings suggest that backrest discomfort may be driven both by the restrictive features of the original seat design and, in part, by human error during the creation of the 3D-printed inserts for this project. Small deviations or imperfections in the insert fabrication process likely contributed to some of the discomfort reported, highlighting the need for careful quality control in custom ergonomic solutions.

Another key theme emerged around the design of the headrest. Multiple participants described discomfort with the headrest, attributing it to the forward-inclined shape of the truck seat's upper section. This is particularly relevant given that the neck region, while showing significant improvement with the insert, remained a source of discomfort for some. These comments suggest that certain discomforts may be inherent to the original seat design rather than the insert itself, highlighting the need for holistic seat redesign when aiming for optimal comfort and musculoskeletal support across all body regions.

Positive effects were also observed regarding postural stability. Two participants reported that the seat insert promoted a stable, neutral posture, noting they could not successfully slouch or sit crookedly despite attempts to do so. This feedback aligns with the pressure mapping results, indicating that the insert not only redistributes pressure but also encourages ergonomic posture—an important protective factor against the development of musculoskeletal disorders (MSDs) over time. Supporting neutral and stable postures is widely recognized as a key intervention to reduce fatigue, excessive tissue loading, and chronic musculoskeletal complaints in professional drivers.

Finally, sensory perception of material layering was noted by one participant, who found that placing the pressure mat over the 3D-printed insert "smoothed down the feeling of individual lines," thus improving comfort. This highlights the significance of surface materials and interfaces in perceived comfort and suggests that future iterations of custom seat design should carefully consider the tactile characteristics of the final seating surface.

7.1.2 Pressure Mapping Outcomes

Objective pressure mapping reinforced the subjective findings by demonstrating a robust reduction in average pressure and a significant increase in contact area when using the inserts. These changes are consistent with improved pressure distribution, which is widely recognized as essential for preventing discomfort and reducing the risk of pressure-induced tissue damage during prolonged sitting. Importantly, peak pressure—often associated with localized discomfort, soft tissue risk, and the development of pressure-related MSDs—was also significantly reduced after artifact removal, although with greater inter-participant variability. This may reflect natural differences in seating posture or the transient nature of pressure spikes, underscoring the importance of both continuous monitoring and artifact management in real-world assessments. The qualitative feedback on seat fit, support, and posture further supports these quantitative outcomes, providing a nuanced perspective on how and why certain individuals benefited more from the insert than others.

7.1.3 Implications

Taken together, these results provide strong evidence that custom-fitted seat inserts can meaningfully enhance both the objective and subjective comfort of truck drivers, particularly in high-pressure regions most susceptible to discomfort and MSD risk. By reducing average and peak pressures and promoting neutral postural alignment, seat inserts may help lower the incidence or severity of musculoskeletal complaints. This is a critical concern given the high prevalence of MSDs among professional drivers as stated earlier in this report. The approach demonstrates the value of combining quantitative pressure analysis with user-reported outcomes and qualitative observations to develop and validate these 3D-printed ergonomic interventions. However, the findings also suggest that further improvements may be necessary to address residual discomfort in the lumbar and upper back regions, as well as to accommodate a wider range of anthropometric profiles.

Finally, the combination of anthropometric diversity, advanced pressure mapping, subjective assessment, and participant observation employed in this study offers a strong foundation for further innovation in personalized seating design within the logistics sector.

7.2 COMPARISON TO EXISTING WORK

This thesis daddresses the challenge of the disparity between standard truck seat dimensions and the diverse body shapes of individual drivers. Conventional seats often fail to adequately accommodate personal variations in body shape, due to their design having a "one size fits most" approach. This can result in suboptimal pressure distribution and the promotion of unhealthy postures during prolonged driving periods. By utilizing 3D-printing technology to produce customized seat inserts, this research demonstrates a clear improvement in pressure distribution relative to standard truck seats. The inserts not only conform more closely to the user's morphology but also provide increased ergonomic support, which encourages better posture and potentially mitigates discomfort associated with long-haul driving

In contrast to traditional foam-based manufacturing, which is both resource-intensive and often wasteful, 3D-printing offers a direct and material-efficient approach to producing customized components. With a unique support structure being generated specifically for this, minimal waste is associated with producing these seat inserts. This methodology significantly reduces material waste by only producing what is required and opens new avenues for on-demand manufacturing of ergonomic seating solutions. The findings of this thesis contribute to bridging the gap observed in previous literature regarding the personalization of mass-produced vehicle interiors and highlight the promise of additive manufacturing in advancing ergonomic seat design.

7.3 IMPLICATIONS FOR DESIGN

The implications of this research extend beyond the context of truck driver comfort and into broader domains of product and furniture design. The introduction of soft, customizable 3D-printed cushions and inserts marks a promising development for both automotive and furniture industries. Importantly, the potential for personalization is no longer confined to the medical or orthopedic sectors but can be feasibly extended to mainstream consumer products. The prototyping and evaluation undertaken in this project represent a critical step toward the commercialization of 3D-printed seating products.

7.4 LIMITATIONS

Several limitations should be acknowledged when interpreting the results of this study. First, the experimental protocol was restricted to short-term and static testing, thereby limiting the assessment of long-term effects and performance under real-world dynamic conditions. The sample size was also constrained, with varying but limited anthropometric diversity among participants, which may affect the general application of the findings. Moreover, the absence of electric seat actuation or air suspension in the testing setup means that certain ergonomic and comfort factors specific to actual truck environments were not fully replicated. A further limitation relates to potential bias, as a majority of participants were colleagues from the host company, rather than professional truck drivers.

Additionally, improvements suggested during the testing phase such as upholstery integration and adjustments to the seat prototype (e.g., seat elevation, cabin features like windows and dashboard depth) could not be implemented due to the need for consistency in the evaluation protocol. Future studies should seek to address these constraints by engaging a broader participant base and employing more realistic seat mock-ups or even conducting tests in a real truck cabin if possible.

7.5 FUTURE RESEARCH

Future research is warranted to comprehensively evaluate the long-term impact of 3D-printed seat inserts on factors such as whole-body vibration (WBV), a major contributor to musculoskeletal disorders among professional drivers. This was not covered within the scope of this thesis, due to the added complexity and safety concerns testing this in dynamic settings.

