Embracing Empowerment

Empathy-Centred Design for Patella Alta: Adaptive and Functional Garment Design Solutions

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An exegesis presented in partial fulfilment of the requirements for the degree of Master of Design, at Massey University, College of Creative Arts, Wellington, New Zealand.
Claire Johnson, 2026.

Abstract Fig: Author’s work. Final fitted trouser/ leggings prototype. 2025.

Abstract

Patella alta is an uncommon congenital condition where the kneecap sits too high, displaced above the femur. This causes pain and discomfort for people living with the condition, the physical impacts of patella alta are underpinned by adverse emotional consequences. This is in part due to the limitations of current wearable knee brace treatment options. Current knee braces extend the impact of the condition to all aspects of a person's daily life, including clothing choice and ease of dressing. In this practice-led research, empathic design approaches are used to create garments to support those who experience patella alta and need to use medical knee braces. Research has been completed using a mixed method approach with an empathy-centred methodology including expert consultation, user feedback, iterative material exploration, garment sampling and prototyping. This design research has resulted in a series of material and garment samples and fashion design prototypes. The resulting prototypes including innovative 3D printing on fabric are able to be created for individual needs for the condition and fit variance. This research also facilitates new perspectives for fashion design generation and industry to contribute meaningfully to those with health challenges through empathic design.

Key Words: Adaptive/Functional Garment Design, Patella Alta, Empathy-Centred Design, Material Innovation

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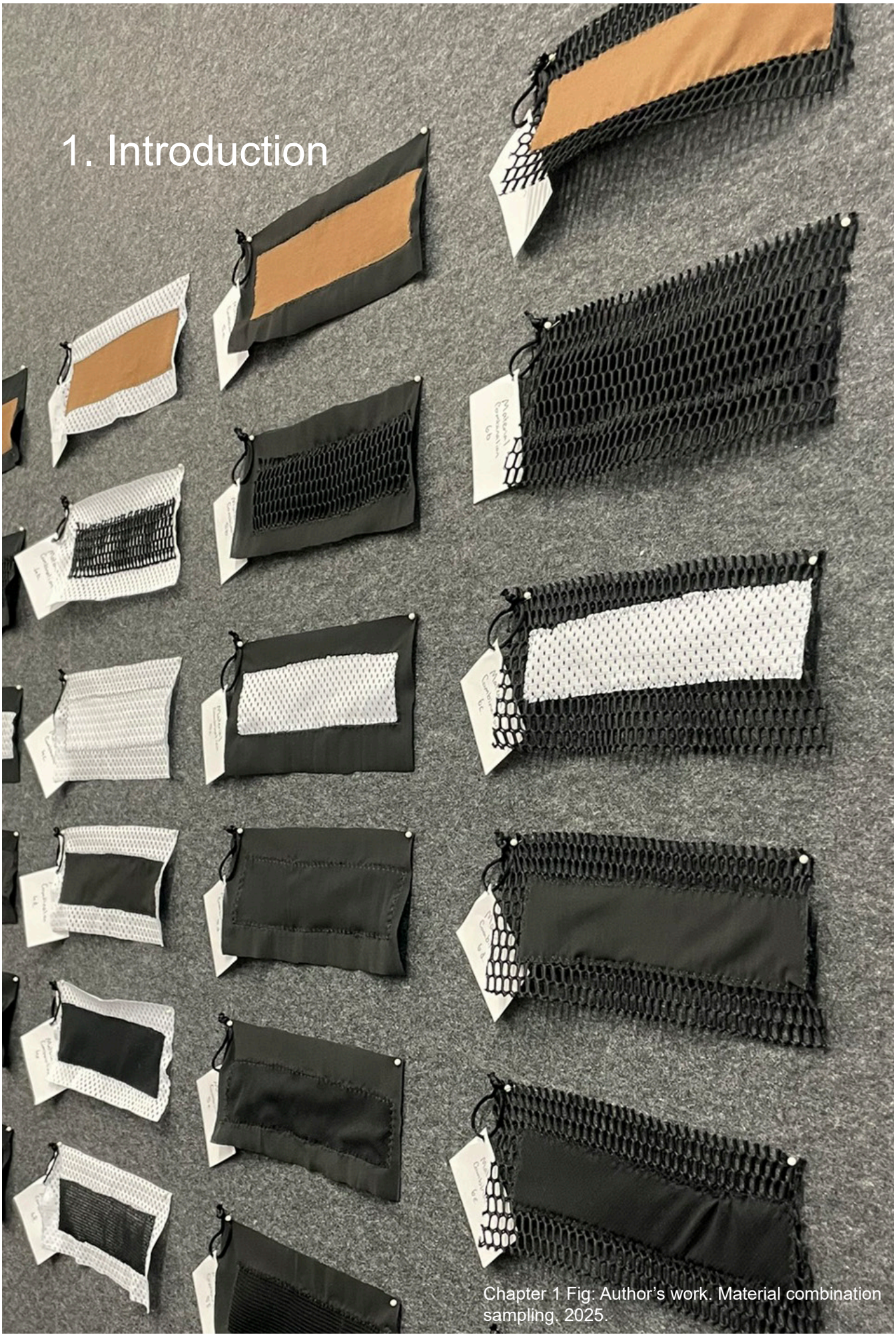
1. Introduction



Chapter 1 Fig: Author's work. Material combination sampling. 2025.

The first introduction I had to designing for patella alta was in my honours year of my fashion design degree. I knew I wanted to create a collection encompassing adaptive and functional design triggered by my personal experiences of having a medical condition and love for fashion which didn't accommodate my everyday health needs. The feelings of not being able to dress as you choose, express your identity, and not being considered by the fashion industry are shared by many others with health issues. This project is not derived from my own condition, but for those with the congenital condition patella alta. The outcome of my honours project 'Enabled 2.0.' was a collection of tailored garments that had integrated braces which were suitable to be worn for a professional career. After completing this project, I decided to further explore the area of adaptive design through a Master of Design research project. My honours project did not include an empathy-centred design process, a thorough exploration of materials, nor did it have a balanced combination of aesthetics and function. It did however consider brace visibility and user empowerment, along with accessibility in terms of dress. For this project there was an opportunity to explore functional and adaptive fashion design solutions for patella alta through user-centered design.

Patella alta is often treated with knee braces which externally supports, prevents dislocations, and guides the patella back toward the correct placement. Braces are known to be very successful as a treatment and prevention method, although they often have limitations with aesthetics and wearability. They are easily seen while being worn and cause functional issues when dressing which can cause negative emotions due to perceptions of others and discomfort. Many adaptive garments exist to accommodate health conditions, however they are aimed at concealing medical devices and have a large focus on function and lack in aesthetics and form.

The research process explores areas of human-centred design, user-centred design, holistic approaches to fashion, adaptive and functional fashion design, and material innovation for health. My research questions to explore these areas are:

- What is patella alta, how does it progress, and what is used to treat it?
- What are the limitations of current adaptive and functional garment design solutions?
- How can garment design solutions be both functional and aesthetically pleasing?

This research has been completed through the use of a mixed-method approach with an empathy-centred design methodology, including but not limited to; designer-oriented user research, medical expert consultancy, experimental and iterative design, and workshops and design feedback with users. While completing this project I followed Lamb and Kallal's Functional, Expressive, Aesthetic (FEA) framework (Lamb and Kallal 42). The framework was used to inform, allocate, and apply empathic garment design principles, which helped me understand the needs and wants of the user group.

In the following exegesis I look into the connection between patella alta and issues with dress, followed by holistic fashion approaches and real life examples, and then the innovation of materials. I then explore the connection between user-centred design and the Functional, Expressive, Aesthetic framework, followed by how I have used these topics to produce outcomes which empower users and celebrate and integrate the medical devices used for patella alta. This research has been completed using patella alta as a vehicle for design to show how user-centred design and using an empathic approach can improve the well-being of those who may need to use knee braces, and can contribute to idea generation and processes for adaptive design in the fashion industry.

The research within this exegesis has been approved under Massey University's low risk ethics guidelines, *see low risk ethics notification in appendix*.

2. Context Review

Chapter 2 Fig: Author's work. Close up of final outcome panelling. 2025.

2.1 Patella Alta - The Condition, Treatments, and Issues

Patella alta is a congenital condition of the knee where the patella (kneecap) is abnormally high in position in relation to the femur, tibia, and trochlear groove (Biedert 65). The abnormal position of the patella increases the chance of exercise-related dislocations, chronic pain, and progression to other conditions such as patellofemoral instability and osteoarthritis.

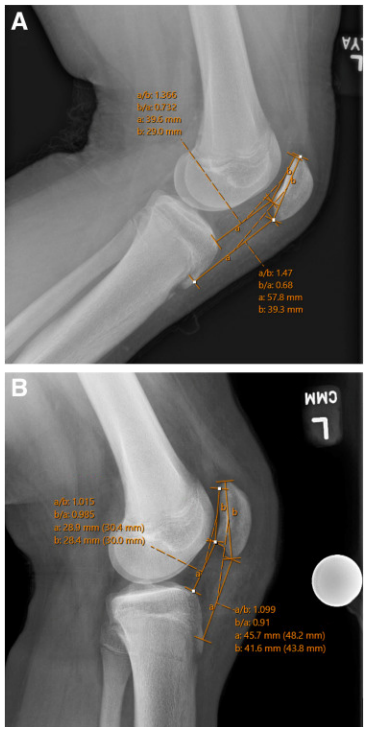


Fig. 1. Harris. S. Sloane, et al. (A) Lateral radiograph portraying patella alta, (B) Lateral radiograph portraying improved patella alta after surgery. 2024.

Although the condition is congenital, meaning the person is born with it, patella alta is not often diagnosed until later in life. Patients are usually diagnosed because of an injury from sport or another kind of high impact exercise and can range in age from young children to mature adults. These injuries mostly occur because of how mobile the patella is sideways which makes it more prone to dislocations and can be both extremely painful and cause further damage (London Sports Orthopaedics). There are three ways that the condition can be diagnosed following the initial dislocation/s: a physical exam, x-ray, and an MRI (Magnetic Resonance Imaging). During a physical exam the main symptom that medical professionals visually look for are “knobbly knees”. In patella alta, “knobbly knees” look like the patella is sitting right on top and slightly to the side of the knee while the patient is lying down with their knees bent at 90 degrees (London Sports Orthopaedics). After the physical exam, an x-ray is completed to see the patella placement and to measure the height difference. There are a range of methods that can be used to measure height; the Insall-Salvati ratio measures the height of the patella

based on the ratio of the length of the patella tendon and the length of the patella itself (Kurowecki et al. 528); the Caton-Deschamps index is used by equaling the distance between the corner of the tibial surface and the articular cartilage of the patella which is divided by the length of the articular cartilaginous surface (Johnson et al. 3); the Bernageau index measures the amount of overlap between the surfaces of the patella and the trochlear groove (London Sports Orthopaedics). An MRI can also be used with the same methods if the x-ray measurements aren't clear and more information is needed.

Initial treatment for the condition comes in the form of external stabilisation, where the patella is both supported and externally guided back into the correct placement. This stabilisation is often achieved by taping with kinesthesiology tape and/or the use of knee braces, the most common treatment. Physiotherapy is also sometimes used alongside external stabilisation as an extra tool to prevent further injury and progression (Holtzman and Harris-Hayes 73). In the case that external stabilisation is not successful, surgery will be considered in the hopes of preventing more damage or pain and to prevent the condition developing any future complications (Biedert 68).

Fig. 2. Back On Track NZ. Patella Stabilising Knee Brace, made from perforated rubber for firmness and stability, flexible side stabilising bars, patella protector, and light fabric in the knee crease. 2025.

Fig. 3. Back On Track NZ. Knee Brace X-Stretch, made from a lightweight four way stretch compressive fabric with added elastic over the patella and a silicone band on the inside to prevent sliding. 2025.

Knee braces that are used in treating patella alta often share similar features. Known as stabilising braces, each brace tends to have common design features: a knee protector which surrounds the patella, metal or plastic boning that sits on the outside and inside of the knee for rigid support, velcro strap closures either elastic or woven, fabric compression, and breathable fabric. Compression sleeves, wrapped, and hinged knee braces include some or all of these components and are the most common form of braces used to treat the condition and prevent future complications (London Sports Orthopaedics). While braces are known to be extremely successful as a treatment and prevention method, they often have aesthetic limitations and issues. They can be bulky while worn and easily seen through or on top of clothing which can cause negative emotions for the wearer, as "a viewer's perception of another person's body is affected by the clothing worn" (MacDonald 222). Along with visibility, there are also issues with

functionality when it comes to dressing with braces. Issues with dressing include: not being able to readjust braces easily or discretely, difficulty with putting on or taking off garments and braces (Squyer et al.), fabric getting caught on the braces causing damage to garments (Frescura 74), and garments becoming tighter because of the bulk from the braces creating movement difficulties and causing discomfort (Squyer et al.).

The issues surrounding aesthetics and wearability arise from the lack of consideration in the fashion industry for those with disabilities, undoubtedly disrupting daily life for those affected. Issues like these could be solved in the mainstream industry if more designers look toward what my project is encompassing; using human-centred or user-centred design processes.

2.2 Human-Centred Design and Holistic Approaches to Fashion Design

Human-centred design and holistic approaches are necessary to ensure accessibility and inclusivity within design systems. Human-centred design is based on the use of methods that communicate, interact, and empathise with, as well as stimulate people involved, to understand their “needs, desires, and experiences” (Giacomin 610). In a human-centred design process, the questions, iterations, and activities that are carried out are aligned to the user for whom the final outcome is intended (Giacomin 610). The alignment of this process creates a holistic approach to design, leading “to products, systems, and services which are physically, perceptually, cognitively, and emotionally intuitive” (Giacomin 610). Intuitive outcomes may be informed by a series of questions and answers, such as those based on categories shown in the human-centred design pyramid below.

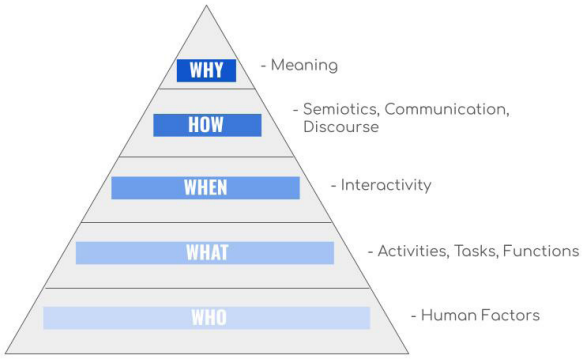


Fig. 4. Adapted from J.Giacomin, The Human-Centred Design Pyramid, 2025, Journal Article.

The pyramid categories are based on a hierarchy that considers human characteristics, social contexts, and their modes of interactions (Giacomin 612). It indicates what topics should be covered when researching, with the base being the widest and most simple portion of information while the top is the narrowest but more complex. The further up the pyramid designers explore, the more likely they are to create outcomes that create new meanings into someone’s life (Giacomin 613). To gather data based on these categories, designers can use a range of tools and models to capture user needs, desires, and meanings, and to simulate possibilities (Giacomin 616). Data and models gathered can cover a range of human data sets, including anthropometric, emotional, and sociological data. Verbal and non-verbal data may be collected to capture needs, desires, and meanings. Verbally based data can be gathered with the use of ethnographic interviews, questionnaires, and personas, whereas non-verbally based data can be gathered by game playing, visual journals, and fly-on-wall observation (Giacomin 616). Simulating future possibilities can be completed by carrying out focus groups, role playing, and following a co-design process (Giacomin 616). By using these design tools and the design pyramid, designers can focus their work on users and improve their quality of life, especially in relation to health and fashion.

Fig. 5. iF Design - Probe Dresses. Philips emotion sensing dress. 2007.

Due to increased awareness of how personal health is impacted through interactions between body, apparel, and the environment (Tillotson 44), more clothing is being created for wellbeing, including mergings of fashion and medical products and new textile hybrids. In ‘Scentsory Design: A “Holistic” Approach to Fashion as a Vehicle to Deliver Emotional Well-Being,’ Jenny Tillotson discusses multiple examples of apparel and textiles created for well-being through a holistic lens. Examples include an emotion sensing dress, light emitting bedding, and jewelery that dispenses scents (Tillotson 44-45). The emotion sensing dress creates light by responding to emotional triggers relating to affection and sensuality (Tillotson 44). In exploring design from a human-centred perspective by researching human characteristics, communication, and interactions, the designers were able to create a dress that monitors changes based on emotions and portrays that through light and colour. The light emitting bedding uses electroluminescent technology to work as a personalised alarm when people are feeling down to improve moods for those with bipolar or seasonal affective disorder (Tillotson 44-45). Again through a human-centred and empathic design approach, the designer has created an outcome which helps to improve the quality of life for those it was designed for. As shown in the given examples, increased consumer demand has led to more fashion designers following holistic design approaches to create garments which mainly contribute to social sustainability, although some others also touch on environmental and economic sustainability (Payne 134-136).

Compared to human-centred design, which focuses on exploring problems and allowing users to shape their own processes and solutions (Gasson 31, 34), user-centred design focuses on well defined problems and solutions and the usability and user interactions of what is being created (Gasson 31, 34). User-centred design works best when combining philosophy and methodology. Ideas of empathy, inclusion, and solutions drive the process to create a tangible form (Still and Crane 43-44). Brian Still and Kate Crane in 'Fundamentals of User-Centered Design: A Practical Approach,' discuss a range of ten principles that they have created to ensure the necessary steps are taken to meet user needs and wants. These principles are: early user involvement, frequent user involvement, design for context, simple design, politeness, knowing users, giving users control, "remember and design for emotion, trust but verify, and discover before designing and delivering but knowing that discovery never ends even after delivery" (Still and Crane 44). There are many ways that an user-centred design process could be carried out while following these principles, however the authors recommend using the RABBIT approach.

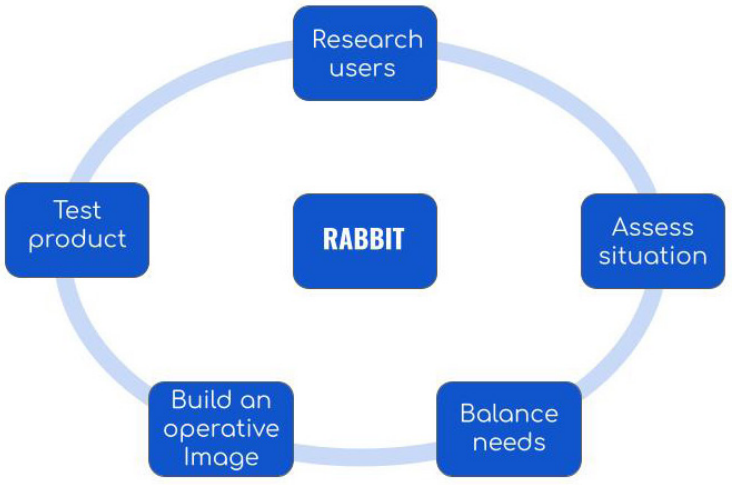


Fig. 6. Adapted from B.Still, and K.Crane, User-Centred Design RABBIT approach diagram, 2025, Journal Article.

"RABBIT is an acronym for:

- Research users
- Assess the environment, goals, requirements, and competition
- Balance user needs and affordances with your design aesthetic and demands
- Build an operative,
- Image for users to interact with
- Test the image with users to gather feedback" (Still and Crane 62).

By using RABBIT, designers have the potential to implement user needs and wants along with their own aesthetics and goals to create adequate design solutions.

Another more holistic design process is referred to as the FEA model comprising Functional, Expressive, and Aesthetic considerations (Lamb and Kallal 42). A similar but slightly different approach to RABBIT, the FEA model uses a specific organisational method of clothing information mixed with satisfaction levels of a target consumer group to create garments that are culturally and situationally appropriate (Chan et al. 31).

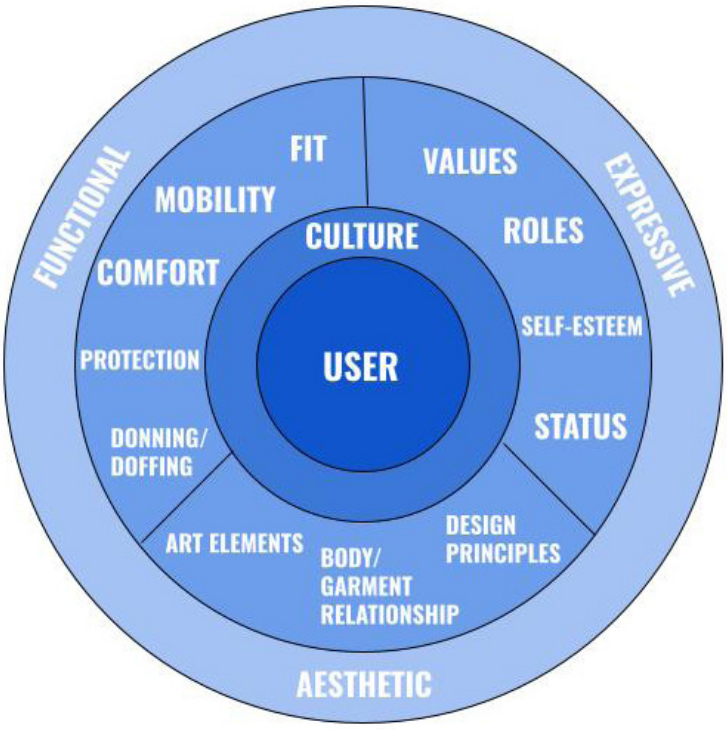


Fig. 7. Adapted from J.M.Lamb and M.Jo.Kallal, The Functional, Expressive, and Aesthetic model, 2025, Journal Article.

Holistic approaches, such as the FEA model, include users early on in the design stage and continually involve them throughout the process (Chan et al. 32). As a result, there are a number of advantages when using holistic approaches for garment design considering those with medical issues or disabilities. Increased comfort, user movement, functionality, psychological well-being, safety, and individuality for users are the most evident (Das 3-7). My project will intend to use the FEA model as an empathy-centred design methodology due to these advantages. Using a holistic approach allows for users to be considered in mainstream fashion and increases the variety of adaptive and functional garments on the market.

2.3 Adaptive and Functional Design in the Fashion Industry

Adaptive and functional are similar terms that are often used interchangeably in the area of design, yet both have different meanings. The term adaptive design can be defined as design solutions that offer those with physical and cognitive limitations a greater level of independence (Chan et al. 27), while the term functional can be defined as “a central component of design, involving not only the technical and practical performance of a product but also aspects of aesthetics, communication, politics, and economy amongst others” (Erlhoff and Marshall 175). There is a fine line of difference between the two; while adaptive design is for projects with specific disabilities and needs in mind, functional design is for all users, regardless of their ability (McBee-Black and Ha-Brookshire 169). In the fashion industry, examples of adaptive design may be having a raglan sleeve armhole to allow for more shoulder movement, easier closures like snaps instead of buttons, added panelling for movement (‘Tommy Adaptive’). Functional design examples include the use of padding in protective wear, adequate pockets for storage, moisture wicking fabric for high performance athletes, and more.

Fig. 8. Cat & JackTM by Target. Toddler Boys’ Adaptive Seated Fit Straight Leg Pull-On Woven Pants, snaps on legs for ease of access. 2025.

The use of both adaptive and functional design in the fashion industry is important to consumers as it allows for specific needs to be met while also ensuring the garments can be used by all. Careful consideration must be taken however, as if not correctly researched and designed there is potential for garments and designers to fall back into the traditional mass-produced fashion system which often does not work for users with specific needs. In the current market this is an issue because the development of the fashion industry has lessened the industry’s ability to not only fit but also to design for individuality in terms of bodily needs (Annett-Hitchcock 148). The system causes many issues which could be solved with adaptive and functional design processes. For example, Kate Carroll, in ‘Disability, Its Effect on the Body, and the Clothing Perspective,’

discusses an arthritis study where patients had common movement problems in the hands, knees, shoulders, and wrists. From a sample of 787 arthritis patients, it was found that clothing increased issues with fatigue, pain, and weakness due to the lack of comfort, design unsuitability, and improper fit (Carroll). Participants described most ready-to-wear garments as having features that are problematic and suggestions were given to improve them including: different fabrics, additional fabric for ease of movement, larger openings, better fastener placements, and improved pocket design and placement (Carroll). Simple changes such as the ones suggested by the study participants are vital to creating both adaptive and functional garments as they ensure users with specific needs are included as a consumer for the market.

Fig. 9. Cat & JackTM by Target. Toddler Girls' Hooded Puffer Jacket. 2025.

In 'Garment+: Challenging the boundaries of fashion for those with long-term physical disabilities,' Chan et al. investigated long-term musculoskeletal conditions and how clothing can be made more user-friendly for those that have them. Participants of the project were presented with garment prototypes and samples and were then invited to use them and share feedback with the researchers (Chan et al. 33). During the initial feedback process, participants identified issues with accessibility, quality of fabric, and the inability to dress with ease with mainstream fashion (Chan et al. 34). Further discussions led to conclusions about garment features that participants tend to look for including: generous necklines, leg, and armholes for access, generous stretch, and natural, breathable, lightweight, moisture-wicking, and soft fabrics for maintaining skin temperature and ease of movement (Chan et al. 34-36).

Feedback was also given for donning and doffing garments in relation to openings with fastenings. While there were a large range of samples given to participants, most comments mentioned velcro was one of the worst fastenings to use because it sticks to everything and that it was more of “a matter of the size and positioning of the fastening that impeded their ability to manipulate closures” rather than the type of fastening (Chan et al. 36-37). The participants found that some fastenings were worse than others but did not note any particular ones as the right option.

As a way to cover a range of abilities and needs in their adaptive lines, fashion brands include multiple garments with differing fastenings, openings, fabrics, and more. Below are a range of examples of garment features used in adaptive fashion design:

Ease of dressing/use of openings:
Target’s adaptive range has features such as hidden abdominal openings and easy access bodysuits (Annett-Hitchcock 151). While in Garment+ the new designs include entry from the bottom up, side openings, and a flip over mechanism (Chan et al.38).

Comfort:
Target’s adaptive range has garments with no tags and seams (Annett-Hitchcock 151). While in Garment+ the new designs are created from natural lightweight fabrics (Chan et al. 36).

Closures/Fastenings:
Target’s adaptive range includes zip on sleeves, and other zip openings (Annett-Hitchcock 151). While Garment+ garments have large zippers, magnetic toggles, and magnetic tape (Chan et al. 37).

Fig. 10. Claire Johnson. Fastening samples. 2023.

While it is important to ensure garments are both adaptive and functional, it is also important that the garments hold aesthetic value and are sought after by consumers; that they feel a sense of comfort and belonging in the clothes. There is a long history of people employing dress and fashion to adhere to society's expectations, yet normative modes of dress can prevent those with disabilities and other needs from being able to comfortably wear garments. Additionally, their full medical and assistance needs may not be met by standard design processes. On the other hand, much to the dismay of intended users, many adaptive and functional garments prioritise function over aesthetic and form. They fulfil their duties but unfortunately they exclude the wearer from society as "there exists a social stigma associated with adaptive clothing due to its disconnect to the contemporary lifestyle and the individual" (Chan et al. 30). When it comes to making adaptive garments, there is often a lack of expressive design due to the focus on enabling users. This often results in garments such as basic shirts with special openings and plain trousers made out of stretchy fabrics with elastic.

Fig. 11. Claire Johnson. Adaptive shirt and trousers for wheelchair users. 2023.

My research intends to address the issues of current adaptive clothing and focus on creating garments that are equally functional and hold aesthetic value. There are some influential designers working in this area, however significant improvements to the mainstream fashion industry could be made through user-centred design and additional resources for research and testing for adaptive and functional garment design.

2.3.1 Design Precedents

There are very few designers who focus on creating adaptive and functional design solutions making it difficult not only for consumers to find suitable products but also for fellow designers to draw inspiration and ideas from. The following designers are those that exemplify ideas discussed in the writing above and stand out as changemakers in the fashion industry.

2.3.1a Werable/Claudia Poh

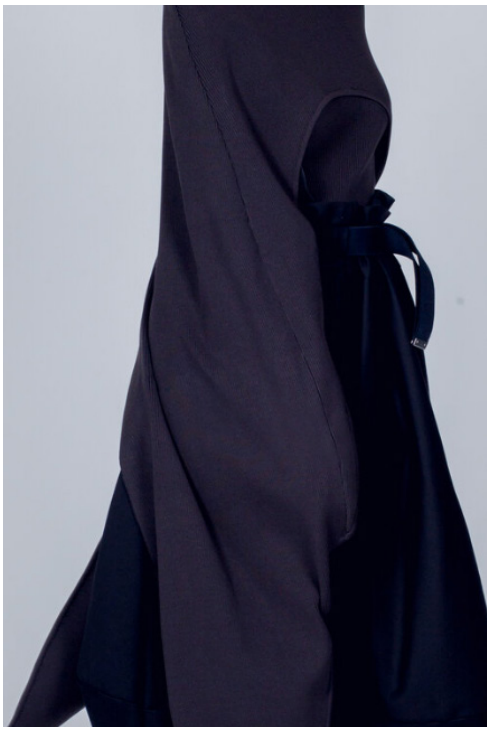


Fig. 12. Claudia Poh and Amy Yu Chen. The Cair Collective. Werable. 2017.

While studying at Parsons School of Design, Claudia Poh discovered that “clothing can do more than just look good… it changes how people navigate the world around them” (Poh). As part of her study, Claudia completed a thesis project with fellow student Amy Yu Chen in 2017. Named the Cair Collective, the project aimed to provide an alternate dressing system for their friend Christina, who has limited arm use due to paralysis, to reduce the amount of energy she uses when dressing (‘Independent Dressing’). Taking a user-centred design approach through following a day in the life of the wearer, Claudia and Amy were able to create garments that could suit her specific needs. Their designs allow the user to attach an air pump with magnets which inflate garments onto the body and then can be cinched by a large drawstring. To take the garment off it simply deflates and falls off the body (‘Independent Dressing’). The use of wearable technology to create self-dressing garments is a unique and creative solution to address issues that come with regular clothing.

Fig. 13. Werable. Hakama Full Length Pants. 2025.

After the success of the project, Claudia moved on to create Werable, an adaptive fashion brand. The vision of the brand is “to fashion a kinder, more inclusive tomorrow” (‘About Us’). The garments made by Werable each contain details created for specific user needs. For example the Hakama Full Length Pants garment details include: an easy-grip ring on the zipper, an elasticated back waistband, and inseam pockets that are designed to store catheters and fully conceal the connected tube (‘Hakama Full Length Pants’). By using her previous experience, Claudia has formed a brand focused on including those who are not represented well nor have positive experiences with mainstream fashion.

2.3.1b Unhidden

Fig. 14. Unhidden. Adaptive Burgundy Double Layer Dress. 2025.

Unhidden is a fashion brand known for their adaptive and universally designed garments. After a surgery in her 20's, founder Victoria Jenkins found herself with a disability that would change her life and ultimately allow her to change others. Unhidden includes garments that are stylish and comfortable but contain unique features for disabled or chronically ill users to create equitable fashion ('About Unhidden'). The garments on their website are produced in an array of bright colours and are seemingly unremarkable until closer inspection enables unique features to be seen. Like Claudia Poh's Werable, Unhidden garments have details created for specific user needs. Their Adaptive Burgundy Dress includes details such as: a double fabric layer at the top to allow for a hidden zip to access the stomach for those with stomas, a keyhole for chest port access, openings in pockets for tube access, and a split hem to allow for wheelchair users to sit comfortably ('Adaptive Burgundy Dress | Stoma | Wheelchair User | Port Access | Post Injury | Operation'). With her many years of industry experience, Victoria has managed to reinterpret what adaptive and universal design can look like. Not only are her garments extremely functional, they are also aesthetically similar to those found within the mainstream fashion market without excluding users from society.

2.3.1c Mindy Scheier

Mindy has been in the fashion industry for a long time, spending over 20 years working in design teams and as a stylist. She has seen changes within the industry, however when her middle child was born with muscular dystrophy (MD) she realised that more change was needed for those with disabilities (Scheier). Her son used to wear sweatpants every day because they were easy for him and trousers with buttons and zippers meant that he couldn't dress himself, something that became upsetting to him when he saw everyone else at school wearing jeans. Mindy used her experience to adapt a pair of jeans specifically for him that didn't have a zip or button and created an opening in the side seam so that it could accommodate his leg braces, creating an adaptive garment that doesn't hide his disability but accommodates it (Scheier 4:08). Her adaptation improved her son's mood so much that she realised she could help others as well, so she created Runway of Dreams, an organisation that empowers people with disabilities to have confidence and self expression ('THE FOUNDATION'). She researched a range of people with disabilities and discovered main issues with clothing were closures, adjustability, and donning and doffing or taking clothes on and off. Her solutions to these were formed by many prototypes of adapted ready to wear clothing and included the use of magnets, elastic, and having an opening in a different area (Scheier 9:14 - 10:30). She then took these ideas and sought to collaborate with a large fashion brand to get the fashion industry to listen to and design for disabled consumers.

Runway of Dreams collaborated with Tommy Hilfiger to create the Tommy Adaptive line. Tommy Adaptive was created to deliver classic American styles with creative design features that make it easier for those with disabilities to get dressed ('Tommy Adaptive').

The garments include the use of magnets and velcro for closures, flat seams, and very soft fabric to ensure that everyday wear is comfortable for users. They also use features such as side seam and centre back openings, and pull up loops in trousers (Annett-Hitchcock 153). For example, their Adaptive Mid Rise Straight Leg Jeans have the following features: a magnetic button fly with a velcro waistband fastening, internal elastic pull up loops, and an internal adjustable waistband. These jeans look conventional from the outside so it is not obvious that they have adaptive qualities, paying homage to Mindy's adaptations to the jeans for her son and bringing the confidence that she gave him to the rest of the disabled community.

Fig. 15. Tommy Hilfiger. Adaptive Mid Rise Straight Leg Jeans. 2025.

My research will use these precedents as references to continuously use during the design process for inspiration, analysis, and design ideation. All of these garments contain some form of adaptations to materials, whether it be design features for accessibility or the use of innovative materials to improve the well-being of users, it is a process that should be seen more in mainstream fashion.

2.4 Material Innovation within Garment Application for Health

Improving and developing apparel for health and performance has often included the use of material innovation. Material innovation is a process that involves creating new or improving existing materials to better suit them to their needed application (Leece and Ferrara 432). The process can be used to develop all kinds of garments including protective equipment and orthotics.

As a garment, protective equipment often focuses on protecting the body from impact, heat, or chemicals. To provide protection against impacts, garments can either have panels or pockets where an impact-absorbing material can be added or can be a protective garment as a whole such as shin pads for sport. Natural and synthetic rubber are good options for when energy absorption is needed, along with other properties, as they can be engineered for specific properties. “The binding forces between polymers are engineered so that the deformation breaks the intermolecular bonds leading to the absorption of energy” (Tyler 358). By changing the forces which bind the polymers, impact to the material will be absorbed, essentially allowing most of the force to go into the material and not the user.

Another material that can be used for protection of the body are spacer fabrics. Instead of absorption, spacer fabrics are better used as cushioning. They have an internal spacer layer which is a material filled with small holes that allows air to flow through with a back layer and a face layer. The spacer layer is usually made from multiple monofilament yarns that connect the two outer layers as a three dimensional form (Tyler 367). These fabrics are often used in car seats to reduce vibration, as breathable panels in apparel, impact protection in rugby jerseys, and cushioning in cycling shorts. The way spacer fabrics are formed can make them incredibly versatile in terms of uses as they can come in many thicknesses and multiple materials can be used specifically for their functions. In terms of knee braces, neoprene is often used as its composition of elastane and method of engineering offers compression, support, and flexibility. However, material properties of neoprene include water resistance and shrinkage when laundering, meaning moisture from the skin is not absorbed and creates friction and discomfort while the shrinkage makes braces tighter and increases discomfort. A study has found that using spacer fabrics may be more beneficial in place of neoprene as spacer fabrics provide structure but also are breathable, durable, and comfortable while offering a higher stretch. Also, “in the case of water vapour permeability, absorption, and wicking test results, spacer fabric outperformed, compared to all the other samples and commercial products” (Rathinamoorthy and Senthilkumar). The study has shown that while neoprene works in terms of support and compression, it does not work as well as spacer fabrics can for braces due to large issues in terms of overall comfort.

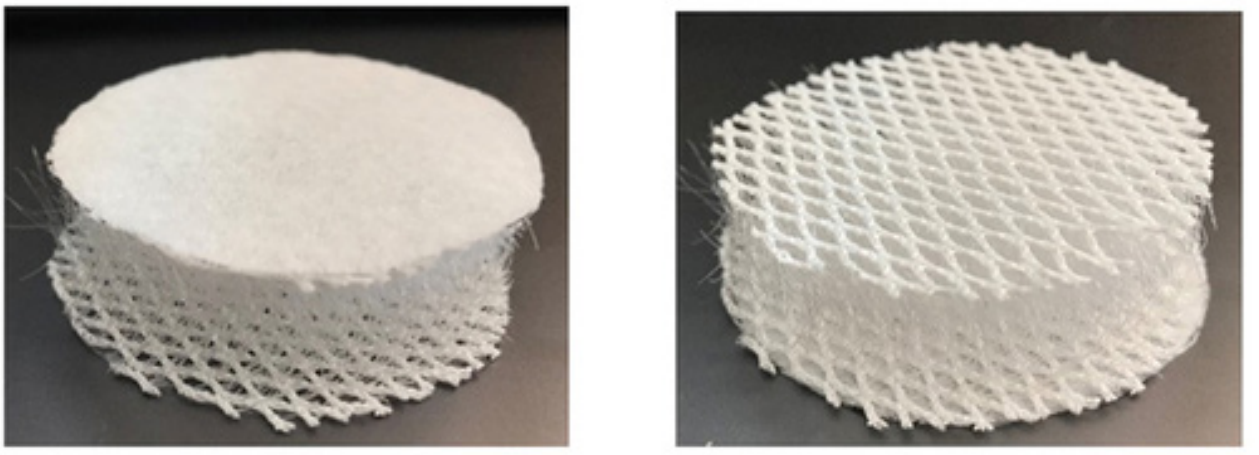


Fig. 16. Qing, Chen, et al. Cotton non-woven – polyester spacer assemblies during the analysis using a hot plate instrument. 2023.

In relation to apparel made for function, materials are considered an important factor of garment development. Many garments are created with a combination of woven and knit fabrics to suit numerous applications (Venkatraman 55). The combination of fabrics allows for essential and desirable fabric properties to be created. Essential properties are necessary in sport for regulations and user requirements while desirable properties relate to users' preferences for aesthetics and performance (Venkatraman 58). Examples of essential properties include stretch, recovery, and breathability, while desirable properties may include fabric stability and softness. These properties are achieved through fabric construction by choice of fibre, yarn, and design (Venkatraman 83). The most common methods used for fabric construction are woven and knit. Woven fabrics are made by a vertical and horizontal yarn that are interlaced in right angles to form a sheet (Sabir and Wood 89). Most fabrics are woven in a plain weave which is cheap, fast, and easy to manufacture, although other forms of weave can offer other desired properties; twill weaves are used for extra durability while satin weaves are used for their draping abilities (Sabir and Wood 89). Knit fabrics are created by interlooping yarns formed by circular or flatbed knitting machines. With fabrics able to be knitted with either a single yarn or multiple in the weft (horizontal) or warp (vertical) direction along with their advanced properties (Sabir and Wood 90-91), knit fabrics are extremely stretchy and more versatile compared to their woven counterparts.

Fig. 17. Claire Johnson. Woven fabric vs knit fabric. 2025.

Knit fabrics have different properties depending on whether they are a weft knit or a warp knit. Weft knits are soft, pliable, extremely stretchy, and durable, while warp knits have little stretch, are strong, and very stable (Sabir and Wood 91-92). The construction of weft and warp knits play a large part in creating their given properties. Weft knits are constructed in a tubular form with a single yarn that is used to create rows of loops in which the interlooping yarns are carried through horizontally (Sabir and Wood 91). The construction and properties of weft knits mean they are most suitable for everyday garments such as socks and t-shirts. Warp knits are constructed in a flat or open width form by vertically running yarns connected to the top of the machine that create lengthwise loops, with the interlooping yarn forming columns of loops (Sabir and Wood 92). The stability and strength of warp knits mean that their use is best suited to technical garment applications such as sportswear.

Fig. 18. Claire Johnson. Weft knit structure vs warp knit structure. 2025.

To further understand the importance of material properties and construction for apparel and function, we can look at the innovation of materials for sports and performance wear. In early developments, woven silk, cotton, and wool dominated due to the availability, protection, and some tactile performance features of natural fibres (Sabir and Wood 88). The use of natural fibres did not come without limitations, however, as a range of garments could not be created and worn effectively. Garments that fall into the swimwear category were essentially useless, as natural fibres absorb liquid which led to sagging fabric and misshaping (Sabir and Wood 88). It was clear that more developments needed to be made to accommodate a full range of sports and performance activities. By the time of the Second World War, synthetic fibres had been developed to a point where they were becoming available to the mass market. These synthetic fibres were highly sought after, durable, and low cost compared to the previously used woven natural fibres, but they too had limitations (Sabir and Wood 88). Poor breathability and fabric handle meant that most of these fibres still had a way to go before meeting optimal performance standards, although one synthetic fibre stood out as a changemaker compared to the rest. Lycra was a revolutionary innovation; the specific use of elastane which improved the stretch qualities of fabric formed a trend of creating knit fabrics in a similar way (Sabir and Wood 88). By the 1980s, materials and construction methods were so developed that sports and performance wear began to resemble the modern garments and fabrics that we know today (Abd El-Hady and Abd El-Baky qtd in Sabir and Wood 95). The innovative mix of technology and science over time has increased demand for fabrics such as knits that are stretchable and snug fitting, but also other woven fabrics that work as protection from the elements, as "by combining material engineering and clothing, science has assisted in the physiology and physiological well-being of an athlete" (Sabir and Wood 96).

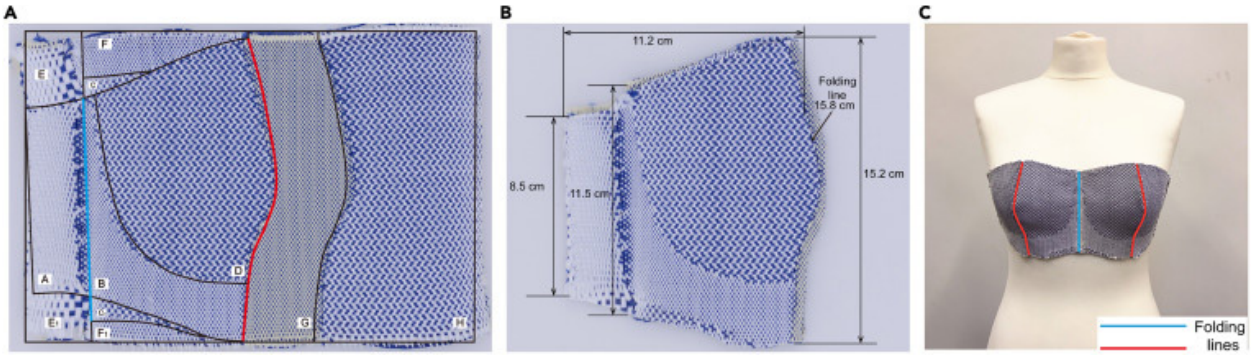


Fig. 19. Yuyuan, Shi, et al. 3D woven bra prototype results (A) The folded bra prototype taking off loom. (B) The flattened 2D form of bra. (C) The final 3D woven bra front block. 2024.