Another promising direction involves improving the customization process using anthropometric data collected during the experiment to further optimize seat fit and comfort. There is significant potential for exploring different printing techniques, including experimentation with infill gradients and densities, which may influence perceived comfort and mechanical performance. The application of graded materials with varying extrusion rates to modulate stiffness in specific seat regions, could provide tailored support and pressure relief in sensitive areas.

Moreover, research should investigate the potential need for additional inserts in regions such as the neck and upper back, in response to participant feedback regarding discomfort in these areas.

Finally, extended studies should be conducted to assess air flow, temperature regulation and humidity control over longer periods and in operational truck environments, in order to validate and refine the proposed seating solutions under real-world conditions.

8. Conclusion

This thesis explored the development and evaluation of personalized, 3D-printed seat inserts as a means of improving seated comfort and reducing musculoskeletal risk among truck drivers. Recognizing the widespread prevalence of musculoskeletal disorders (MSDs) in the transportation sector, particularly due to poor pressure distribution and anthropometric mismatches in conventional seating, this thesis proposed a custom-fit ergonomic intervention using additive manufacturing techniques.

Through a structured process involving anthropometric measurement, vacuum-based body contouring, digital modeling, and 3D printing with flexible thermoplastic elastomer (TPE), seat inserts were designed to align with each participant's unique body shape. These inserts were tested in a representative truck cabin mock-up using pressure mapping and short-term comfort questionnaires.

The results demonstrate that personalized seat inserts produced a 39.2% reduction in average pressure, an 18.1% reduction in peak pressure, and a 15.1% increase in contact area relative to the regular seat configuration. Subjective comfort ratings showed statistically significant improvements ($p < 0.05$) in key body regions, including the knees, thighs, buttocks, and neck. Participants also reported improved postural stability and support. However, the backrest was perceived by some as restrictive, and comfort improvements in the back and shoulders were not statistically significant, likely due to production variability and limitations in dynamic support.

8.1 ANSWERS TO RESEARCH QUESTIONS

Can 3D-printed seat inserts improve seating comfort for truck drivers?

Yes. Results from both pressure mapping and user feedback indicate significant short-term improvements in comfort and pressure distribution.

Can custom seating reduce ergonomic risk factors associated with MSDs?

Partially. While reductions in pressure and improvements in posture suggest lowered risk, longer-term testing is required to confirm sustained impact on MSD prevention. Moreover, other relevant MSD-causing factors such as whole body vibrations are not evaluated in this study, but play a significant role in MSD.

8.2 MAIN CONTRIBUTORS

This thesis study was motivated and supported by a collaboration between the TU Delft faculty of Industrial Design Engineering and Perfect Fit Upholsteries. As part of product design and the research and development branch of Perfect Fit Upholsteries and from an ergonomics research project for the faculty of Industrial Design Engineering.

8.3 RECOMMENDATIONS FOR FUTURE WORK

To fully validate the long-term effectiveness of 3D-printed seat inserts, future research should extend testing duration and include dynamic conditions (e.g. exposure to whole-body vibrations). This could be evaluating real-world use by active truck drivers across different vehicle models and conditions. Investigate material gradation and infill optimization for improved lumbar support and postural adaptability. Explore integration with seat upholstery, air-flow channels, or embedded sensors for smart seating applications. By continuing to refine and validate these customized solutions, personalized seating may play a pivotal role in promoting health, reducing absenteeism, and enhancing long-term well-being in professional driving occupations.

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APPENDICES

Appendix A - Graduation Project Brief

Appendix B - HREC Checklist

Appendix C - Informed Consent Form

Appendix D - Device Report

Appendix E - Questionnaire 1 | Fitting Session

Appendix F - Questionnaire 2 | Pressure Mapping

Appendix G - Grasshopper Script

Appendix H - Simulated truck cabin dimensions

Personal Project Brief – IDE Master Graduation Project

Name student Boris Steenhuis **Student number** 5,057,612

PROJECTTITLE,INTRODUCTION,PROBLEMDEFINITIONand ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Improving truck driver wellbeing through custom seating solutions that reduce muscoskeletal discomfort while seated.

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

Introduction

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

Truck drivers spend extended periods - often up to 4.5 hours or longer - seated while driving, leading to physical discomfort and musculoskeletal issues. Prolonged sitting in poorly designed seats contributes to back pain, fatigue, and other health concerns, affecting their well-being and work efficiency. Addressing these ergonomic challenges is crucial for improving long-term health outcomes and job satisfaction.

Perfect Fit Upholsteries aims to expand its expertise in ergonomic seating solutions, specifically tailored to truck drivers. Their current approach effectively measures body shapes, but the challenge lies in translating these measurements into functional seating solutions that accommodate different truck seats. Additionally, the ideal solution must balance customization with adaptability to various truck models and user preferences.

By focusing on user-centered design principles, this project seeks to develop an ergonomic seating insert that enhances comfort and reduces musculoskeletal discomfort. The project will explore research-backed ergonomic strategies and engage with truck drivers to ensure the design meets their needs. The findings will also assess how improved seating can reduce absenteeism and increase driver efficiency, providing benefits to logistics companies and the trucking industry as a whole.

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

Problem Definition

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

Truck drivers frequently experience musculoskeletal discomfort due to extended periods of sitting. Many existing truck seats fail to provide adequate support, leading to pain, injuries, and increased sick leave. Logistics companies also face financial losses due to absenteeism and reduced productivity.

Perfect Fit Upholsteries aims to refine its seating solutions but faces challenges in developing an adaptable, ergonomic insert that fits different truck seats while catering to individual driver needs. The project must address this challenge by balancing customizability, ergonomic support, and ease of integration.

Assignment

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

Design, prototype, and test a custom seating insert that reduces musculoskeletal discomfort and enhances truck driver ergonomics while demonstrating potential reductions in absenteeism for logistics companies.

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

his 20-week project will follow a structured approach:
1. Conduct a literature review on musculoskeletal discomfort in seating and ergonomic solutions.
2. Facilitate initial user tests with truck drivers at Perfect Fit Upholsteries.
3. Gather insights through co-creation sessions and user testing.
4. Develop seating concepts through sketches and digital models.
5. Create prototypes using 3D printing and other fabrication techniques.
6. Test prototypes with truck drivers, refine designs, and iterate.
7. Provide final recommendations for continued development of ergonomic truck seating solutions.

Project planning and key moments

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

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

Kick off meeting	3 Feb 2025
Mid-term evaluation	31 Mar 2025
Green light meeting	26 May 2025
Graduation ceremony	2 Jul 2025

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

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

Comments:

Motivation and personal ambitions

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

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

I have always had an interest in ergonomics and user experience during previous related courses and I liked doing user tests both in design courses as in the research that Mr. Wolf was supervising. This project seems like a subject I can stay committed to for 20 weeks.

Im interested in and have experience with 3D printed prototyping. I am especially curious about the techniques used at Perfect Fit Upholsteries.

I want to see how those two things combine in practice at a (relatively new) company and experience what it is like to be and Industrial Designer in an ergonomics department.

Other projects related to Mobility or Automotive felt less meaningful: this one however directly impacts health concerns of a broad group of hard working people. Other projects in this area felt quite luxuryoriented and only for the happy few.

Appendix B - HREC Checklist

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments here

I. Applicant Information

PROJECT TITLE:	
Research period: *Overwhatperiodof time will this specific part of the researchtakeplace*	**May 2025 – June 2025**
Faculty: Department: Type of the research	**Industrial Design Engineering**
project:	
(Bachelor's, Master's,DreamTeam,PhD, PostDoc, Senior Researcher, Organisational etc.) **Funder of research:**	**Masters Thesis**
(EU, NWO, TUD, other – in which case please elaborate) **Name of Corresponding Researcher:**	**TUD**
(If different from the Responsible Researcher) **E-mail Corresponding Researcher:**	**Boris Steenhuis**
(If different from the Responsible Researcher) **Position of Corresponding Researcher:**	
(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor) **Name of Responsible Researcher:**	**Masters student**
***Note:** all student work must have a named Responsible Researcher to approve, sign and submit this application* **E-mail of Responsible Researcher:**	**Yu (Wolf) Song**
*Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials* **Position of Responsible Researcher :** *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Professor**

II. Research Overview

NOTE:** Youcanfindmoreguidance on completing this checklist **here

a) Please summarise your research very briefly (100-200 words)
What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)
I will be evaluating 3D-printed cushions by having participants' prototypes be pressure mapped. Before this, they are firs fitted and their body contours scanned in. There will be at least 16 participants and they will be recruited through personal channels like colleagues, friends and family.

b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbrevations)
-

III. Risk Assessment and Mitigation Plan

__NOTE:__ Youcanfindmoreguidanceoncompletingthis checklist here

Please complete the following table in full for all points to which your answer is “yes”. Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alighment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) – **but this is not compulsory**.

It’s worth noting that **you’re much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: • One or more collaborating research and/or commercial organisations • Either a research, or a work experience internship provider1 [1] *If yes, please include the graduation agreement in this application*	x		**Influence of partnering company might come into play to alter research in their favor.**	Data is discreetly held in a location where the company has no access, so analysis and evaluation of data can be done without bias or commercially based influence.		
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third party supplier? *If yes please provide a copy of the signed DTA/DPA*		x				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? *If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below*		x				
B: Location						

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		**x**				
5. Will the research take place in a country or countries outside the EU?		**x**				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		**x**				
C: Participants						
7. Will the study involve participants who **may** be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes,).		**x**				
8. Will the study involve participants who **may** be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		**x**				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)? *It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student's failure to participate to your satisfaction to affect your evaluation of their coursework).*		**x**				
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?		**x**				
D: Recruiting Participants						
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups	**x**		**Altough not necessarily professional channels like attendance lists, participants will most likely be recruited through my own connections. Colleagues at the company, friends and family. This might lead to slight biases.**	Iwill clearly instruct to be critical and not refrain from any harsh feedback. Especially with close friends or family members I will instruct them to please do make negative statements, for it I will only improve later iterations.		
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a		**x**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)						
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third party data-gathering service, such as a survey platform?		x				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		x				
E: Subject Matter *Research related to medical questions/health may require special attention. See also the website of the CCMO before contacting the HREC.*						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and *In Vitro Diagnostic Medical* Devices Research		x				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? *If yes see here to determine whether medical ethical approval is required*		x				
17. Will blood or tissue samples be obtained from participants? *If yes see here to determine whether medical ethical approval is required*		x				
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		x				
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) *Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.*		x				
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)		x				
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? *If yes please attach the advice/ approval from the Privacy Team to this application*		x				
22. Does your research investigate causes or areas of conflict?		x				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
If yes please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.						
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences *If so please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.*		x				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		x				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).		x				
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		x				
27. Will the experiment involve the use of devices that are not 'CE' certified? *Only, if 'yes': continue with the following questions:*		x				
• Was the device built in-house?	x		The weight of the seat combined with the weight of an adult could potentially be high enough to break certain parts of the setup. Additionally, connections between certain parts like wooden panels or beams might have slightly sharp edges.	It was not necessarily built in-house at IDE, since it was built at the internship company, with guidance and advice from the PMB staff. I specifically inquired about the seat and weight of participants for building a strong and secure base for the truck seat with a person on top of it. This is why the extra height was provided by pallets that can carry such a load with a safety margin, commonly used in transport of heavy goods. Edges that could make contact with participants were sanded down.		
• Was it inspected by a safety expert at TU Delft? *If yes, please provide a signed device report*		x				
• If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? *If yes, please provide records of the inspection*		x				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?		x				
29. Will your research involve **either:** a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants **and/or** b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		x				
G: Data Processing and Privacy						
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)		x				
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and **what other Personal Research Data** (including personal or professional views) will you be collecting?	x		Gender, age, height and some less identifiable anthropometrics are gathered for the research. These could theoretically lead to a way of identifying participants.	All of the data is stored safely in the TU Delft Onedrive and anomized.		
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants		x				
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	x		PIRD could be leaked through the open publication of the thesis.	My master thesis will end up on the repository in the end, but without appendices. That way, I could keep awaysensitive information from the public domain.		
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?	x		The research data will be shared with my thesis supervisors and further analyzed within the department at IDE. The same will happen for the company at which I am currently doing the graduation project. They could use the data in a harmful way, but that would be a.) a complex task with anonimzed data and b.) going against both the interest of the TU Delft and the company.	Once again, the data is completely anonimized and access to it is going to have to be requested specially.		