While technology and science have helped to create materials and processes already in use, it is also aiding future developments. Nanotechnology is already being used in materials. By variating the fibres, nanotechnology can increase functional properties such as moisture regulation, antibacterial action, and comfort; examples include material fibres created with silver to repel bacteria and a fabric made with a nanoplasma layer that repels water to enhance a swimmer's glide (Sabir and Wood 97). Another development in the area is 3D weaving. 3D weaving forms a fabric where the yarns are disposed in three perpendicular planes. The final structure is not flat like traditional woven materials and instead has a noticeable depth which adds a third dimension (Sabir and Wood 97). At this point in time, 3D weaving is used in engineering for applications in car manufacturing and ballistics protection, although there is potential for it to move into more apparel applications. Spacer fabrics are another development previously mentioned in the chapter. The two layers of knitted fabric that are sandwiched together are joined by yarn which takes the form of tubes, pleats, or engineered forms (Sabir and Wood 98). As mentioned, these fabrics are mostly used for impact protection and have the capabilities to be used for other applications. Composite fabrics and garments are constructed using one of two techniques; a combination of different fibres, or a combination of different fabric constructions in one garment (Sabir and Wood 99). For example, one layer of fibres in a fabric could be made with natural yarn while another layer is made with a synthetic yarn. Dry wool is created in this way, it combines merino wool and synthetic fibres to have a final outcome that leaves the body dry and comfortable (Sabir and Wood 99).

Fig. 20. Shuai, Liu, et al. The schematic of spacer fabrics: (a) warp-knitted spacer fabric, (b) weft-knitted spacer fabric, and (c) woven spacer fabric. 2023.

Ultimately, the innovation of materials has improved the garments that are used to protect and support the body. Garments that are made with these kinds of materials can fulfill their duties to the user without compromises such as comfort or pain. In this project, materials will be explored to ensure user needs and wants are addressed for functionality, comfort, and aesthetic qualities, while including finding other ways to make existing features more suitable to their uses.

3. Methodology and Methods

Chapter 3 Fig: Author's work. Close up of overlocker. 2025.

3.1 User-Centred Design - An Empathic Design Approach

Despite its focus on designers working with users to create a final outcome, user-centred design as a singular approach will not always include the user early on in the process, whereas an empathic approach includes users from the very beginning (McDonagh and Thomas 184). Occasionally employed in industrial design, empathic design relies on early user inclusion to ensure more intuitive and appropriate outcomes as empathy allows the designer to intuitively identify with and relate to the way others feel, think, and value (McDonagh and Thomas 182, 183). As designers, we place ourselves in others' lifestyles and attempt to understand issues and everyday behaviours from their point of view. The diagram below illustrates user input and design approaches throughout an iterative design process. It shows an empathic approach as designed by the user, beginning at the design brief stage and having continual feedback through the process. Whereas a user-centred or universal approach is shown as designing with the user and including them in the middle of the design process.

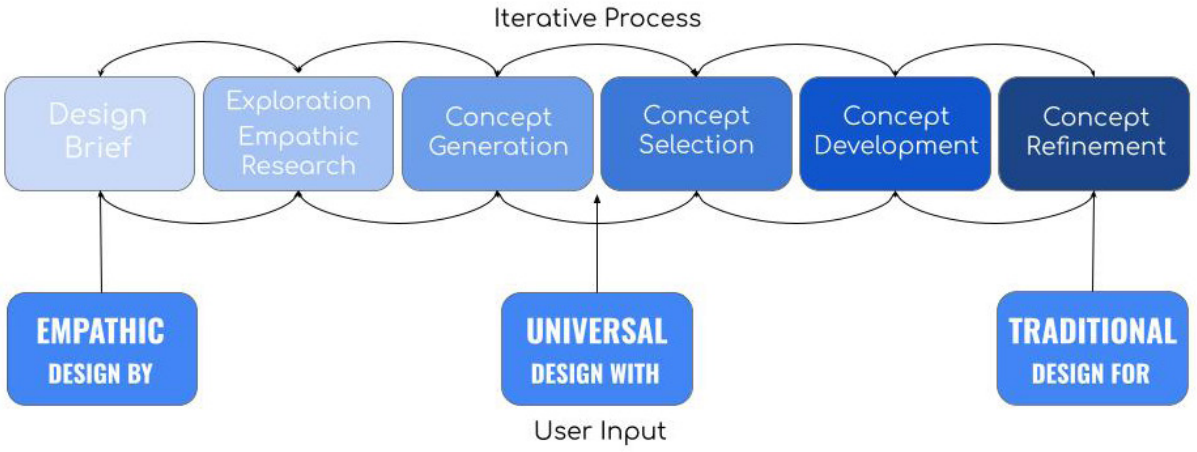


Fig. 21. Adapted from D.McDonagh, and J.Thomas, Designing process and user input, 2025, Journal Article.

The chosen methodology for this project is user-centred design with an empathic approach to create inclusive solutions in tangible forms. With the increasing consideration of disabilities in the fashion industry, there are risks of adaptive and functional garments being unsuitable for use, due to designers not having the disabilities they are designing for (McDonagh and Thomas 182). By following an empathic user-centred design approach, my work focuses on understanding user needs and wants through user inclusion early in the design stage and throughout the process while allowing myself to control the final outcome. With having a small participant group, it also allows me to form a strong and more personal connection with users.

3.1a The Functional, Expressive, Aesthetic Model (FEA)

To gather user information, my research has followed the Functional, Expressive, Aesthetic model. The model is focused around the targeted user and their attributes along with their cultural context, including what they consider to be acceptable options for resolving design issues (Lamb and Kallal 42-43). To create acceptable options, establishing a design criteria based on user needs and wants is critical. The functional sector of the model contains considerations relating to utility; fit, comfort, and protection are some factors that are included (Lamb and Kallal 43). The functional component allows for disabilities to be considered in apparel designs adequately, much like the garments created by Tommy Hilfiger Adaptive and Unhidden. The expressive sector of the model contains considerations relating to communicative and symbolic notions of dress; they include the user's values, self-esteem, and how they want to appear to others (Lamb and Kallal 43). The expressive area allows for user preferences to be realised in apparel design and allows designers to address issues with the visibility of medical equipment within the adaptive design sector. Both Werable and Unhidden use design features which hide medical devices as preferred by their users, increasing user self-esteem and letting them choose how others perceive them. The aesthetic sector of the model contains considerations relating to the human desire for beauty; line, colour, and texture, along with anything else that creates a pleasing design is included (Lamb and Kallal 43). The aesthetic area informs adaptive apparel that is visually pleasing to users without compromised function.

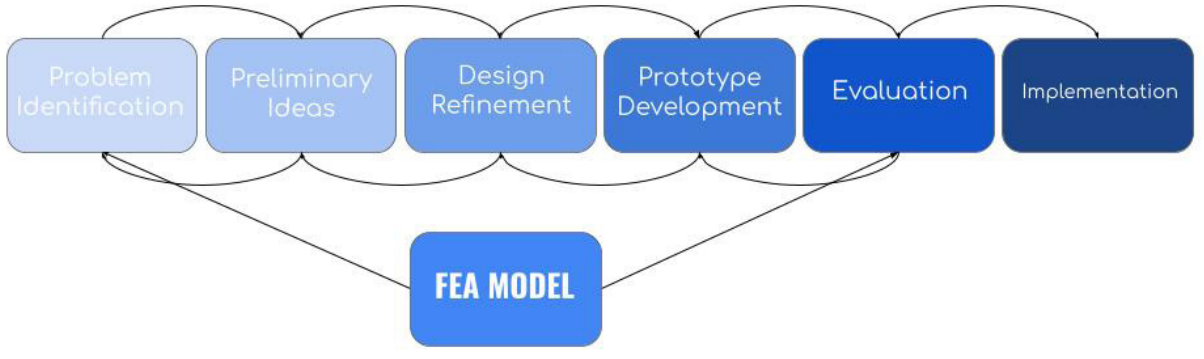


Fig. 22. Adapted from J.M.Lamb, and M.Jo.Kallal, FEA apparel design framework, 2025, Journal Article.

The previous figure illustrates the FEA model situated in an apparel design process. The model is applied in the problem identification and evaluation stages, with information gathered during the identification stage considered throughout the process. The problem identification stage entails designers choosing and defining a problem within apparel to become the focus of their project, which then leads to identifying target consumers and analysing their needs and wants (Lamb and Kallal 44). The process then moves into preliminary ideas, where design solutions are created through existing research, drawings, and potentially user research in the form of questionnaires and interviews, for example. The next stage, design refinement, focuses on refining the ideas generated in the previous stage. This part of the process emphasises critique, with each idea analysed against the design criteria to assess if it meets user needs and wants (Lamb and Kallal 44). The ideas that are less successful are put aside and the ones with the most potential are selected for further development. Once ideas have been selected, the process then moves into the prototype development stage. During this stage, physical samples of the ideas are created to test their overall suitability to the design criteria as well as individual components including fabric choice, stitching and machine selections, and construction sequence (Lamb and Kallal 44). Anything that may need to be tested and further explored is produced during this stage. The evaluation stage includes assessing the samples against the design criteria and how well they meet each of the FEA sectors; if they need to be refined further then the designer can repeat the suitable stage. The implementation stage is reached once a final design has been selected and is ready for production. For this project I have chosen to follow this apparel design process with the implementation of the FEA model.

3.2 Methods - Problem Identification

In order to achieve my research aim, the focus of gathering data was based on participatory involvement with a person with lived experience of patella alta to feed iterative design development. The participant explained their condition and provided information regarding functional elements that could become adaptive fashion features. These mechanisms and processes can be developed and adapted to varied garments, e.g. trousers, skirt, or dress. To gather further information and a more empathic understanding, designer-orientated user research completed through the use of perceptual maps and brace to trouser analysis was also undertaken. Using this combination of methods has allowed me to comprehensively understand the design problem and create adequate design solutions that add to existing adaptive apparel and further improve the physical, spiritual, and mental well-being of users.

3.3 Designer Orientated User Research

3.3a Perceptual Mapping

This methodological component explored current treatment options available to those with patella alta and what their strengths and limitations are. Images of different types of knee braces were gathered through a Google image search under the search terms ‘wrap knee brace’, ‘hinged knee brace’, ‘unloader knee brace’, and ‘immobiliser knee brace’. Similar braces from Bauerfeind New Zealand and Back on Track New Zealand were investigated to estimate materials, cost, and brace use. Information gained from journal articles on patella alta and treatment options during the secondary research stage was also used. Due to not being able to gather all of the actual information for each shown brace, there is potential for some estimation inaccuracies, however it provides enough information to be used to inform an approximate understanding. Five images of braces were chosen: one wrap, two hinged, one unloader, and one immobiliser brace, each with different uses for a range of condition severities. The images were placed on five perceptual map set ups comparing the disruption of the condition to life, the cost, the feel of materials, dressing accessibility, and quality of materials.

Fig. 23. Author’s work. Knee braces chosen for perceptual mapping and their descriptions. 2025.

Fig. 24. Author's work. Perceptual map showing condition severity versus knee brace cost. 2025.

Fig. 25. Author's work. Perceptual map showing knee brace cost versus knee brace materials. 2025.

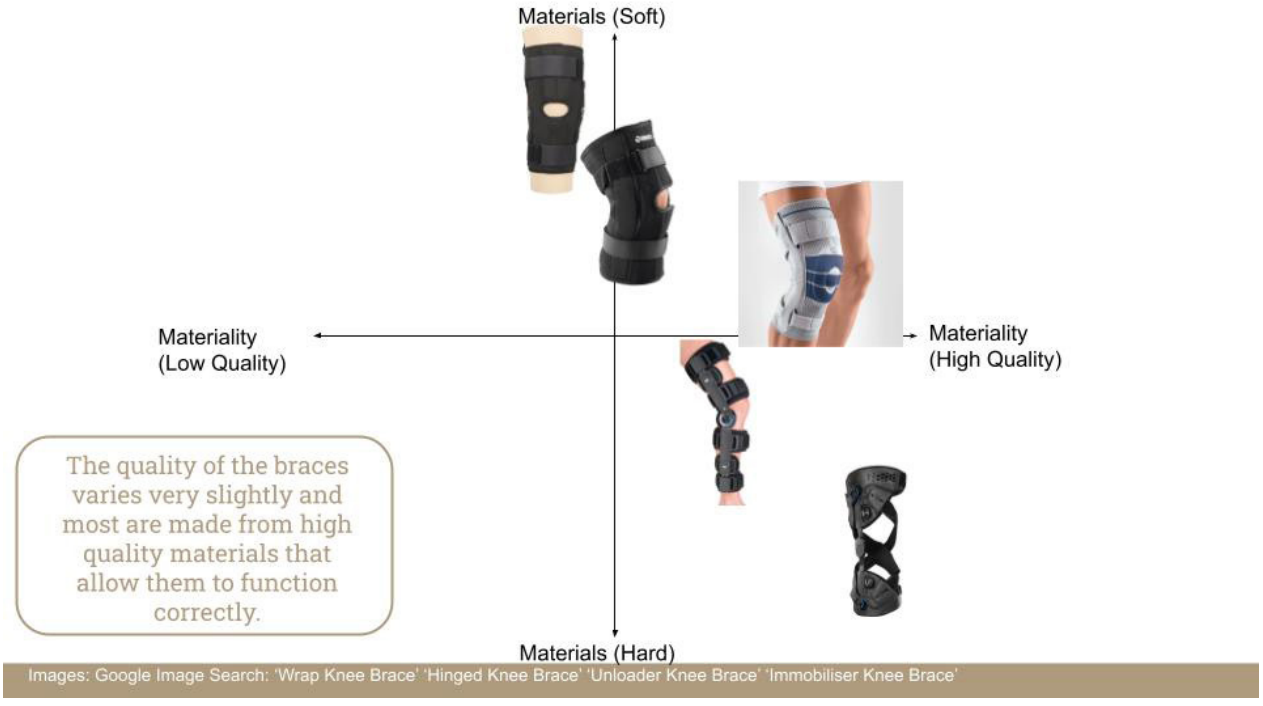


Fig. 26. Author's work. Perceptual map showing knee brace quality versus knee brace materials. 2025.

Fig. 27. Author's work. Perceptual map showing dressing accessibility versus condition severity. 2025.

Fig. 28. Author's work. Perceptual map showing dressing accessibility versus knee brace materials. 2025.

The findings from these perceptual maps are as follows:

- The more extreme the condition, the higher the cost of the brace.
- There is a gap in the market for braces that are made from hard materials and are low cost.
- The quality of the braces vary slightly and most are made from high quality materials that allow them to function correctly.
- There's a gap in the market for braces that ensure ease of dressing and are suitable for a more severe condition.
- There are no braces that are low cost, easy to get dressed with, made with hard materials, and are for an extreme condition.

3.3b Brace to Trouser Analysis

The brace to trouser analysis aimed to understand the relationship between knee braces and trousers, their fit and comfort along with their visual impact. Two knee braces were used for this: one existing Elastoplast adjustable knee support brace that I have had for many years, and one fashion fabric brace made out of ponte from my own knee brace pattern developed for previous related project. Three types of trousers were used: a flared, fitted, and straight legged trouser, all size 10. Two of the trousers are made from knit fabrics and the other is made from woven. This allowed for both kinds of fabric construction to be tested although no analysis was conducted on a heavy weight fabric, which could create more diversified results. Both of the braces were worn with each trouser in three ways: externally, internally, and partially external and internal. While wearing them myself, each interaction was measured against a likert scale from 1-5 in relation to donning trouser/brace first, doffing trouser/brace first, and adjusting brace, with 1 being the easiest and most comfortable and 5 being the least. The results of these interactions were photographed, drawn, and then put into tables for a systematic analysis which is shown below.

Fig. 29. Author's work. Fashion fabric knee brace made from developed pattern, applied externally to flared trouser. 2025.

Fig. 30. Author’s work. Fashion fabric knee brace made from developed pattern, applied internally to flared trouser. 2025.

Fig. 31. Author’s work. Fashion fabric knee brace made from developed pattern, applied partially internally and externally to flared trouser. 2025.

Fashion Fabric Brace
Trouser 1/Flare

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	2
Doffing brace first	2
Adjusting brace	1
Visual Impact:	Significant alteration to the design silhouette

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	3
Doffing trouser first	4
Adjusting brace	3
Visual Impact:	No alteration of design silhouette

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	5
Doffing trouser first	4
Adjusting brace	3
Visual Impact:	Significant alteration of design silhouette, lumpy, odd

Fig. 32. Author's work. Systematic analysis of brace to trouser interaction for fashion fabric brace and flared trouser, impacts shown through the use of a likert scale. 2025.

Fig. 33. Author's work. Existing medical knee brace, applied externally to flared trouser. 2025.

Fig. 34. Author’s work. Existing medical knee brace, applied internally to flared trouser. 2025.

Fig. 35. Author’s work. Existing medical knee brace, applied partially internally and externally to flared trouser. 2025.

Store Bought Brace
Trouser 1/Flare

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	1
Doffing brace first	1
Adjusting brace	1
Visual Impact:	Moderate alteration to the design silhouette, cohesive

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	3
Doffing trouser first	2
Adjusting brace	4
Visual Impact:	Minimal alteration to design silhouette

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	4
Doffing trouser first	3
Adjusting brace	4
Visual Impact:	Significant alteration to the design silhouette, bulky

Fig. 36. Author's work. Systematic analysis of brace to trouser interaction for existing medical brace and flared trouser, impacts shown through the use of a likert scale. 2025.

Fig. 37. Author's work. Fashion fabric knee brace made from developed pattern, applied externally to straight trouser. 2025.

Fig. 38. Author’s work. Fashion fabric knee brace made from developed pattern, applied internally to straight trouser. 2025.

Fig. 39. Author’s work. Fashion fabric knee brace made from developed pattern, applied partially internally and externally to straight trouser. 2025.

Fashion Fabric Brace
Trouser 2/Straight

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	2
Doffing brace first	2
Adjusting brace	1
Visual Impact:	Significant alteration to the design silhouette, looks imposed, disrupted

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	3
Doffing trouser first	3
Adjusting brace	3
Visual Impact:	No alteration of design silhouette

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	5
Doffing trouser first	4
Adjusting brace	5
Visual Impact:	Moderate alteration of the design silhouette, rippled, tight

Fig. 40. Author's work. Systematic analysis of brace to trouser interaction for fashion fabric brace and straight trouser, impacts shown through the use of a likert scale. 2025.

Fig. 41. Author's work. Existing medical knee brace, applied externally to straight trouser. 2025.

Fig. 42. Author’s work. Existing medical knee brace, applied internally to straight trouser. 2025.

Fig. 43. Author’s work. Existing medical knee brace, applied partially internally and externally to straight trouser. 2025.

Store Bought Brace
Trouser 2/Straight

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	1
Doffing brace first	1
Adjusting brace	2
Visual Impact:	Significant alteration to the design silhouette, disrupted, bunched

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	2
Doffing trouser first	2
Adjusting brace	3
Visual Impact:	No alteration to design silhouette

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	4
Doffing trouser first	2
Adjusting brace	4
Visual Impact:	Significant alteration to the design silhouette, imposed, pulled, messy

Fig. 44. Author's work. Systematic analysis of brace to trouser interaction for existing medical brace and straight trouser, impacts shown through the use of a likert scale. 2025.

Fig. 45. Author's work. Fashion fabric knee brace made from developed pattern, applied externally to fitted trouser. 2025.

Fig. 46. Author's work. Fashion fabric knee brace made from developed pattern, applied internally to fitted trouser. 2025.

Fig. 47. Author's work. Fashion fabric knee brace made from developed pattern, applied partially internally and externally to fitted trouser. 2025.

Fashion Fabric Brace
Trouser 3/Fitted

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	2
Doffing brace first	2
Adjusting brace	1
Visual Impact:	No noticeable alteration to design silhouette, looks cool, militaristic, and cohesive

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	5
Doffing trouser first	4
Adjusting brace	5
Visual Impact:	Minimal alteration of silhouette around the knee

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	5
Doffing trouser first	4
Adjusting brace	5
Visual Impact:	Moderate alteration of the design silhouette, rippled, tight

Fig. 48. Author's work. Systematic analysis of brace to trouser interaction for fashion fabric brace and fitted trouser, impacts shown through the use of a likert scale. 2025.

Fig. 49. Author's work. Existing medical knee brace, applied externally to fitted trouser. 2025.

Fig. 50. Author’s work. Existing medical knee brace, applied internally to fitted trouser. 2025.

Fig. 51. Author’s work. Existing medical knee brace, applied partially internally and externally to fitted trouser. 2025.

Store Bought Brace
Trouser 3/Fitted

Brace Interaction: External to Trouser

Action:	Fit and Comfort:
Donning trouser first	1
Doffing brace first	1
Adjusting brace	1
Visual Impact:	No alteration to the design silhouette, disruption from colour

Brace Interaction: Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	4
Doffing trouser first	3
Adjusting brace	4
Visual Impact:	Significant alteration to the design silhouette, lumpy, tight

Brace Interaction: Partial External and Internal to Trouser

Action:	Fit and Comfort:
Donning brace first	5
Doffing trouser first	4
Adjusting brace	5
Visual Impact:	Significant alteration to the design silhouette, bold, out of place

Fig. 52. Author's work. Systematic analysis of brace to trouser interaction for existing medical brace and fitted trouser, impacts shown through the use of a likert scale. 2025.

The findings from these brace to trouser analysis are as follows:

- The store bought brace is generally easier to put on and off for all trouser silhouettes and interactions.
- The fashion fabric brace is generally easier to adjust when worn for all trouser silhouettes and interactions.
- The fashion fabric brace had minimal to no visual impact on the fitted trouser, while the store bought brace mostly had a significant visual impact.
- Both of the braces mostly had a significant visual impact on the straight trouser.
- The fashion fabric brace mostly had a significant visual impact on the flared trouser, with the store bought brace had a range of visual impacts with each interaction.