H: More on Informed Consent and Data Management

NOTE:Youcanfindguidanceandtemplatesforpreparingyour Informed Consent materials) here

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD, and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments here

IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

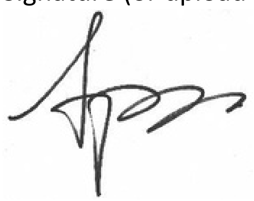
Name of Corresponding Researcher (if different from the Responsible Researcher) (print)
Boris Steenhuis

Signature of Corresponding Researcher:

Date: 19-05-2025

Name of Responsible Researcher (print)
Yu (Wolf) Song

Signature (or upload consent by mail) Responsible Researcher:



Date: 19-05-2025

V. Completing your HREC application

Pleaseuse thefollowinglisttocheckthat you have provided all relevant documentation

Required:

o **Always:** This completed HREC checklist
o **Always:** A data management plan (reviewed, where necessary, by a data-steward)

Appendix C - Informed Consent Form

Delft University of Technology
HUMAN RESEARCH ETHICS
INFORMED CONSENT TEMPLATES
(Dutch Version: January 2022)

The following templates have been developed by the Human Research Ethics Committee (HREC) to assist you in the design of your Informed Consent materials for non-medical research involving human Research Subjects. **It is important to adapt this template to the outline and requirements of your particular study, using the notes and suggestions provided.**

For additional information or specific expertise on preparing your Informed Consent materials you can consult the following:

- The TU Delft Research Ethics webpages,
- Your faculty Data Steward, the TU Delft Privacy Team
- Our brief guide on Completing the HREC checklist
- Our Risk-Planning tool, Managing Risk in Human Research

If you have any questions about applying for HREC approval which are not dealt with on the Research Ethics webpages, please contact HREC@tudelft.nl

Youcan find guidance on Informed Consent together with **English versions** of the Informed Consent templates in the Informed Consent section of the Research Ethics webpages.

Inleiding
U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd: *"Improving truck driver well-being through custom seating solutions that reduce muscoskeletal discomfort while seated"* . Dit onderzoek wordt uitgevoerd door Boris Steenhuis van de TU Delft en Perfect Fit Upholsteries. Het doel van dit onderzoek is het ontwikkelen van een zitting in een auto stoel, ter vermindering van klachten voor mensen die veel achter het stuur zittenen zal ongeveer 30 minuten in beslag nemen. De data zal gebruikt worden voor het evalueren van het product en educatieve doeleinden. U wordt gevraagd om een vragenlijst in te vullen en tweemaal te gaan zitten en uw comfort door te geven. Zoals bij elke digitale activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door de data op te slaan binnen de beveiligde omgeving van de TU Delft en de resultaten hiervan te anonimiseren, zodat u niet valt te identificeren aan de hand van de data. Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden. De data van dit onderzoek wordt opgeslagen binnen de faculteit en kan worden gebruikt voor publicatie op later moment.

:

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gedateerd 05/04/2025 gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	◻	◻
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	◻	◻
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent:	◻	◻
• *Er worden persoonlijke gegevens verzameld door middel van een vragenlijst, ingevuld door u als participant.* • *U wordt opgemeten op verschillende parameters van uw lichaam en gewogen.* • *Er wordt een 3D-scan gemaakt van een mal die gevormd is naar uw lichaamscontouren.* • *Er worden drukmetingen gedaan waarbij wordt vastgelegd hoe uw zitvlak de druk verdeeld.*		
5. Ik begrijp dat de studie 03/06/2025 eindigt.	◻	◻
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt: tijdelijk minimaal fysiek ongemak bij de fitting naar uw lichaamscontouren en het opmeten van antropometrische data. Ik begrijp dat deze risico's worden geminimaliseerd door discreet en zorgvuldig handelen van de onderzoeker.	◻	◻
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden.	◻	◻
8. Ik begrijp dat binnen de Algemene verordering gegevensbescherming (AVG) een deel van deze persoonlijk identificeerbare onderzoeksdata als gevoelig wordt beschouwd. *Lijstvangevoelige onderzoeksdata:*	◻	◻
• *Leeftijd* • *Gewicht* • *Geslacht* • *Lichaamsmaten*		
9. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk […]	◻	◻
Providebrief summaries of the mitigating measuresto betaken (eg:anonymousdatacollection, (pseudo-)anonymisationor aggregation, secure data storage/limited access, transcription, blurring, voice modification etc) • *Participanten en hun bijbehorende datapunten worden grotendeels geanonimiseerd.* • *Data-opslag en de toegang daartoe wordt gelimiteerd tot de onderzoeker en enkele directe collega's .* • *Deverzamelde data wordt opgeslagenin debeveiligde omgevingvan de TU DelftOneDrive.*		
10. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals [*naam, leeftijd en geslacht*], niet gedeeld worden buiten het studieteam.	◻	◻

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor het vergelijken en in kaart brengen van de effectiviteit van een product en eventuele latere publicaties over 3D-geprinte zittingen.	☐	☐
• *Er zullen geen foto'sworden gemaakt vande participanten.* • *Er zullen enkel visualisaties van de verworven data in het verslag van de onderzoeker terecht komen.* • *Eventuele latere onderzoekspublicaties door verwante onderzoekers van de TU Delft zijn verbonden aan dezelfde grenzen als de initiële onderzoeker.* • *Het bedrijf (Perfect Fit Upholsteries) waar deze experimenten uit worden gevoerd, kan deze data alleen geanonimiseerd verkrijgen en enkel gebruiken voorhetitereren ophetuiteindelijkeproduct.*		
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
16. Ik geef toestemming om de geanonimiseerde data van de drukverdeling van het zitoppervlakte die over mij verzameld worden gearchiveerd worden in de TU Delft OneDrive omgeving, opdat deze gebruikt kunnen worden voor toekomstig onderzoek en onderwijs.	☐	☐
17. Ik begrijp dat de toegang tot deze repository beperkt blijft tot de afdeling "Human Ergonomics" aan de faculteit Industrieel Ontwerpen.	☐	☐

Handtekening

__________________________ __________________________ ________

Naam van participant Handtekening Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Boris Steenhuis

Naam onderzoeker Handtekening Datum

Contactgegevens van de onderzoeker voor verdere informatie:
Boris Steenhuis
06-816 186 48
btsteenhuis@tudelft.nl

Delft University of Technology
INSPECTION REPORT FOR DEVICES TO BE USED IN CONNECTION WITH HUMAN SUBJECT RESEARCH

This report should be completed for every experimental device that is to be used in interaction with humans and that is not CE certified or used in a setting where the CE certification no longer applies1.

The first part of the report has to be completed by the researcher and/or a responsible technician.
Then, the safety officer (Heath, Security and Environment advisor) of the faculty responsible for the device has to inspect the device and fill in the second part of this form. An actual list of safety-officers is provided on this webpage. Note that in addition to this, all experiments that involve human subjects have to be approved by the Human Research Ethics Committee of TU Delft. Information on ethics topics, including the application process, is provided on the HREC website.

Device identification (name, location):

- Truck cabin buck (simulation of a truck cabin)
  - o Located at thesis company in Katwijk

Configurations inspected2:

- Standard configuration, with either pressure mat or vacuum bags placed on seating area.

Type of experiment to be carried out on the device:3

- Fittings of body shape with vacuum bags
- Pressure mapping of buttocks, legs and lower back with and without 3D-printed seat insert.

Name(s) of applicants(s):

Boris Steenhuis & Wolf Song

Job title(s) of applicants(s):

(Please note that the inspection report should be filled in by a TU Delft employee. In case of a BSc/MSc thesis project, the responsible supervisor has to fill in and sign the inspection report.)

1 Modified, altered, usedforapurpose not reasonably foreseen in the CE certification

2 If the devices can be usedinmultiple configurations, otherwise insert NA

3 e.g. driving, flying, VR navigation, physical exercise, ...

Date: 07-05-2025

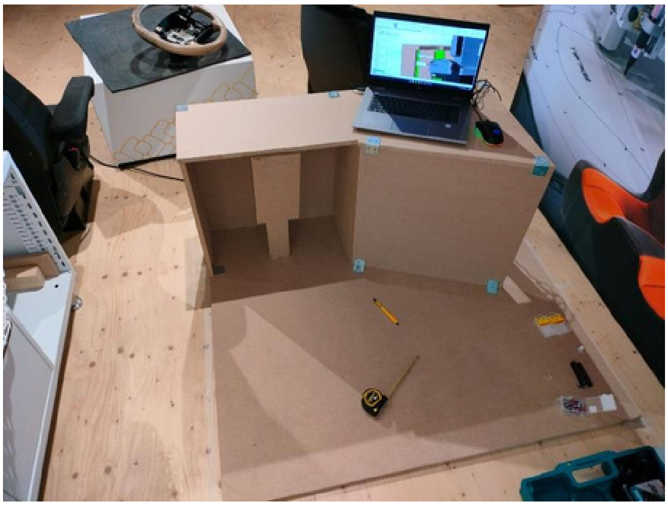
Signature(s):

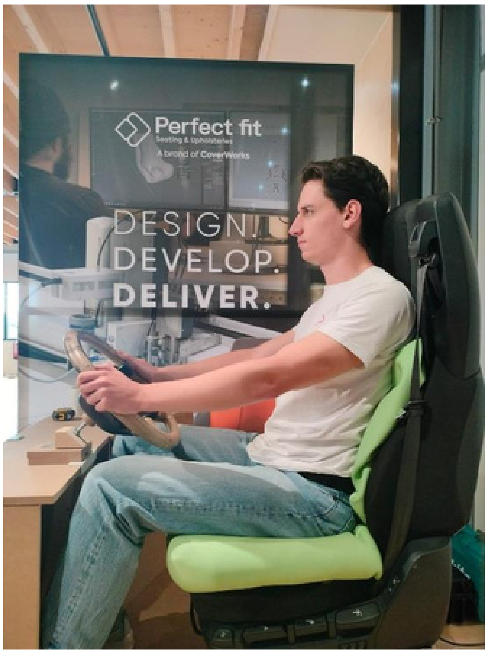
Setup summary

Please provide a brief description of the experimental device (functions and components) and the setup in which context it supposed to be used. Please document with pictures where necessary.

More elaborate descriptions should be added as an appendix (see below).



This is the truck cabin/buck under construction and in nearly completed state. The steering wheel has had all of its components scrapped and the rest of the setup is MDF wood sanded down onsharp edges. The seat has been tightly fastened down to the baseplate with wood beams, as to keepit down and not fall or tip over.


Perfect fit
Seating & Upholsteries
A brand of CoverWorks
DESIGN.
DEVELOP.
DELIVER.

DEVELOP.
DELIVER.

Risk checklist

Please fill in the following checklist and consider these hazards that are typically present in many research setups. If a hazard is present, please describe how it is dealt with.

Also, mention any other hazards that are present.