3.4 Empathy Led User Research

Empathy-led user research comprised in-depth semi-structured interviews and design feedback workshops with participant with patella alta and medical expert consultants. My research was limited with one participant due to scope and timing of this project however it did lead to deeper insight due to a strong relationship built. Future research would benefit from larger participant feedback.

3.4a Participant Identification

My user research resulted in using only one participant with patella alta. Although limited, having one participant meant that my empathic approach was stronger as there was a constant one on one connection with the participant through the project. The participant was a young woman I had met in a previous related project. She works in a customer facing job where she has to stand for most of the day and is moderately active. She described her patella alta as being moderate with one knee being more severe than the other. Her treatment options are Thermoskin compressive knee braces, which she wears everyday while at work, and physiotherapy. Having a participant that stands all day while working and is moderately active is beneficial to my project. I gained valuable information relating to all day comfort of materials and existing braces, as well as brace and garment functions and movement. I also gained information about their desired fashion aesthetics.

I contacted Peke Waihanga, the Artificial Limb Service, to set up a zoom meeting with one of their research and development engineers. The engineer I spoke to is involved with researching and creating prosthetics and orthotics along with the technological aspects to create outcomes for particular needs. Their experience and the consultation helped validate the reasonings and need for my project, and they provided further recommendations post study.

Near the end of my research I was able to find a physiotherapist that was happy to respond to my design work. The physiotherapist has over 30 years of experience in sports medicine and injury rehabilitation and has experience working with professional sports teams in Australia and New Zealand. Their experience was vital to validating the design feedback in relation to functionality that the participant with patella alta gave me and I was also provided with further recommendations for after study.

3.4b Semi-structured Interviews and Workshops

To help me understand the condition, treatment, and issues, I used a combination of semi-structured interviews and design feedback workshops following Massey University's low risk ethics guidelines.

The participant was given an information sheet and consent form to fill out before any information was recorded which informed them of the study objectives, data use, nature of confidentiality, and voluntary participation. The semi-structured interviews were completed with the use of open-ended questionnaires. The design feedback workshops were carried out with the use of design work that had been recently created and the participant was given open-ended questions to answer about these and also encouraged to provide any other feedback they had.

The first workshop was intended to understand the challenges of daily life with patella alta, brace suitability, and clothing issues. The questionnaire asked the participant about their condition, knee brace use, issues with clothing, and possible improvements. The participant was asked to give design feedback for the lower body garments and the initial sampling I had completed. The results from this workshop gave me important information about the condition and user needs and wants such as the visibility of knee braces to others, comfort, accessibility, support, and aesthetics. These results formed my initial design criteria which informed what features would be needed and which ones could be discarded.

The second workshop was intended to gain feedback on a range of samples that had been created as an alternative to using an existing knee brace. The questionnaire used in this workshop asked the participant for their thoughts on the materials, shape, and function of a number of knee brace samples and drawings. It also asked for similar design feedback of four trouser leg samples and drawn garment designs. This workshop had an emphasis on function rather than aesthetic. The results from this workshop gave me specific information about the compression, feel, stretch, support, and suitability of my sampling. It also gave me further information about how my design work should develop by selecting what samples should be refined and which could be left as is. These results also refined my design criteria to allow my project to work toward a focused outcome.

Not being able to complete interviews or workshops with a range of people is a significant limitation for this project. While it is useful to work with a participant with lived experience, a more in-depth exploration with those with different lifestyles, condition severity and knowledge bases would be beneficial.

3.4c Medical Expert Consultation

The conversation with the engineer was intended to gain information around clothing in healthcare and the interaction with users and what it looks like from a medical viewpoint. This was an open discussion where I described my ideas and potential outcomes and they responded with feedback and further ideas. Their response included investigating issues with braces and clothing, considering aesthetics as subjective and how medical devices are perceived by users and others, and the future recommendation of creating frameworks from garment alteration that could be used as a prescription.

The consultation with the physiotherapist was intended to gain validation of design work based on feedback from the participant with patella alta. The questionnaire used for this asked for validation of feedback about shape, placement, and other applications. It also asked for a response to materials, size, 3D printed design for functionality, along with any further recommendations. The answers given validated the need for specific shaping for the 3D printed support structures and the use of chosen materials, and thinking about how the users mental state is affected by the improvement of ability given by knee braces.

3.5 Defining Participant Feedback

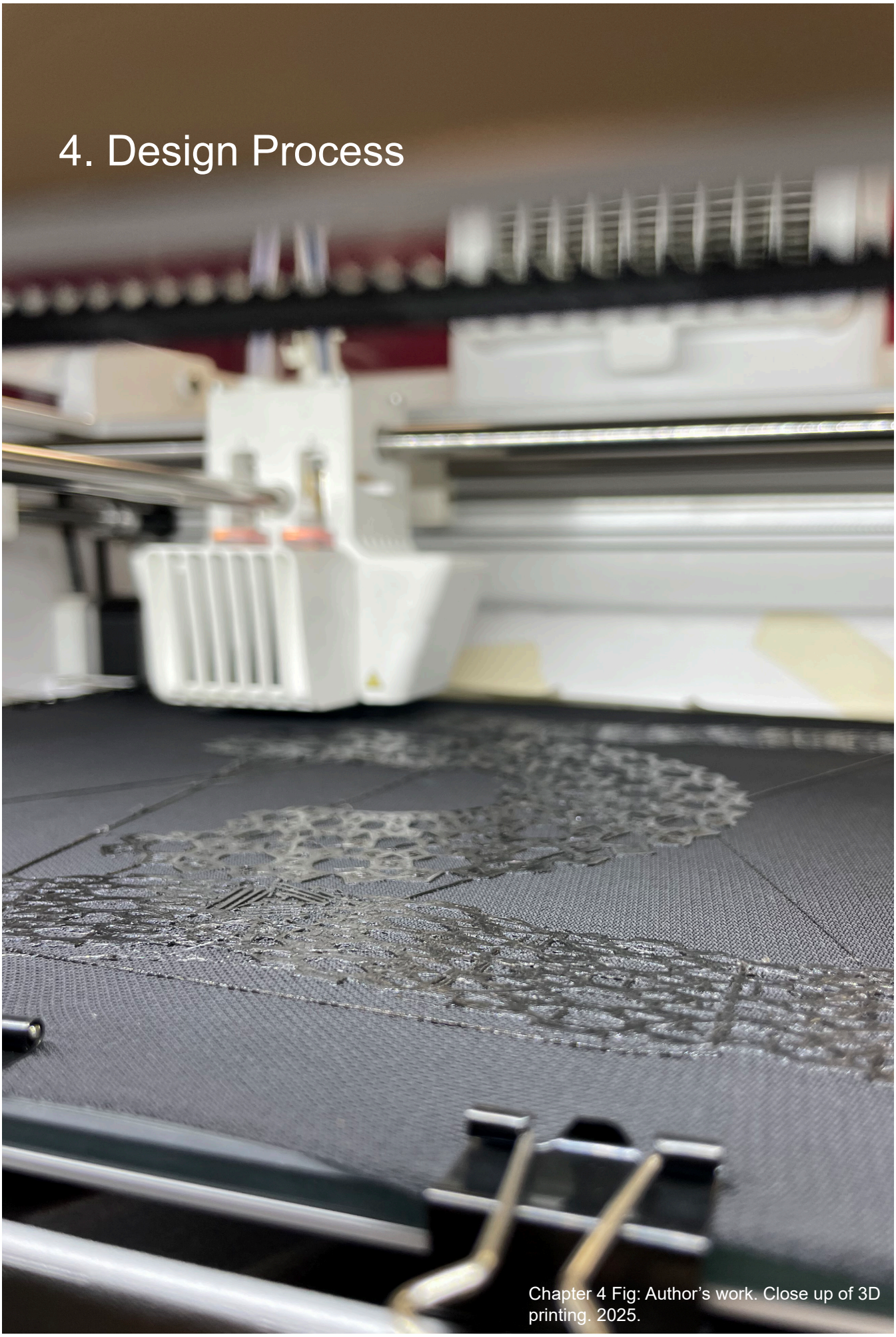
All of the workshops were sound recorded with the consent of the patella alta participant. Recording the sessions allowed me to be able to write down all of the given information without missing key details.

The information given from the consultations with the engineer and physiotherapist was written down instead of recording.

3.5a Data Visualisation

To clearly understand the information given by the participant, all of the feedback was written out in full on a table laid out with the questions on one side and the answers on the other. Common themes were then chosen from the information and allocated to the Functional, Expressive, Aesthetic sectors. This allocation allowed me to understand each theme and how they relate to the user to then create a design criteria from. The design criteria was created on a table with the chosen themes and FEA sectors on one side and the expanded user needs and wants on the other. *These tables are provided in the appendix under data visualisation.*

4. Design Process



Chapter 4 Fig: Author’s work. Close up of 3D printing. 2025.

4.1 Preliminary Ideas

My design work included a large amount of analysing and sampling a range of techniques and ideas that seemed suitable to continue exploring. To begin design ideation I completed a range of word maps that were used to draw inspiration and inspire a new way of thinking. Words such as comfort, function, soft, and ergonomic were chosen based on key words and findings from my designer-orientated user research, and were then expanded with their synonyms.

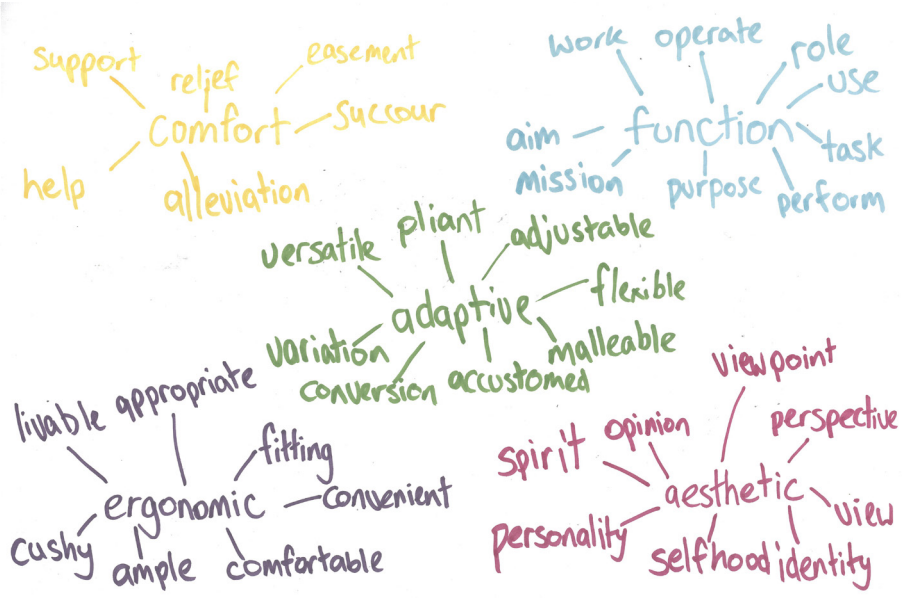
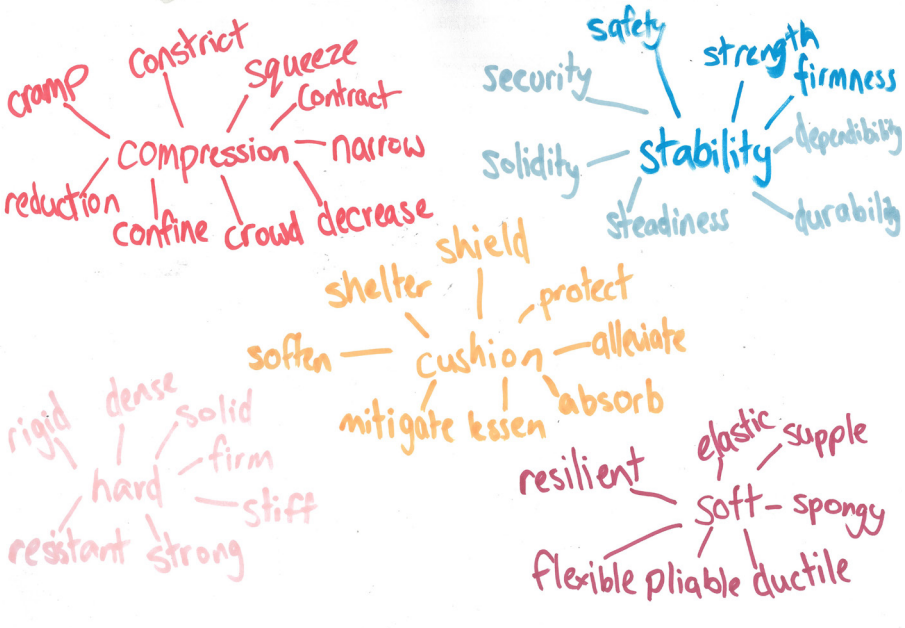
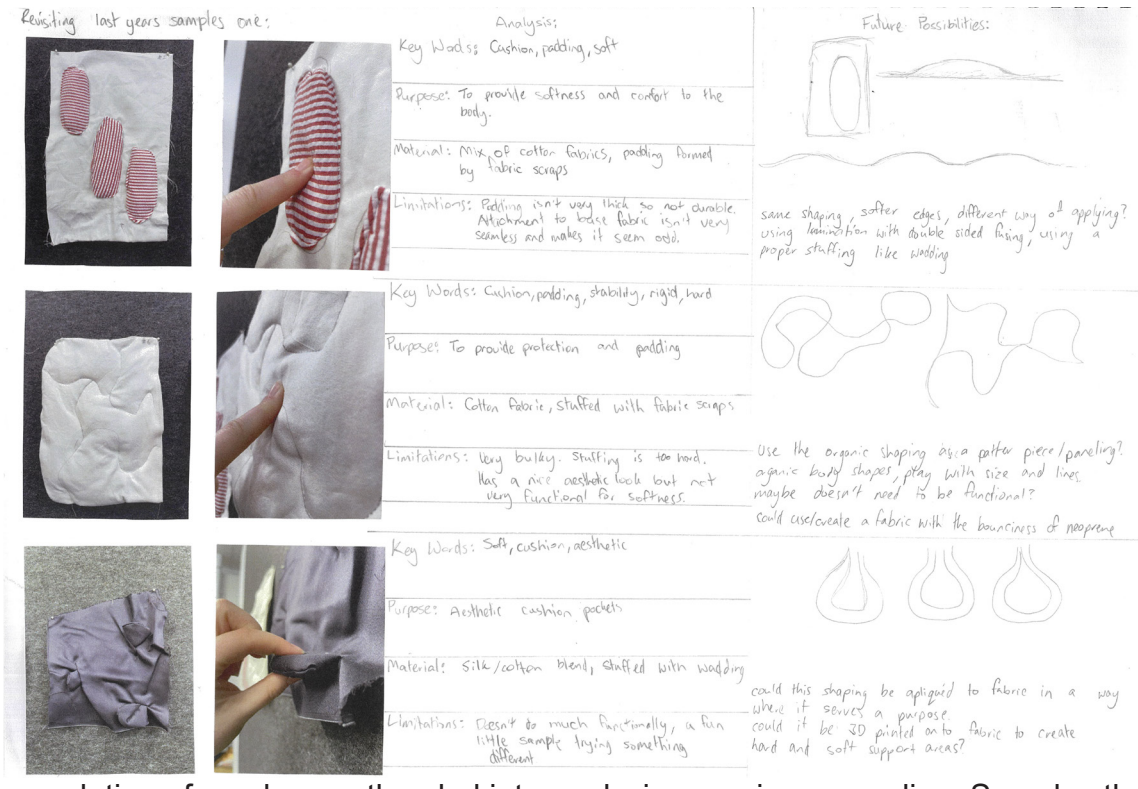
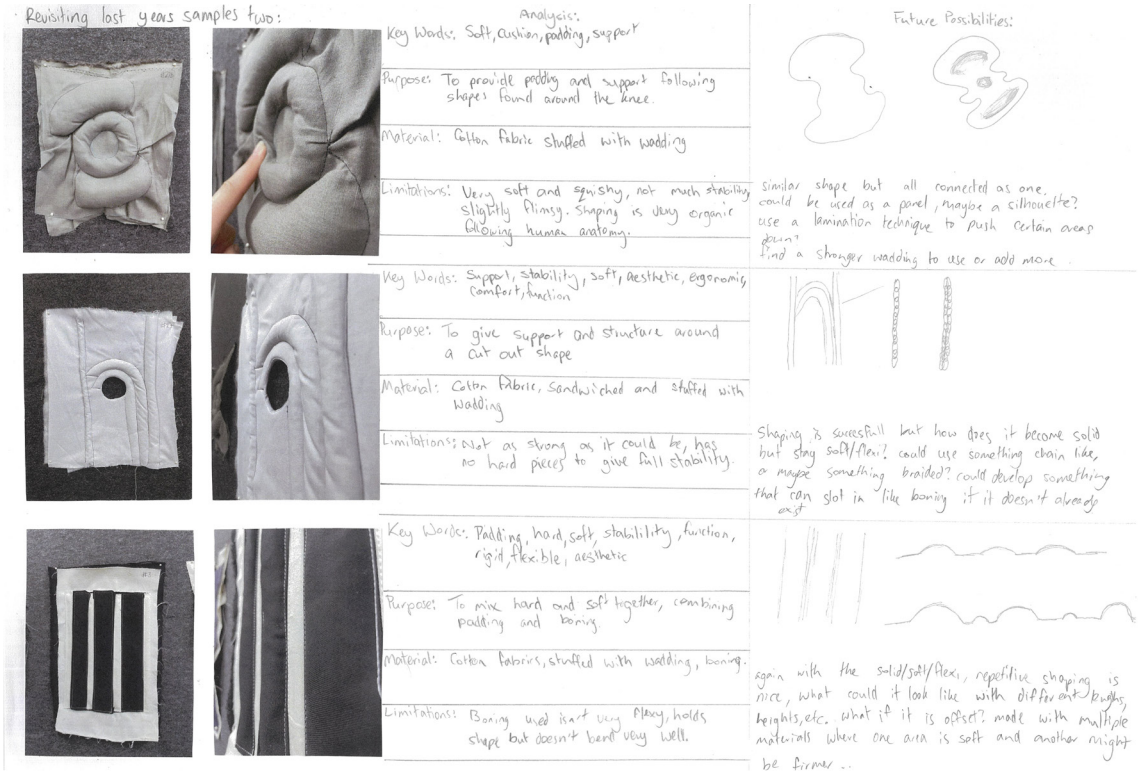


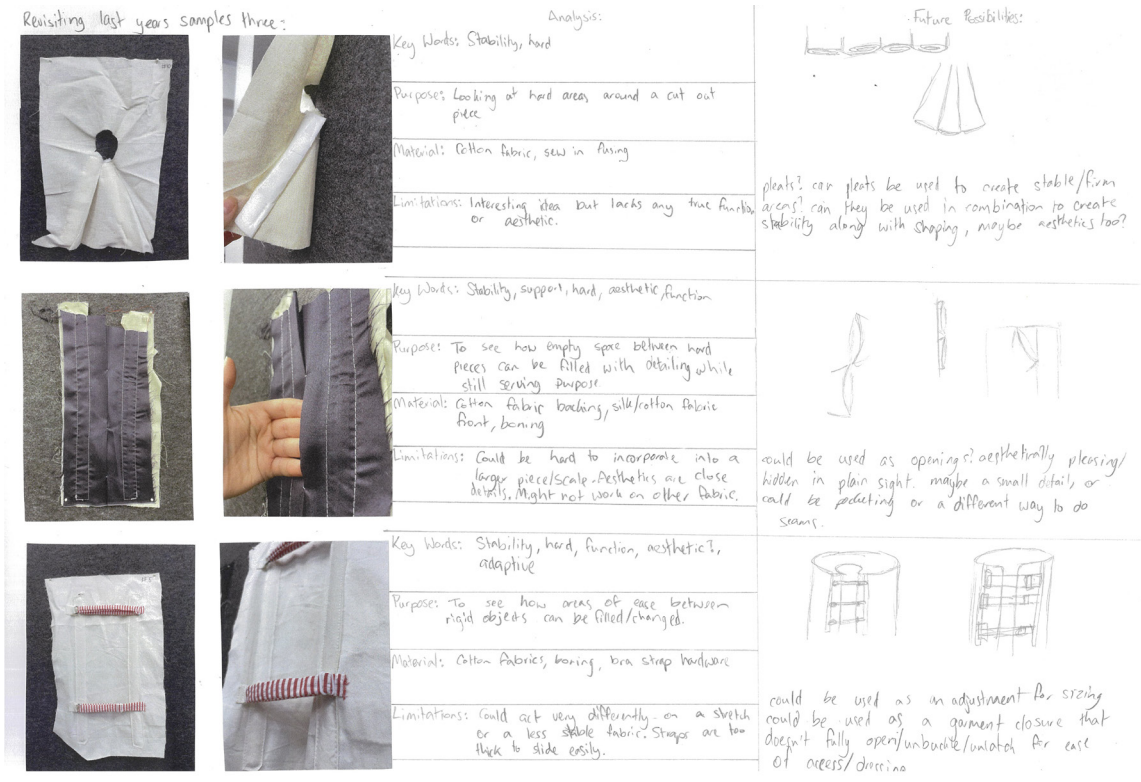
Fig. 53. Author's work. Word maps showing words relating to assumed needs and wants for the redesign of knee braces. 2025.