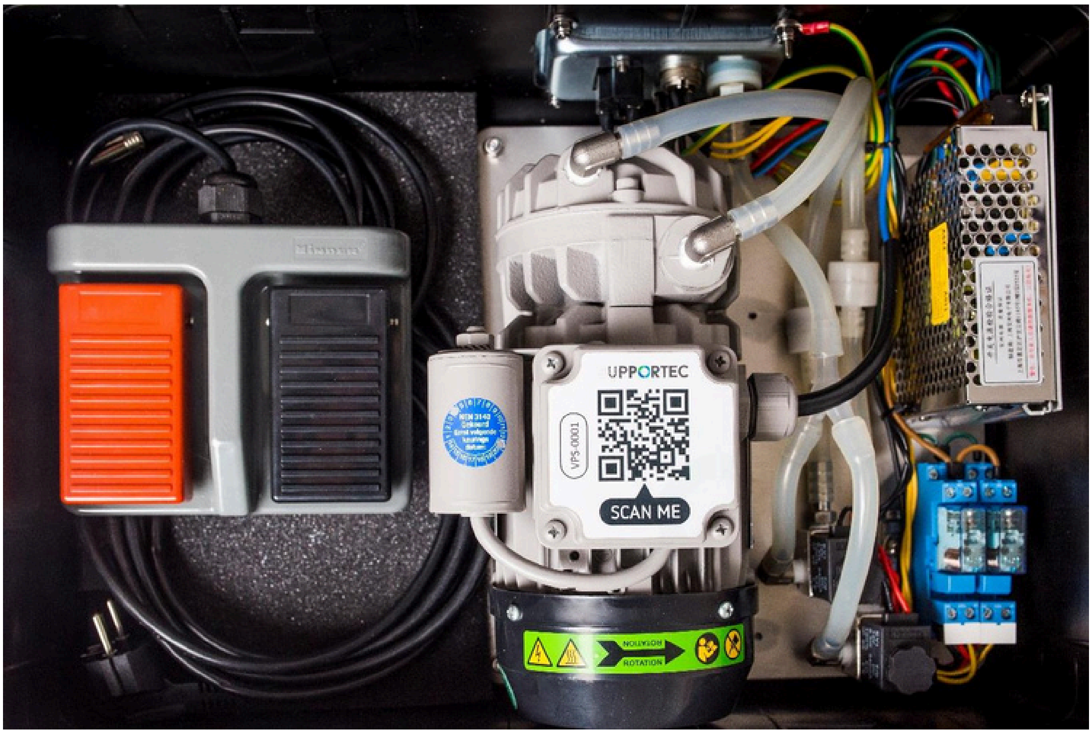
Hazard type	Present	Hazard source	Mitigation measures
Mechanical (sharp edges, moving equipment, etc.)	Yes	The truck seat used in the testing setup is adjustable and can therefore move accordingly. The seat is installed and secured appropriately, but sudden movement of a chair could hurt a participant.	Participants will be told to not touch these buttons before being seated. Only when they are seated properly will they be instructed to adjust the seat as they would in their own car. Their body weight on the chair is more than sufficient to keep adjustments controlled and safe.
Electrical	Yes	Improper management of power cables can lead to overheating, tripping and/or short circuiting.	The standard cable provided with the compressor kit is used and connected to a group that is grounded and used only for other lights in the building. Additionally, the cable is then neatly tucked away alongside the wall during testing, to negate any tripping hazards.
Structural failure	No	Not relevant.	-
Temperature	Yes	The compressor used for the in/deflating of the vacuum bags can become warm or hot when used. If this is not monitored, prevented or negated, it could pose a risk.	The cooling vents and internal fan are in use for thermal management. Additionally, the compressor is only on for a maximum of one minute at a time, with around 10 minutes cooldown before the next use. As is standard with a rotary vane -
Electromagnetic radiation	No	Not relevant.	
Ionizing radiation	No	Not relevant.	-
(Near-)optical radiation (lasers, IR-, UV-, bright visible light sources)	No	Not relevant.	-
Noise exposure	No	Not relevant.	-
Materials (flammability, offgassing, etc.)	Yes	Working with bags that alternate between being pulled to near vacuum and inflated state. This could become safe if equipment is faulty or the limit of the bags/compressor are reached.	A Vacuum relief valve is in place to prevent over-vacuum or sealing under continuous vacuum. Silicone tubes are used that can take pressures from 1 bar down to -1 bar. (Rotary vane pumps typically vacuums to around -0.8 bar and may

			pressurize air to 0.3 bar used for inflation.) These tubes are fastened with quick connect clamps, to make sure they stay in place. - - The researcher has
Chemical processes	No	Not relevant. Not relevant.	trained to perform these fittings
Fall risk	No	Vacuum bags will be used to	and keeps in touch with the
Other: Vaccuum bags	Yes	gather the lower body contours of participants. These can become stiff and hard, but not sharp. This might lead to momentary minimal discomfort.	fitting bag during this process, to see when the bags are hard enough. Additionally, the participants is told beforehand to let the researcher know when they feel uncomfortable enough to stop.

Appendices

Here, you may add one or more appendices describing more detailed aspects of your setup or the research procedures.

The vacuum bags and the environment in which I have learned to work with them. This configuration will be copied to the testing environment. With the compressor and foot pedals moved away and the electric connection being stored safely away from the participant.



An instance of the Supportec rotary-vane vacuum pump system and McLean Rehatechnik latex-free vacuum bags will be used, both designed and rated for safe operation within the following limits:
–Vacuum ≈ -0.8 bar (200 mbar abs), over-pressure <0.3 bar during inflation.
–The pump includes built-in safety valves and cooling features.
–All pressure-rated components are compatible and certified for these pressures.
–Tubing is medical-grade PVC or silicone, rated ≥ -0.8 bar, and secured with quick connect
–Power supply is via a grounded EU outlet with FI protection; cables undergo pre-use checks.

Device inspection

(to be filled in by the AMA advisor of the corresponding faculty)

Name: Peter Kohne

Faculty: IO

The device and its surroundings described above have been inspected. During this inspection I could not detect any extraordinary risks.

(Briefly describe what components have been inspected and to what extent (i.e. visually, mechanical testing, measurements for electrical safety etc.)

Date: 10-06-2025

Signature:

Inspection valid until[4]:

Note: changes to the device or set-up, or use of the device for an experiment type that it was not inspected for require a renewed inspection

4 Indicate validity of the inspection, with a maximum of 3 years

1. Questionnaire | Fitting Session

Thefirstquestionnairethatshouldbe filled in to gather anthropometric data correspondingtothe participantnumber.It is bestto do thisat thefitting, since that procedure is shorter than the pressure mapping and short term comfort evaluation.

---

1. Participant Number*

2. Age*

3. Sex*

4. Weight *

5. Stature *

6. Seated Height *

7. Hip Width*

8. Buttock-Knee Depth*

9. Ground to Knee*

10. Buttock-Inner Knee Depth*

11. Is the participant driver by occupation?*

12. Any history of musculoskeletal disorders? If yes, what kind?*

2. Questionnaire | Pressure Mapping

The first questionnaire that should be filled in to gather anthropometric data corresponding to the participant number. It is best to do this at the fitting, since that procedure is shorter than the pressure mapping and short term comfort evaluation.

1. Participant Number*

____

Comfort Rating Seat

The participant is seated in the driver seat of a truck and rates the comfort levels of different areas.

2. How does the area under your knees feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

3. How does the area under your thigs feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

4. How does the area under your buttocks feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

5. How does your lower back feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

6. How does the area around your back and shoulders feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

7. How does your neck feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

Comfort Rating Insert

The participant is seated in the 3D-printed insert on the driver seat and rates the comfort levels of different areas.

8. How does the area under your knees feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

9. How does the area under your thigs feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

10. How does the area under your buttocks feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

11. How does your lower back feel?*

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

12. How does the area around your back and shoulders feel?*

Markeer slechts één ovaal.

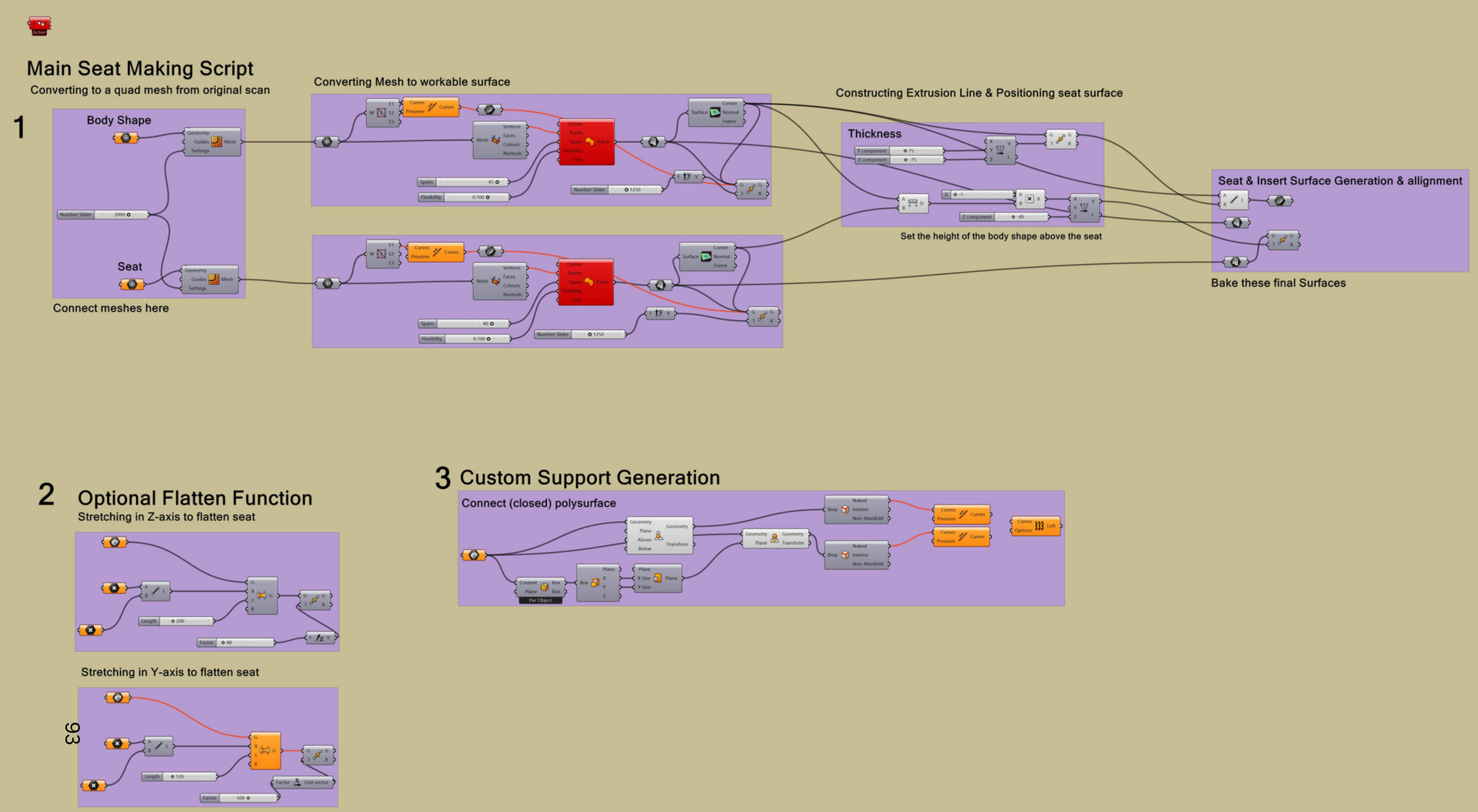
	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

13. How does your neck feel?*

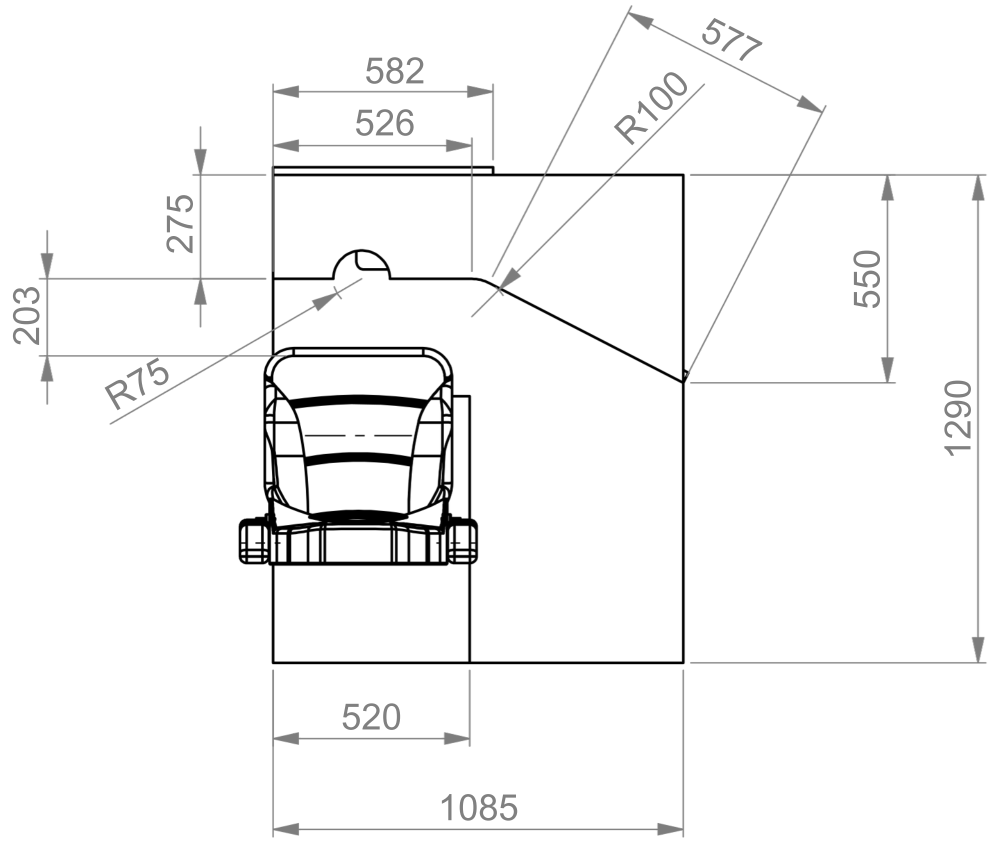
Markeer slechts één ovaal.