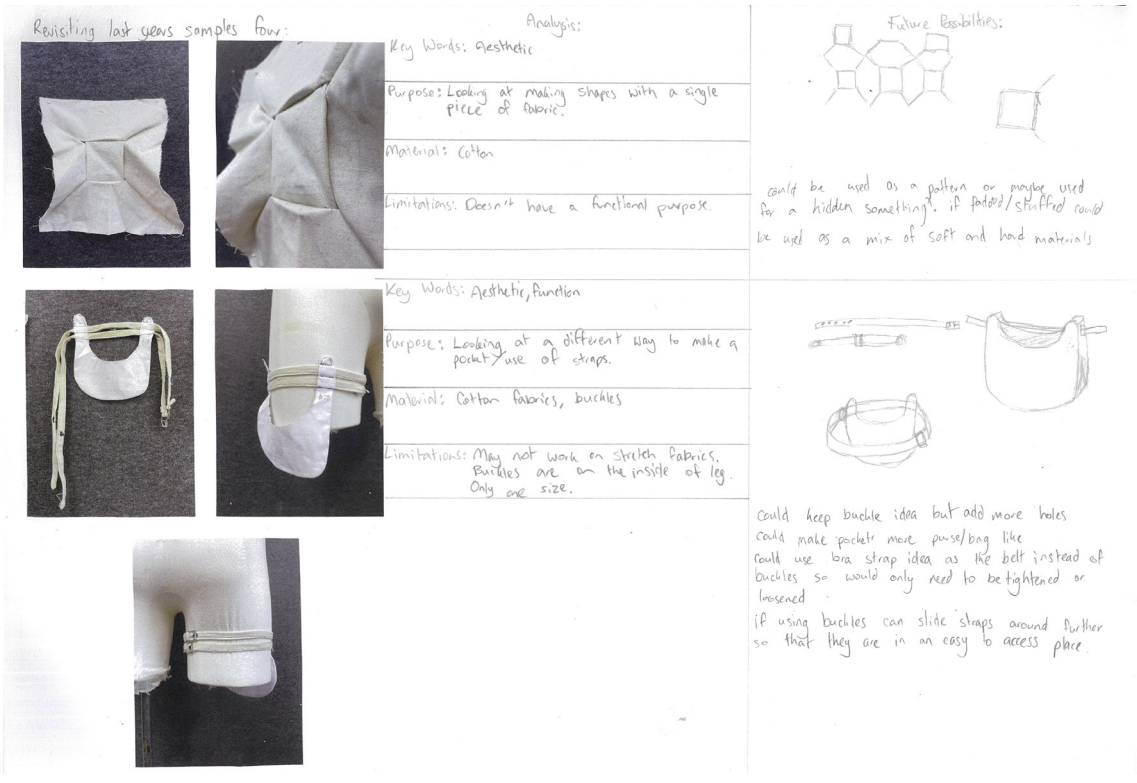


The completion of word maps then led into analysing previous sampling. Samples that were analysed were chosen from their relating key words to the ones explored in the word maps.





Previous Page - Fig. 54. Author's work. Analysis of samples from previous related project. 2025.
Fig. 55. Author's work. Analysis of samples from previous related project. 2025.



The analysis included key words, purpose, materials, and limitations, to which I came up with future possibilities to begin the exploration into fashion fabrics and properties, the structure of the fabric itself, as well as the structure created through the design and construction. *The tabled analysis can be found in the appendix under Sample Diary.*

After completing the analysis I chose the ideas that were the most similar to existing knee brace properties and began sampling improved ideas based on cushioning and stability, cushioning and support, adjustment and fit, and closures and openings. These samples were used to further explore fashion fabric properties, structure, and ways to construct that would be suitable for use as a knee brace structure. *The tabled analysis can be found in the appendix under Sample Diary.*

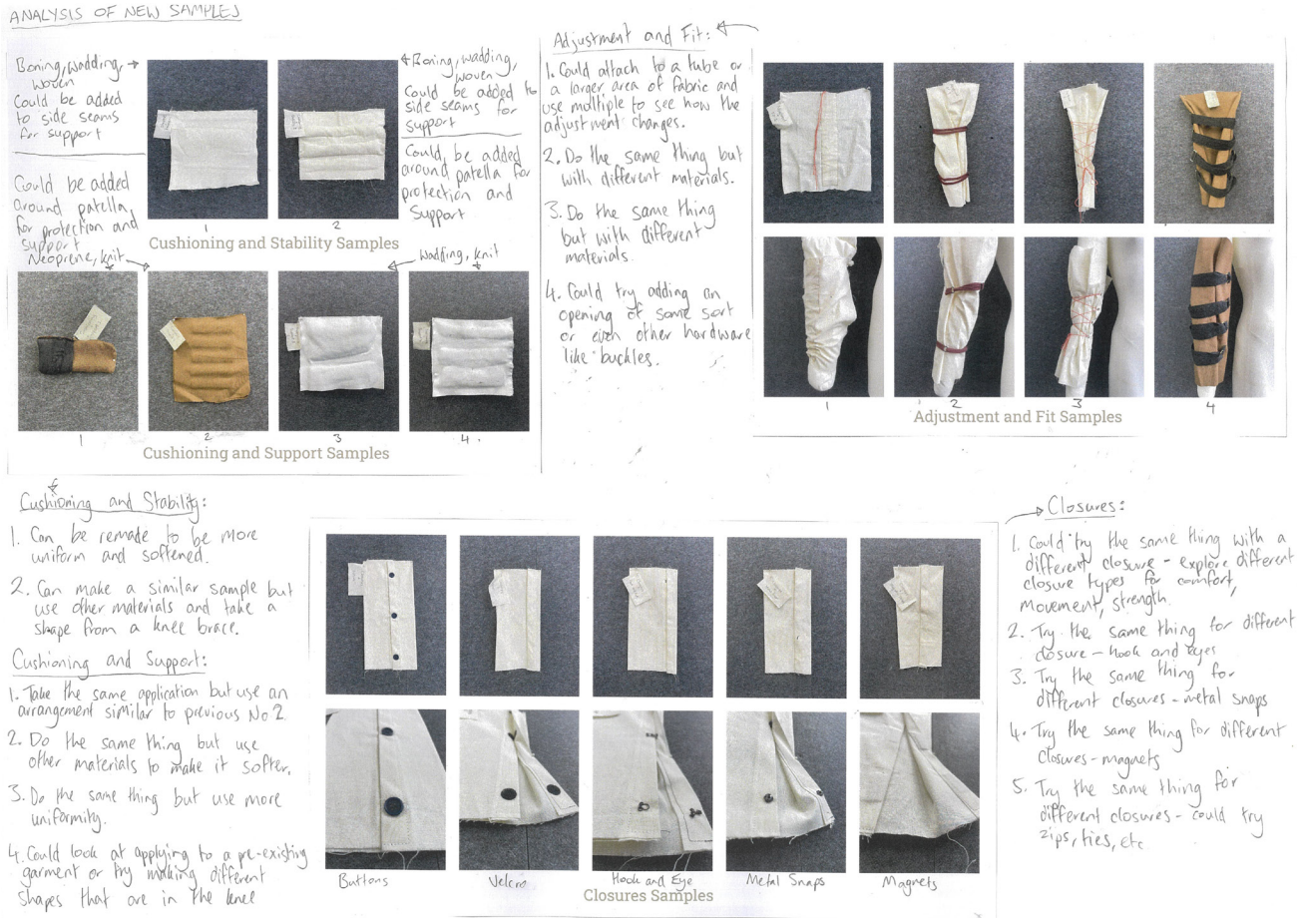


Fig. 56. Author's work. Exploration of cushioning, stability, support, adjustment, fit, openings, and closures, through sampling. 2025.

Once I gained an initial idea of what material properties and structures would work best for my project I completed an analysis of knit fabrics which then inspired an analysis of lace fabrics as they are usually associated with couture fashion or intimate apparel. I looked at the direction of stretch, construction, structure, and composition for knit fabric and then looked at physical qualities and visual impact for the lace. Completing these analyses further deepened my material research and exploration to find optimal qualities for knee brace design.

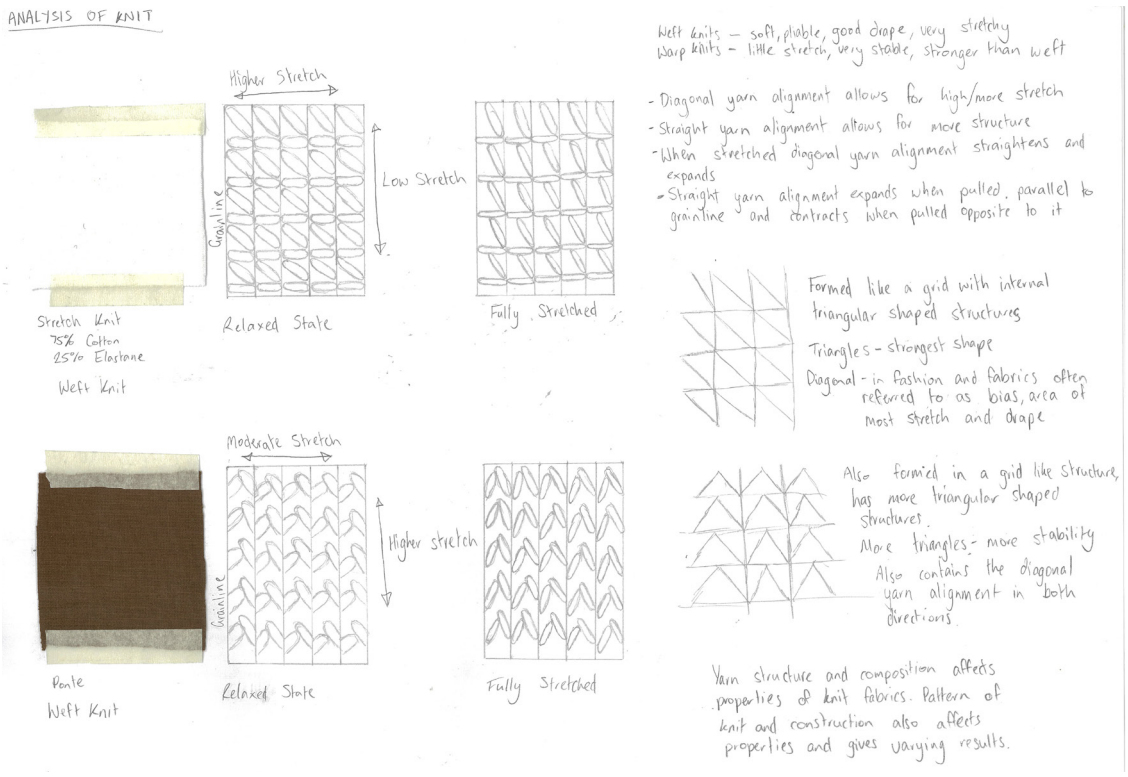
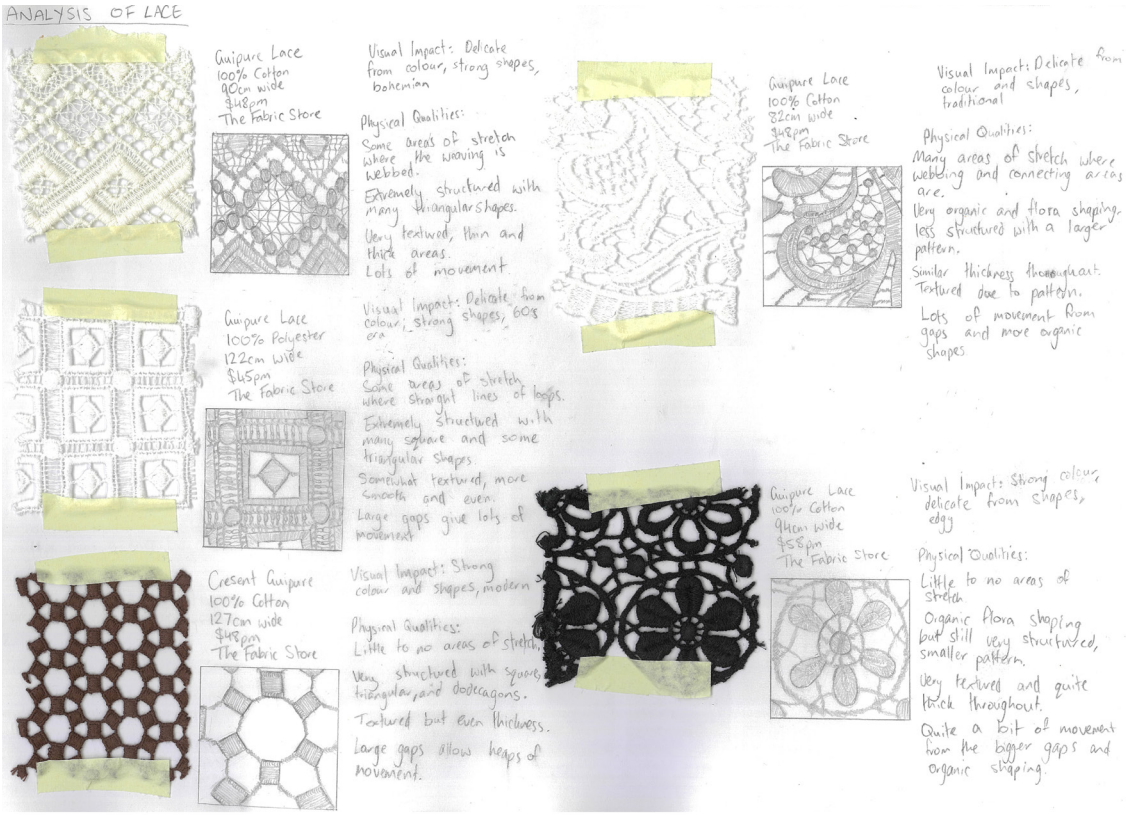


Fig. 57. Author's work. Exploration and analysis of knit and lace fabric properties, structure, and construction. 2025.



The analyses and parts of my context review led me to look at combinations of six fashion fabrics that are used for more industrial purposes to understand how stretch, compression, and feel are affected based on the application of materials. These fabrics can be categorised into their purposes, ponte, woven mesh, athletic poly mesh, and powermesh are more used for everyday and activewear, whereas poly mesh, and double mesh serve costuming and industrial wear. *The tabled analysis can be found in the appendix under Material Combination Analysis.*

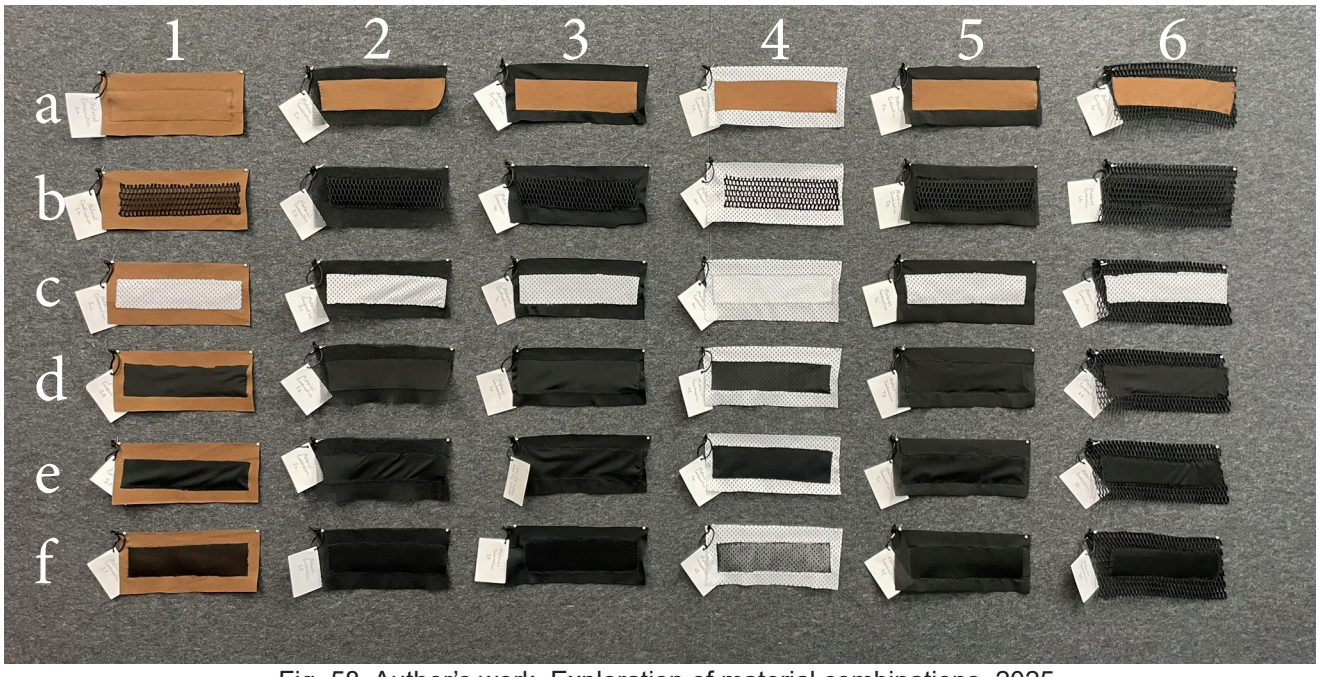


Fig. 58. Author's work. Exploration of material combinations. 2025.

Taking what I learned about combining materials I further explored ways to create materials by the use of 3D printing. I created models based on the structure of knit fabrics and how they are constructed to investigate the way 3D printing materials, PLA and TPU, and the structure of the model create movement and support. Through this exploration I also came across printing directly onto fabric, a form of combining materials which influenced how my project progressed. This also led into the investigation of existing auxetic structures and how their construction influences movement across three dimensional planes as I knew that would be an important aspect for designing around the knee, although further in the design process I did not use auxetic structures for their expansion properties. *The tabled analysis of PLA and TPU samples can be found in the appendix under Sample Diary.*

To be able to create the models for 3D printing I had to first teach myself a 3D modelling software, in this case Autodesk Fusion. As I was new to the software my samples based on knit fabric structure consisted of basic shapes, squares and triangles, that were either connected in triangular lineage or aligned in a way that would create movement between structures.

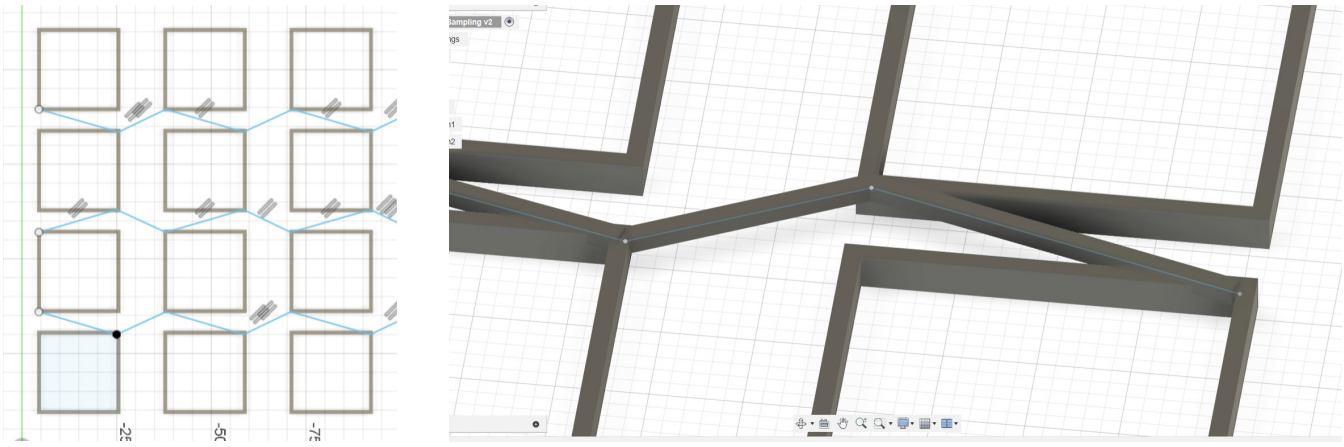


Fig. 59. Author's work. Learning Autodesk Fusion and creating models based on knit fabric to print as 3D printed samples and structures. 2025.

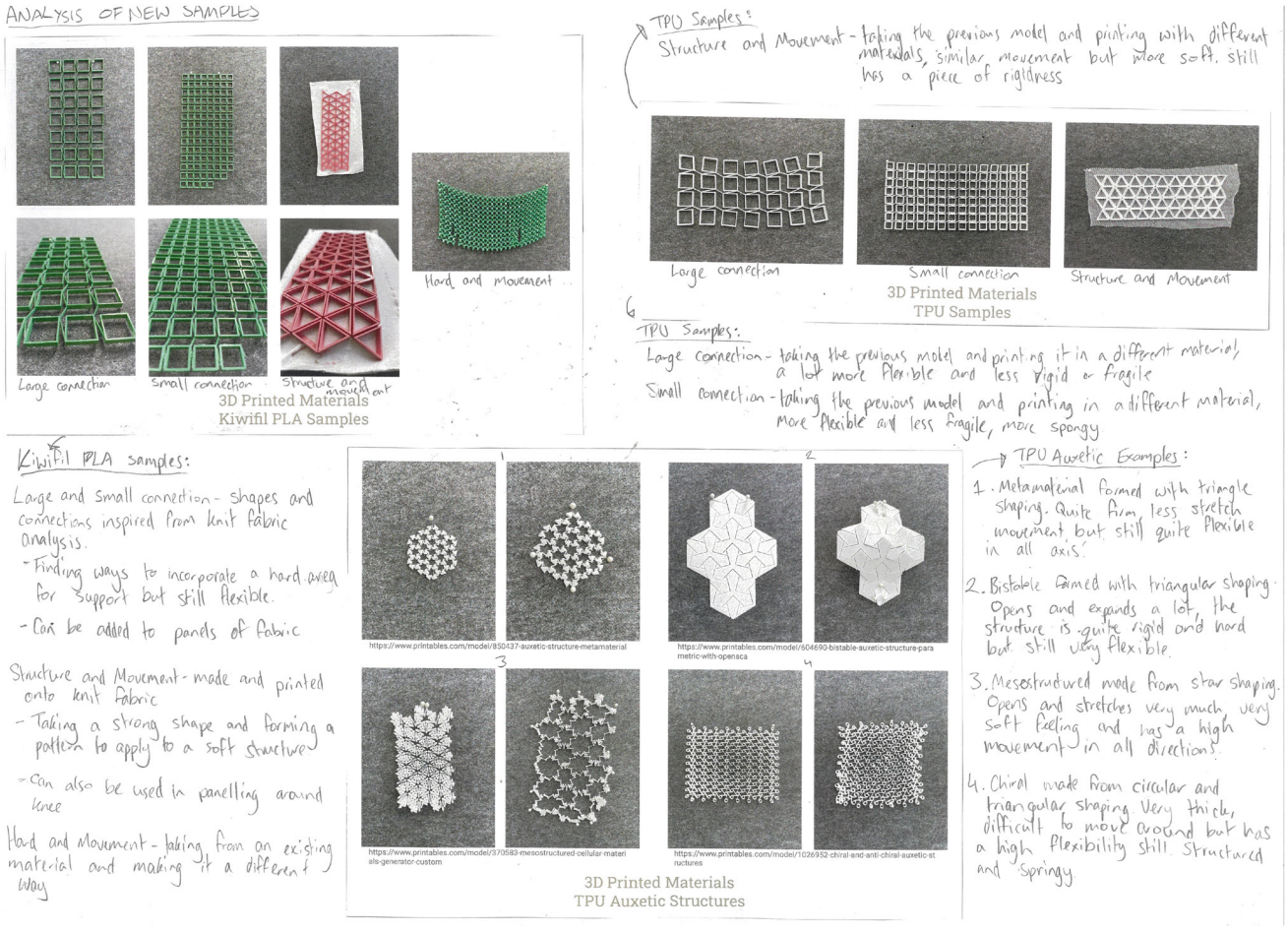


Fig. 60. Author's work. Exploration and analysis of 3D printed samples and structures. 2025.

This range of sampling and analysis was then used as part of my first workshop with my user with patella alta to gain a better understanding of the condition and user preferences.

4.1a User Workshop One

The first workshop with my user was used to understand how patella alta affects daily life, what knee braces are the most suitable, issues with clothing, and potential improvements that could be made to existing braces or clothing for accessibility, function, and aesthetics.

This workshop included a semi-structured interview and design feedback, with the initial sampling, and the open ended questionnaire, *see appendix*, being used as resources.

The questionnaire asked:

- General information their condition
- General information about their knee brace use
- Response to initial sampling
- Issues with clothing
- Possible future improvements
- Further involvement

The workshop was set up as shown below:

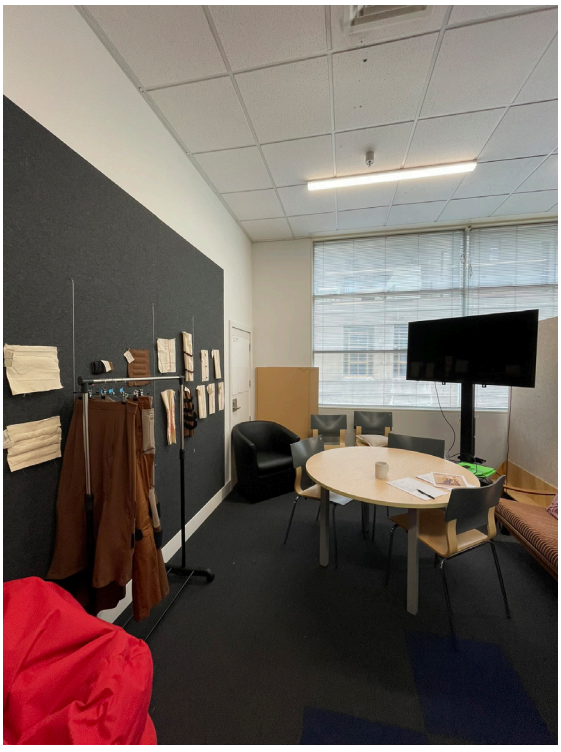


Fig. 61. Author's work. Workshop one set up. 2025.

Fig. 62. Author's work. Workshop one set up - samples on wall. 2025.

4.1b Initial Design Criteria

Visibility	• Slimlined - not having any bulk or odd areas sticking out • Able to hide the braces • Professional enough for work
Comfortable	• Fabric - natural, breathable, lightweight, and versatile • Loose - so the braces don't get caught in fabric with movement
Accessible	• Adjustable - garment openings that can be adjusted to allow adjustment of braces • Easy to use - something that can be put on quickly and not fiddly
Supportive	• Compression - underneath, above, or on the knee • Stability - down the inside and outside of knee
Aesthetically Pleasing	• Cross between empowerment and futuristic

Fig. 63. Author's work. Table of key themes and responses given by workshop participant. 2025.

The responses given by the participant were analysed and key themes were pulled out as shown in the table above. The responses from this workshop showed visibility, comfort, accessibility, support, and aesthetics being key themes that the user felt needed to be considered.

These themes fit into the Functional, Expressive, Aesthetic model as follows:

- Functional: Accessible, Supportive, Comfortable
- Expressive: Visibility
- Aesthetic: Fashion Oriented

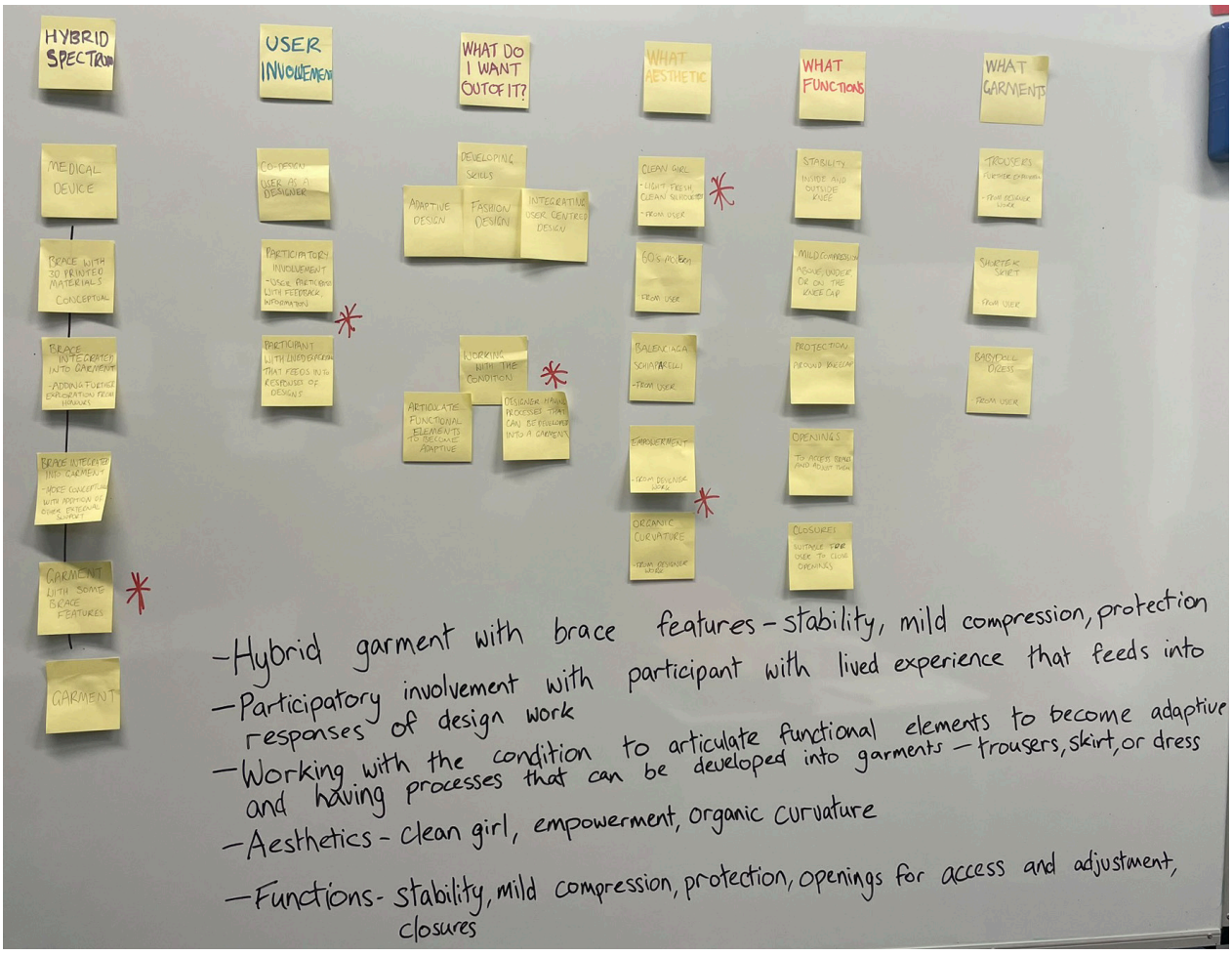


Fig. 64. Author's work. Design direction planning for outcomes, functions, methods, and fashion aesthetics. 2025.

After pulling out the functional aspects of the initial criteria I brainstormed the direction I wanted my project to go in as it was still very open and I had not made a decision on what my outcomes could look like. The direction I chose to take includes creating a hybrid garment with brace features - stability, mild compression, protection, or garments that can be worn with the wearer's existing braces. It was dependent on how further iterations work out. Functionally they would have stability, mild compression, protection, garment openings for access and adjustments and closures. My method was participatory involvement with lived experience that feeds design development and responses of design work throughout iterations. This was to be done by working with the participant to articulate their condition and provide information of functional elements to become adaptive fashion features. These mechanisms and processes can be developed and adapted to varied garments e.g. trousers, skirt, or dress. Chosen fashion aesthetics were derived from design values to change the mindset of disability to ability and strength through empowerment, and organic curvature inspired by body shape and dynamic lines.

4.2 Design Refinement

Having a focused direction led me to revisiting existing braces to begin designing a brace structure. I compared a soft strapped brace with a soft compression stabilising brace to understand the most important aspects that should be included in my design. I looked at the materials, uses, construction, and what they felt like while wearing to decide what design features would be the best to keep. Both braces had strengths and limitations but I found the compressive stabilising brace to be the most comfortable and suitable for use compared to my user feedback. It was made from multiple materials that had breathable, comfortable, and supportive properties, along with having flexible metal supports that could bend with the knee. The strapped brace was less effective as its base material harbours moisture against the skin and has a raw edge which made it less likely to stay in place against your leg and caused it to slip down. Both braces were quite comfortable in terms of compression but for movement and all day wear the stabilising brace was optimal.

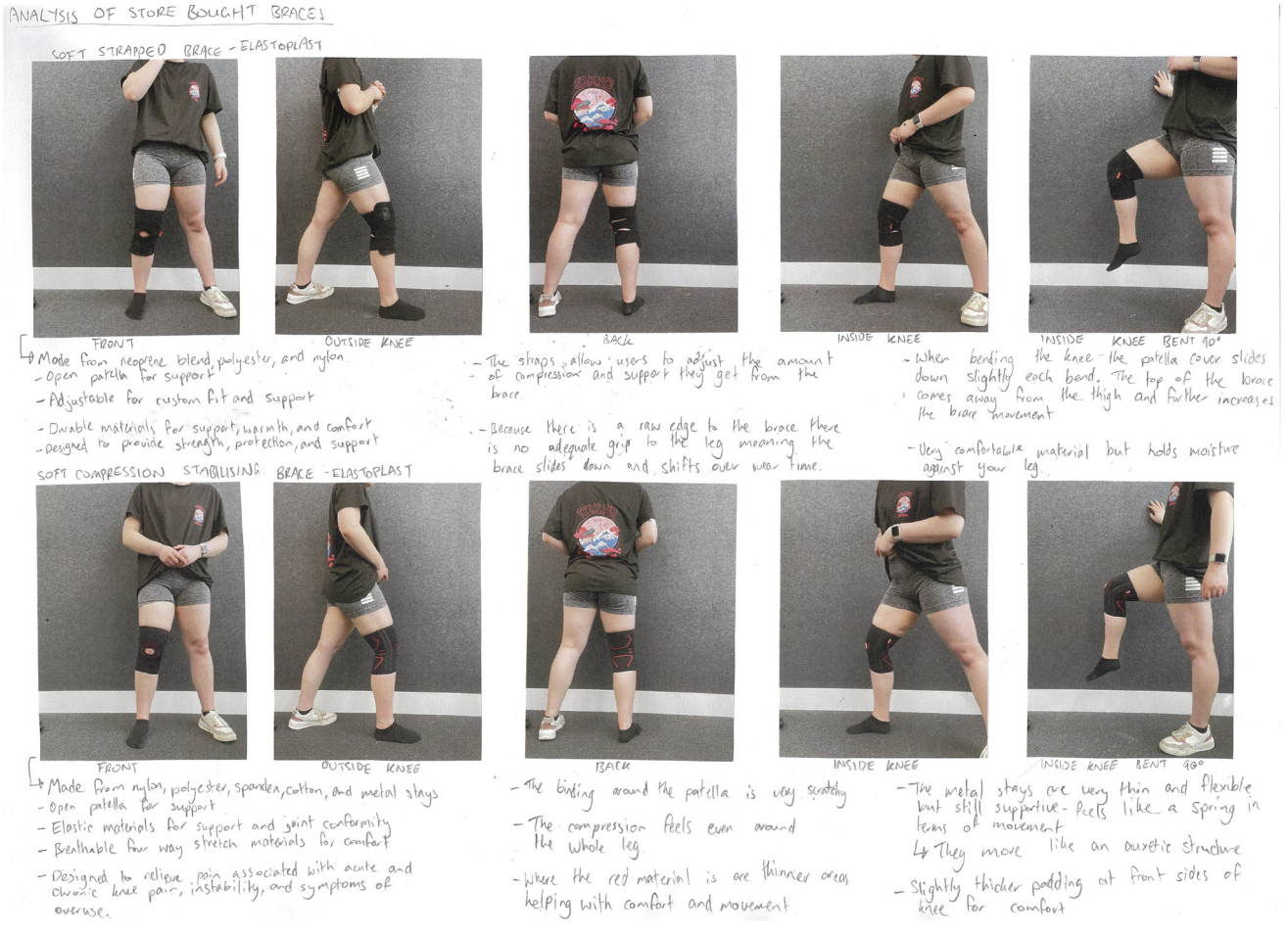


Fig. 65. Author's work. Analysis of soft store bought braces comparing, materials, pattern shape, construction, compression, and comfort. 2025.

Sampling research including 3D printing and lace fabric is combined to meet functional and aesthetic needs.

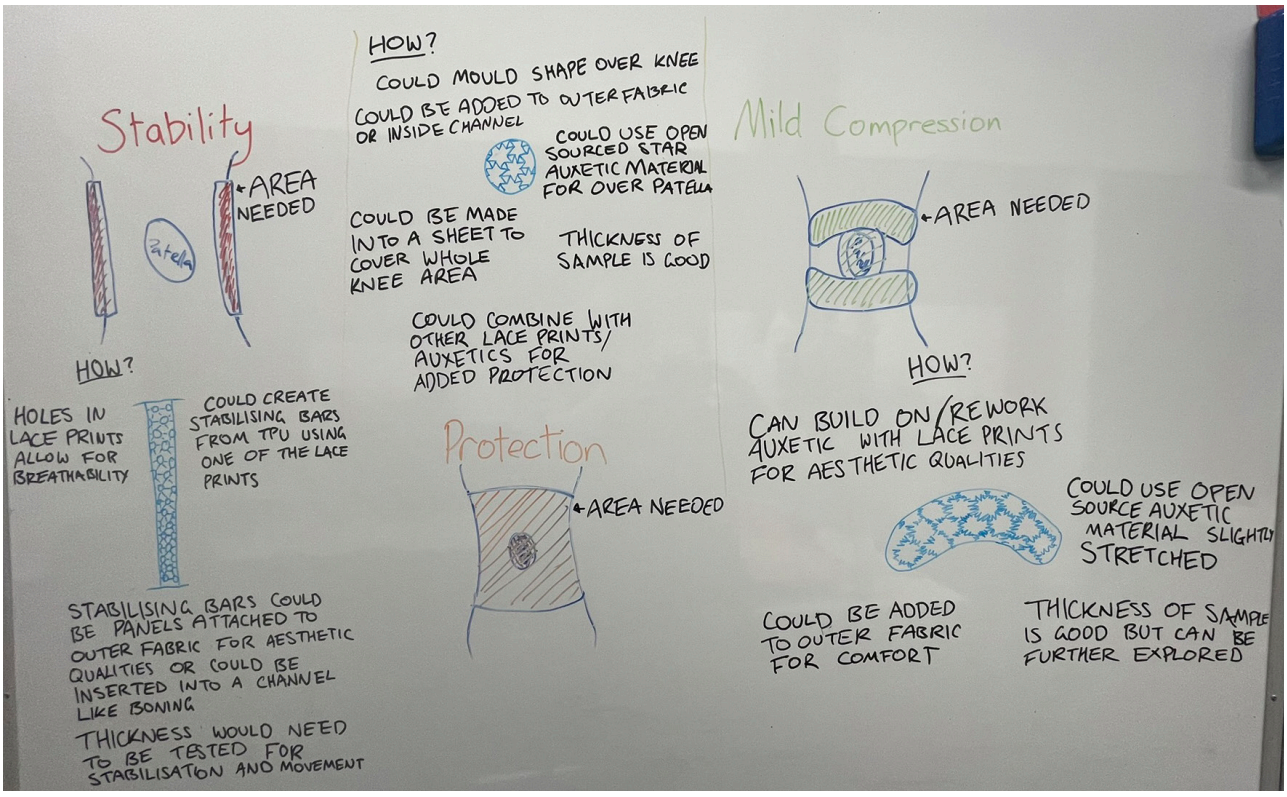


Fig. 66. Author's work. Planning the use of 3D printing. 2025.

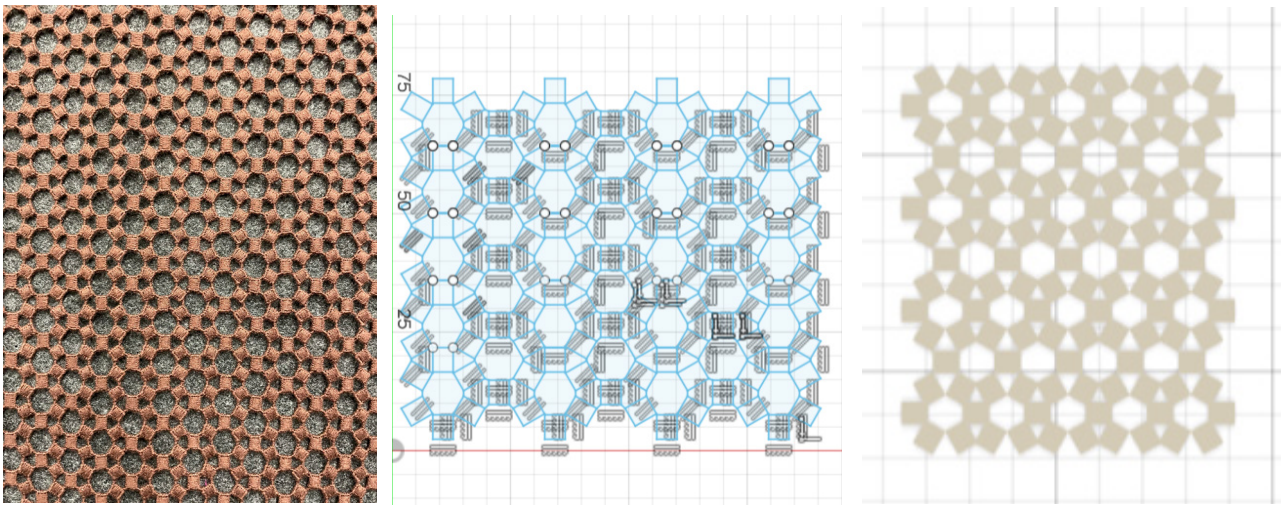


Fig. 67. Author's work. Using a square lace fabric as a reference to 3D model. 2025.

Fig. 68. Author's work. Using a square lace fabric as a reference to 3D model, printing model in TPU on it's own and on powermesh as stabilising bars. 2025.

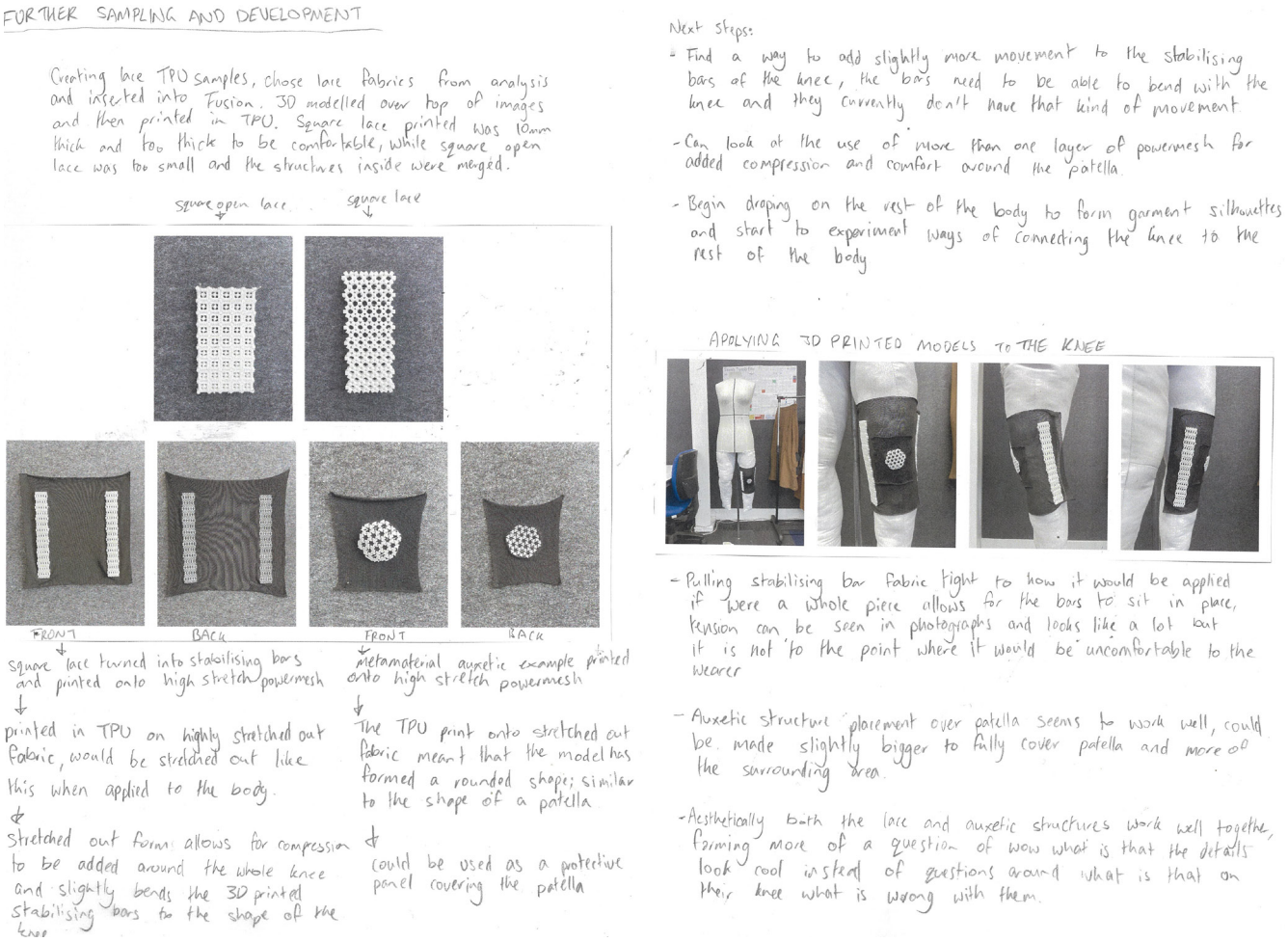


Fig. 69. Author's work. Analysis of lace structure models, printing TPU on fabric, and applying to a knee. 2025.