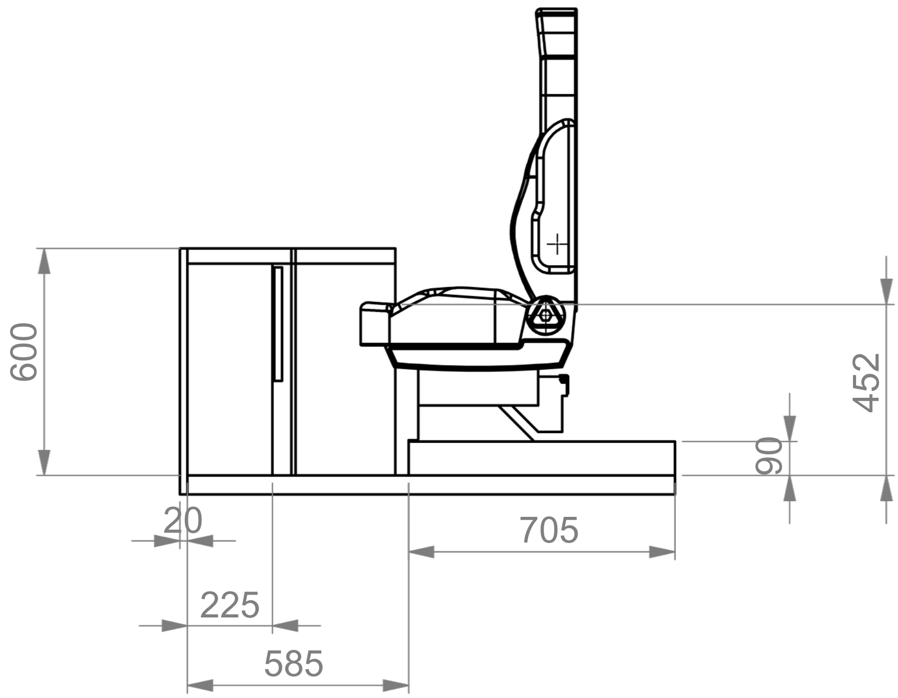
	1	2	3	4	5	6	7	
Very Comfortable	◯	◯	◯	◯	◯	◯	◯	Very Uncomfortable

Appendix G - Grasshopper Script



Appendix H - Simulated truck cabin dimensions





units mm | scale 1:20 | quantity <<nr>> | date 21-5-2025 | remark <<remarks>>

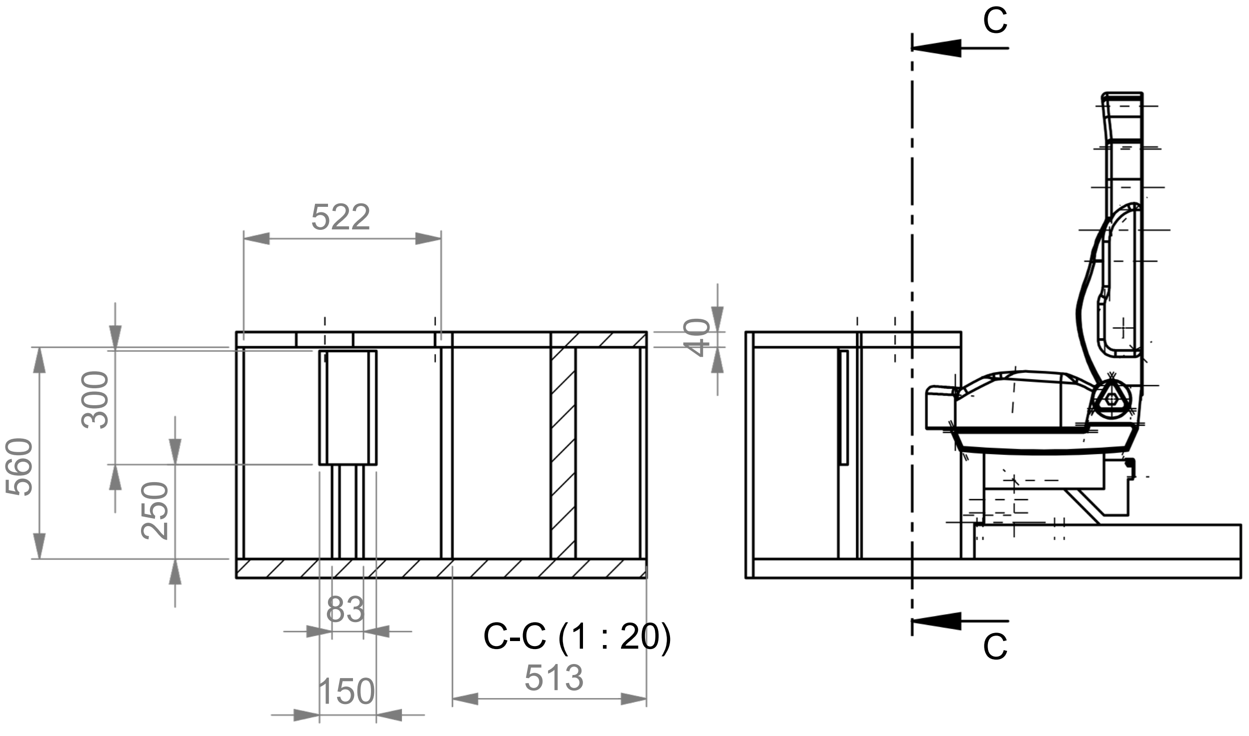
material | mass gr

author Boris Steenhuis | group

Delft University of Technology

name **Dimension Drawing Setupformat** | A4 | drawing no. 94 <<drawing no.>>

C:\Users\boris\Desktop\Thesis\Test Set-up\



	units mm	scale 1:20	quantity <<nr>>	date 21-5-2025	remark <<remarks>>
material				mass gr	
author Boris Steenhuis				group	TU Delft Delft University of Technology

name **Dimension Drawing Setup** format A4

drawing no. <<drawing no.>>

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