The previous pages show how I began the brace structure design. I developed a 3D model in Fusion based on the structure of one of the lace fabrics I analysed. I chose this square lace for ease of design but also for the way the fabric moved when I was holding it. I formed the model into rectangle structures to form stabilising bars that are found in existing braces. To look at how it could be applied to a garment I printed the model using a TPU filament for its flexibility and printed onto powermesh as it is thin enough for the layers of filament to stick to each other but it is also used in fashion design as a stabilising fabric in lingerie. I also looked at printing one of the auxetic structures onto a powermesh and applied both prints to the knee. After analysing the prints and the relation they have to the knee I realised that the protection over the kneecap was not needed as the braces I looked at both had open patella holes. I also noticed the stabilising bars were quite thick and could not move in a direction that would replicate the way a knee bends so further development was needed.

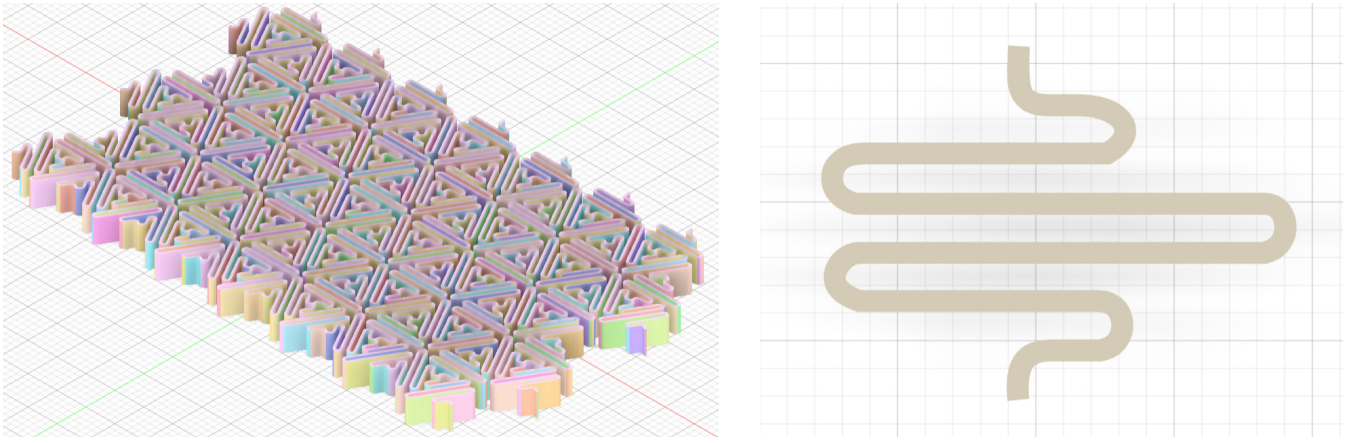


Fig. 70. Author's work. Remodelling an existing auxetic structure in Fusion to be used for movement. 2025.

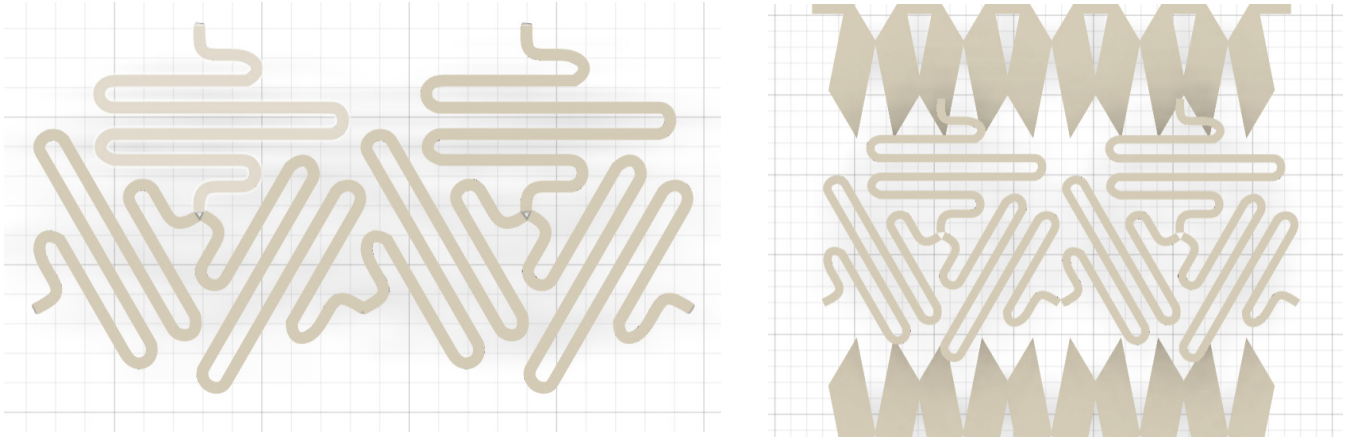


Fig. 71. Author's work. Remodelling an existing auxetic structure in Fusion to be used for movement, and applying it to existing 3D stabilising bar models. 2025.

Fig. 72. Author’s work. Updated stabilsing bar sample, black TPU on powermesh. 2025.

To add extra movement in the middle of the stabilising structures I took inspiration from one of the auxetic structures I investigated and applied it to the existing 3D model. I took the original model and put it into individual shapes to build a smaller version of it that would allow movement through the middle of the knee. I also made this model thinner than the last one and is the same thickness as the stabilising bars found in the existing soft compression brace. I printed on the powermesh by stretching it over the build plate of an Ultimaker 3D printer and holding it down in place with bulldog clips, it was the same technique as what I used for my initial sampling but I used black filament instead of white due to the colour of the fabric and found that this sample functionally worked better than the last. It can move slightly with the movement of a knee while still having enough stability to serve its purpose. The finish is also a lot smoother and would feel more comfortable for wear. At this stage in the process, the stabilising bars proved strong and flexible, so I changed my focus to creating a circular support piece for the patella.

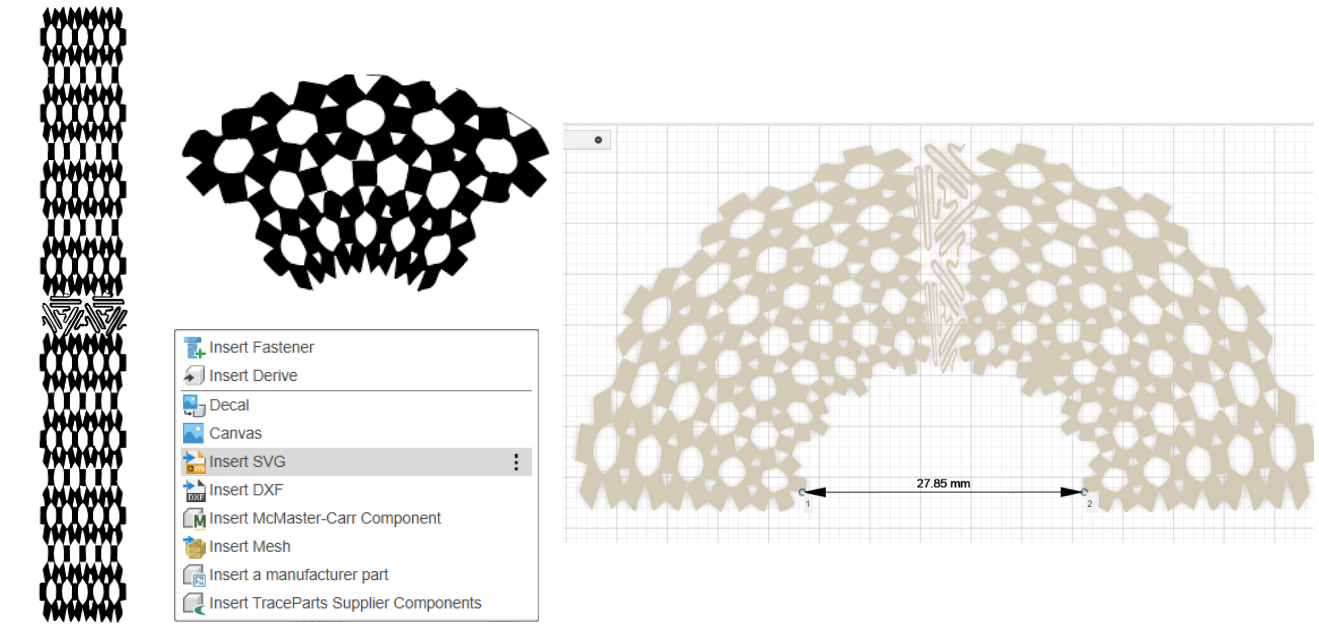


Fig. 73. Author's work. Creating an image trace in illustrator, arcing it, then reinserting into Fusion as a SVG file to form a 3D model. 2025.

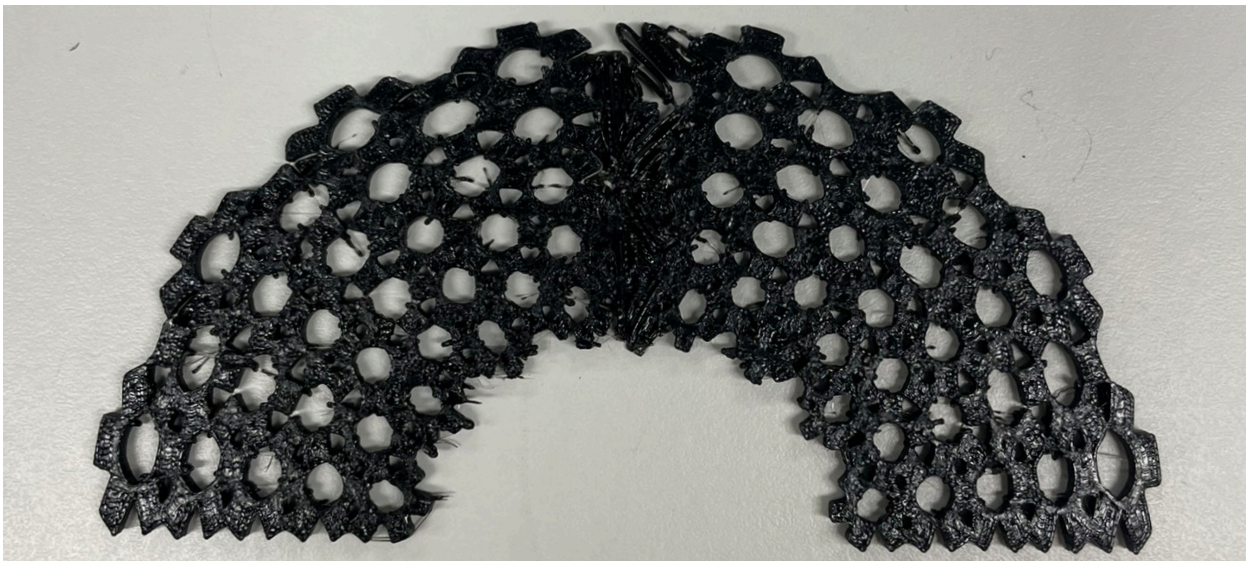


Fig. 74. Author's work. 3D printed circular support model in TPU. 2025.

The area around the patella is often a padded shape in existing braces so I wanted to try to create support in a more lightweight form and structure with the 3D printing. I took an image of my most recent stabilising bar model and imported it into illustrator to create an image trace that I could edit using the arc function to form a rounded shape. I exported it as a SVG file and imported it back into Fusion to create a model from it. I printed the model out on its own first so I could see what it would look like before applying it to fabric. Once printed I realised the arc shape worked well but there was no use for the areas of movement in the center so it was removed before the shape was developed further.

Fig. 75. Author's work. Concept board, fashion aesthetics and organic curvature. 2025.

To begin merging ideas together I started to develop concepts based on fashion aesthetics. These aesthetics are derived from design values to change mindsets of disability to ability and strength. I originally had four concept boards but the direction of my project has brought that number down to two. This concept is based on organic curvature which is inspired by body shape, dynamic, and movement lines. It portrays a range of rounded shapes formed by organic lines to create the relationship of the body silhouette, the way we move and how it changes, and the effect of garment silhouettes to the body. The colouring represents the materials that have been used and explored.

Fig. 76. Author’s work. Concept board, fashion aesthetics and celebrating brace pattern shapes. 2025.

This concept is based on celebrating shapes formed by brace patterns. The image portrays the leftover material from creating strapped braces out of a fashion fabric. The brace patterns have created a unique and organically shaped piece of materials that shows how beautiful knee braces can be, along with paying homage to their origins.

4.3 Prototype Development

To consider how the brace structures could be applied to garments I completed a series of fitted trouser legs with panel shaping based on shapes found from knee brace patterns. These trouser legs were also used to explore combining the powermesh I had been using to 3D print, which is a high stretch knit, with ponte, a moderate stretch knit, and also the layering of fabrics to suit a range of purposes such as compression and comfort.

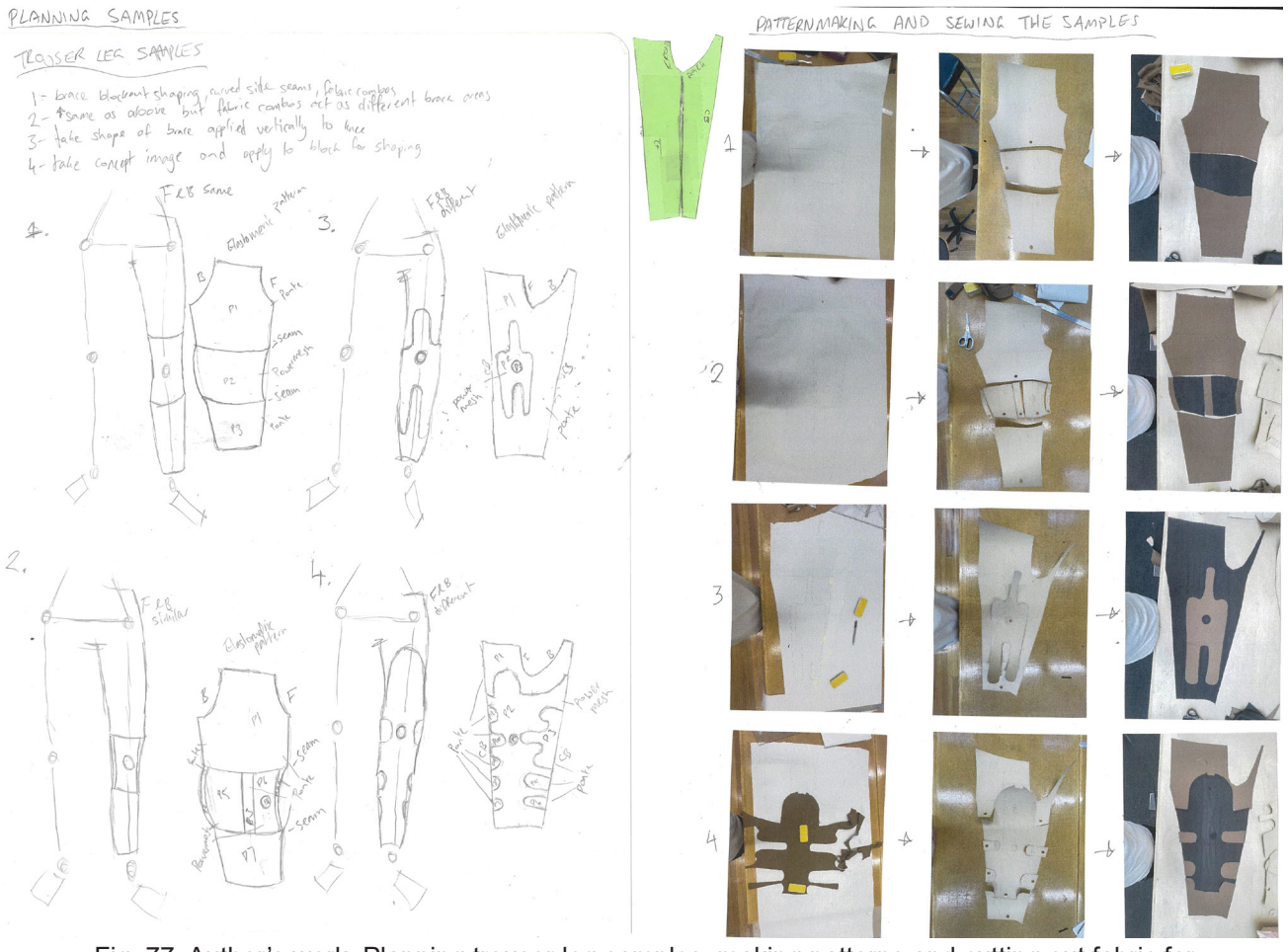


Fig. 77. Author's work. Planning trouser leg samples, making patterns and cutting out fabric for construction. 2025.

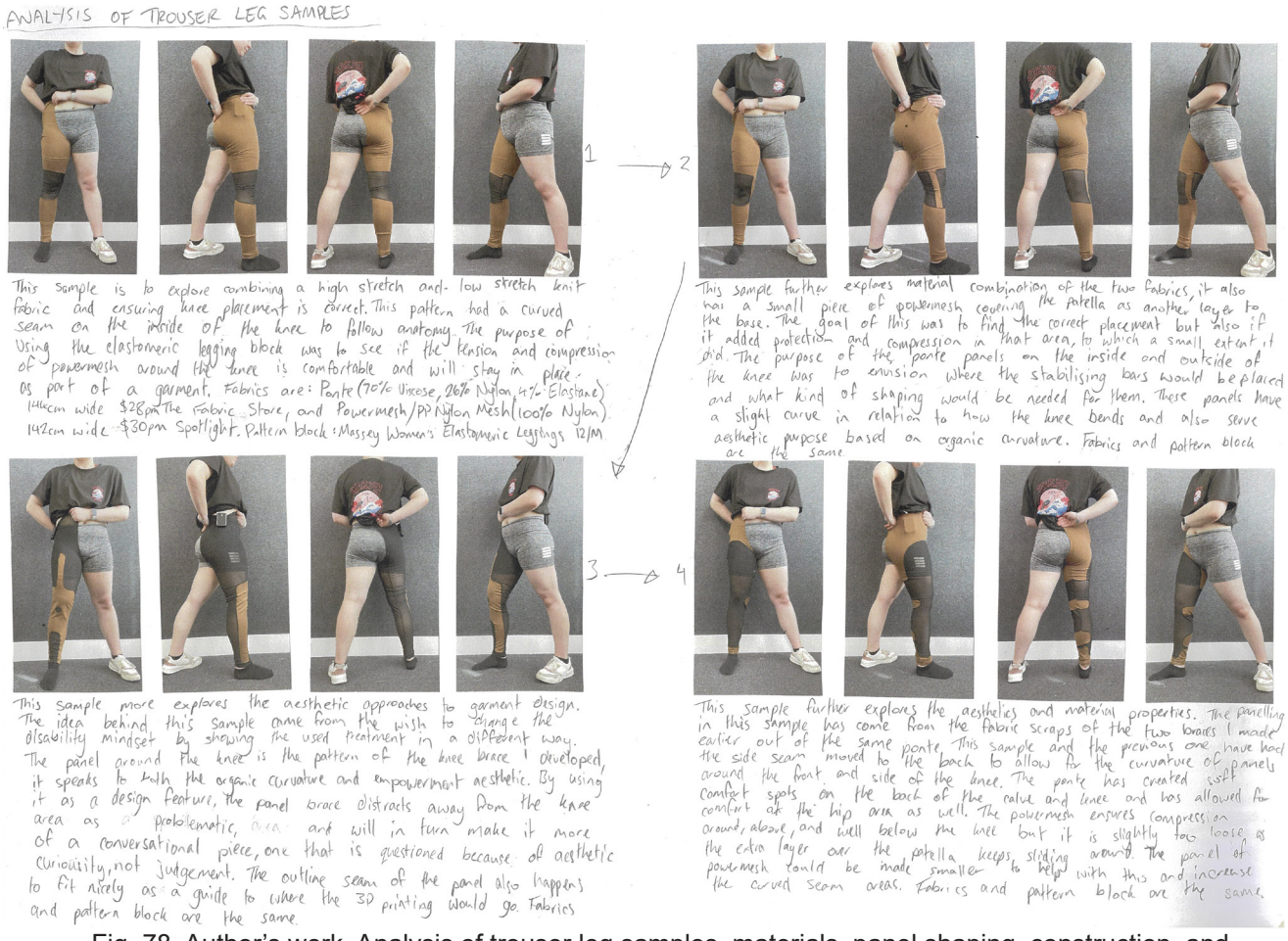
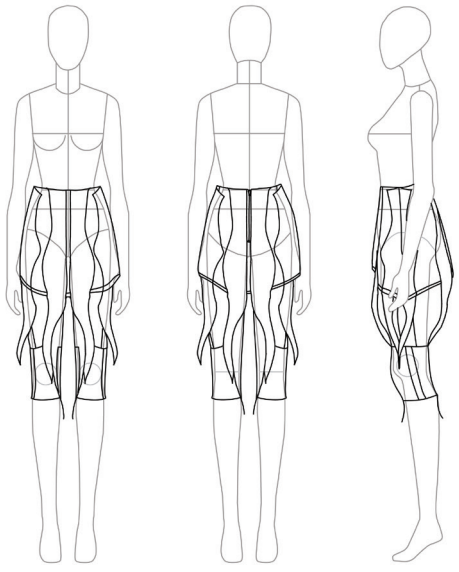
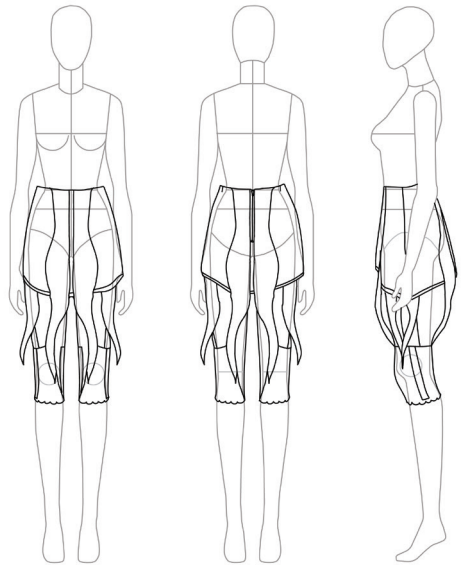
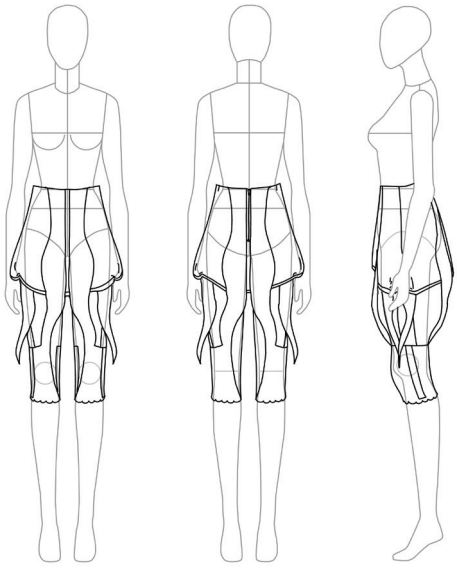


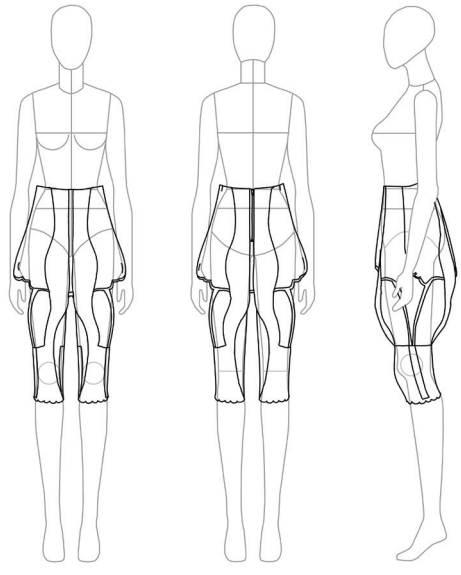
Fig. 78. Author's work. Analysis of trouser leg samples, materials, panel shaping, construction, and purpose. 2025.

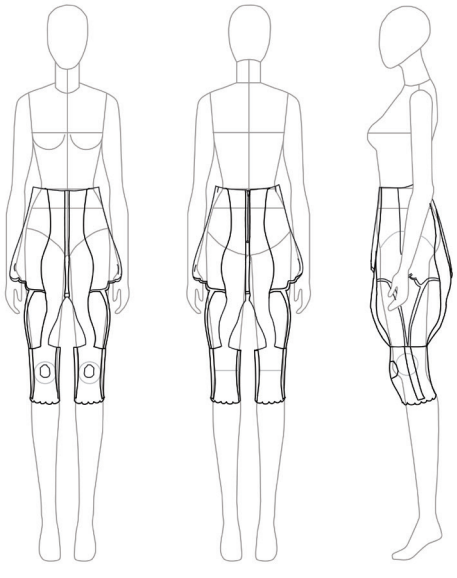
This trouser leg series along with a range of garment research inspired the beginnings for my garment iteration sketches. My iterations explore a range of garments and look at how a knee brace structure could be integrated into a design in a more creative and aesthetic way. The garment silhouettes come from a range of references; streetwear, casualwear, my concept boards, and the disruption caused to garments from knee braces, have all been considered and explored. The focus of my iterative sketches was to develop final designs for four outcomes that had been chosen to effectively show how my process can be applied in the fashion design industry. Those outcomes were a brace, fitted trouser/leggings with built in braces, bootleg trousers with a partial internal and external built in brace, and balloon pants with a front opening to show off the brace which could be worn with the brace from this project or an already existing medical brace. Figure 79 over the following five pages show my iterative sketching journey from start to end.

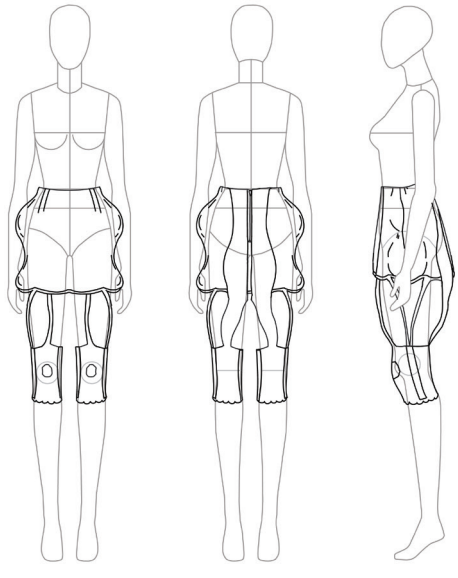


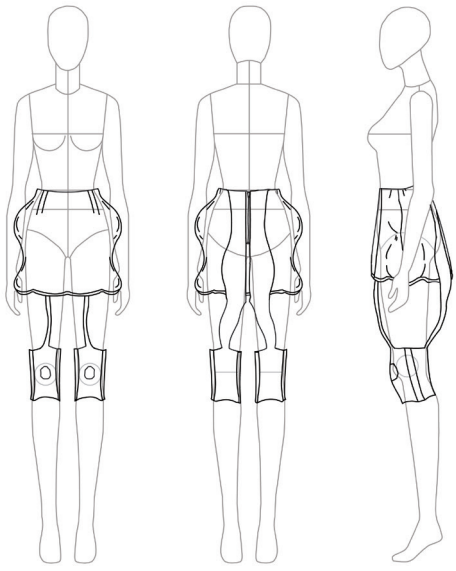


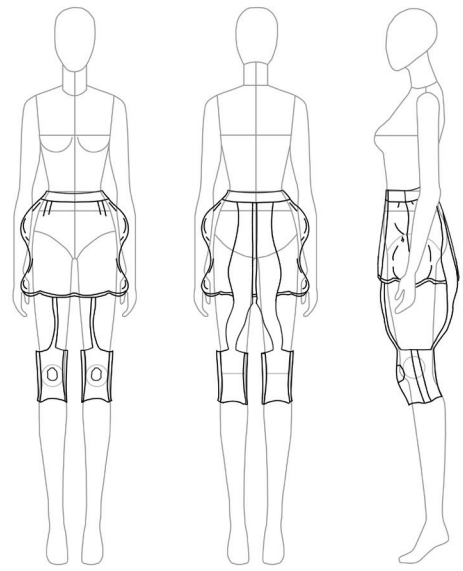


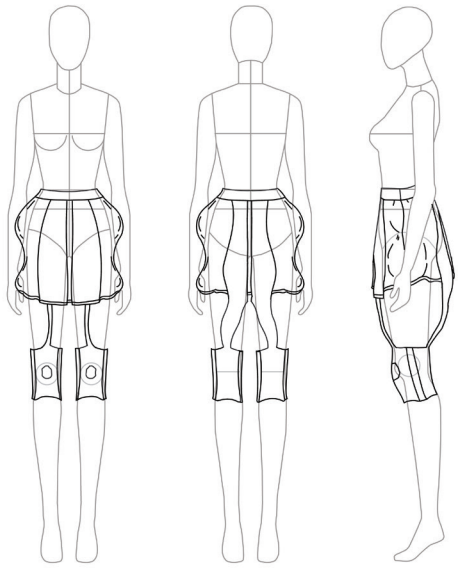


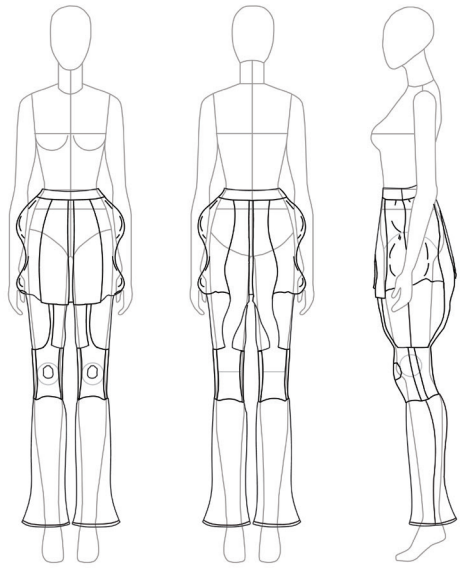


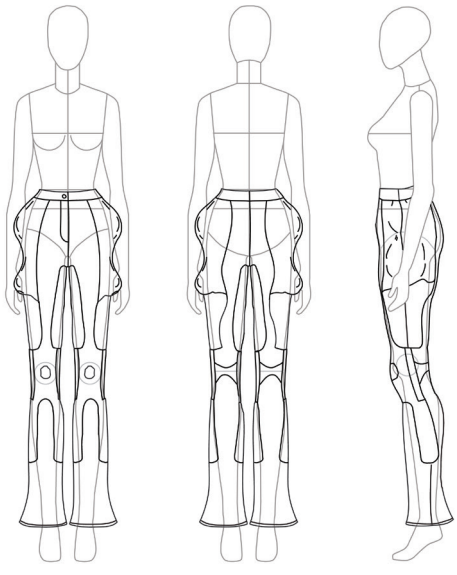


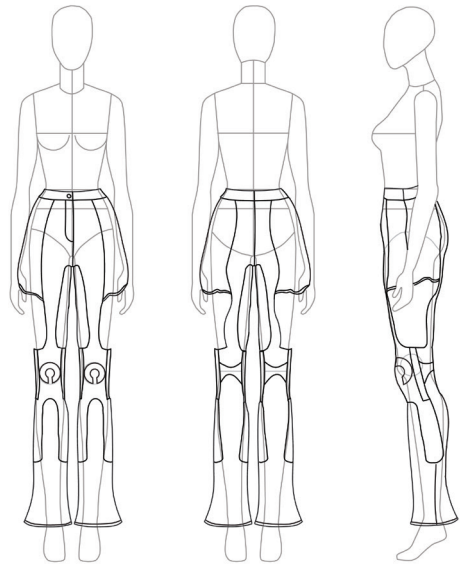


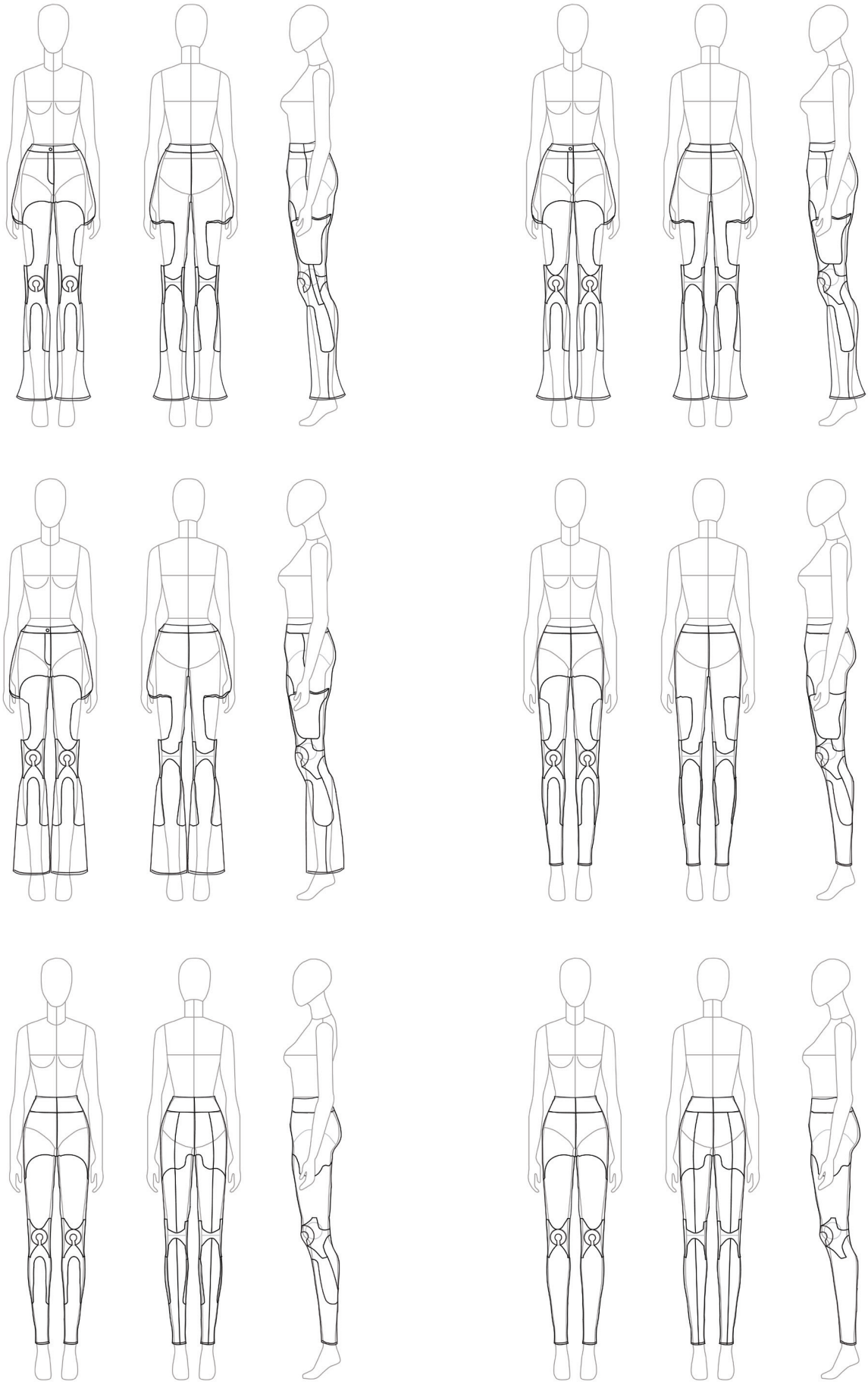


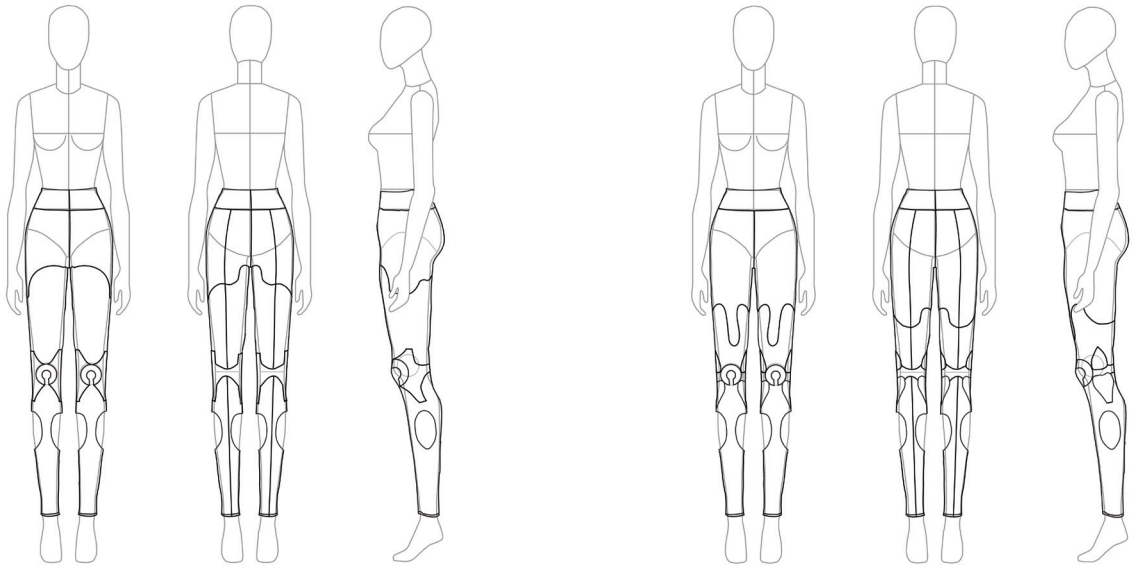


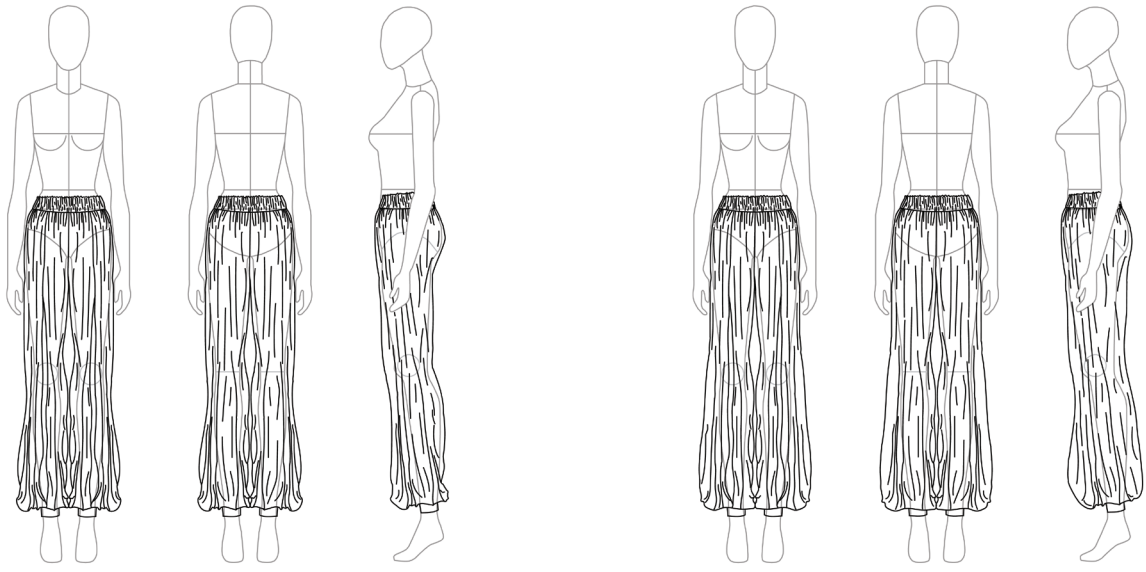


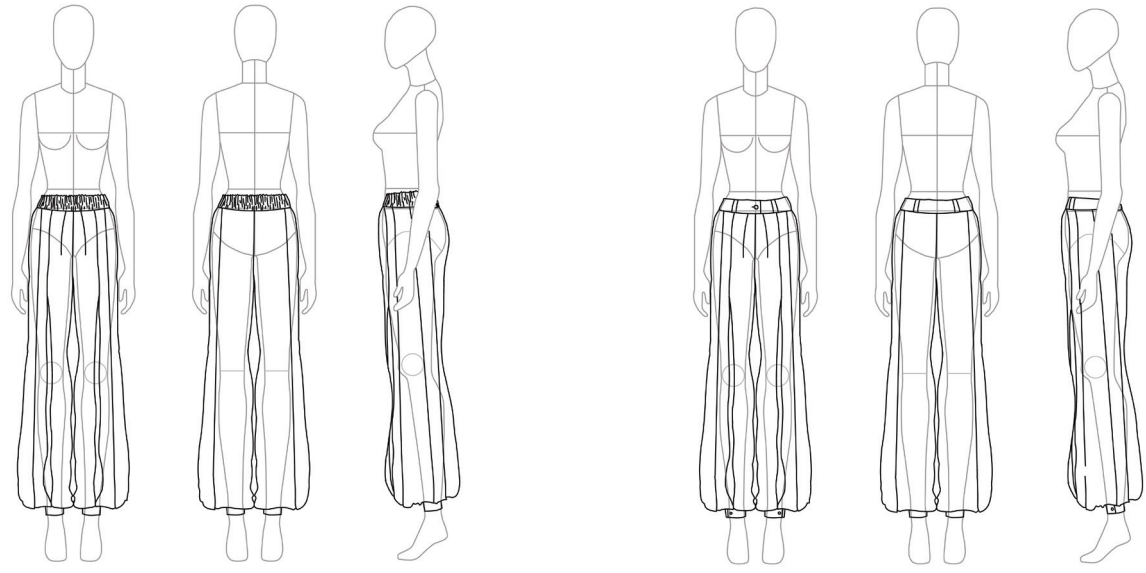


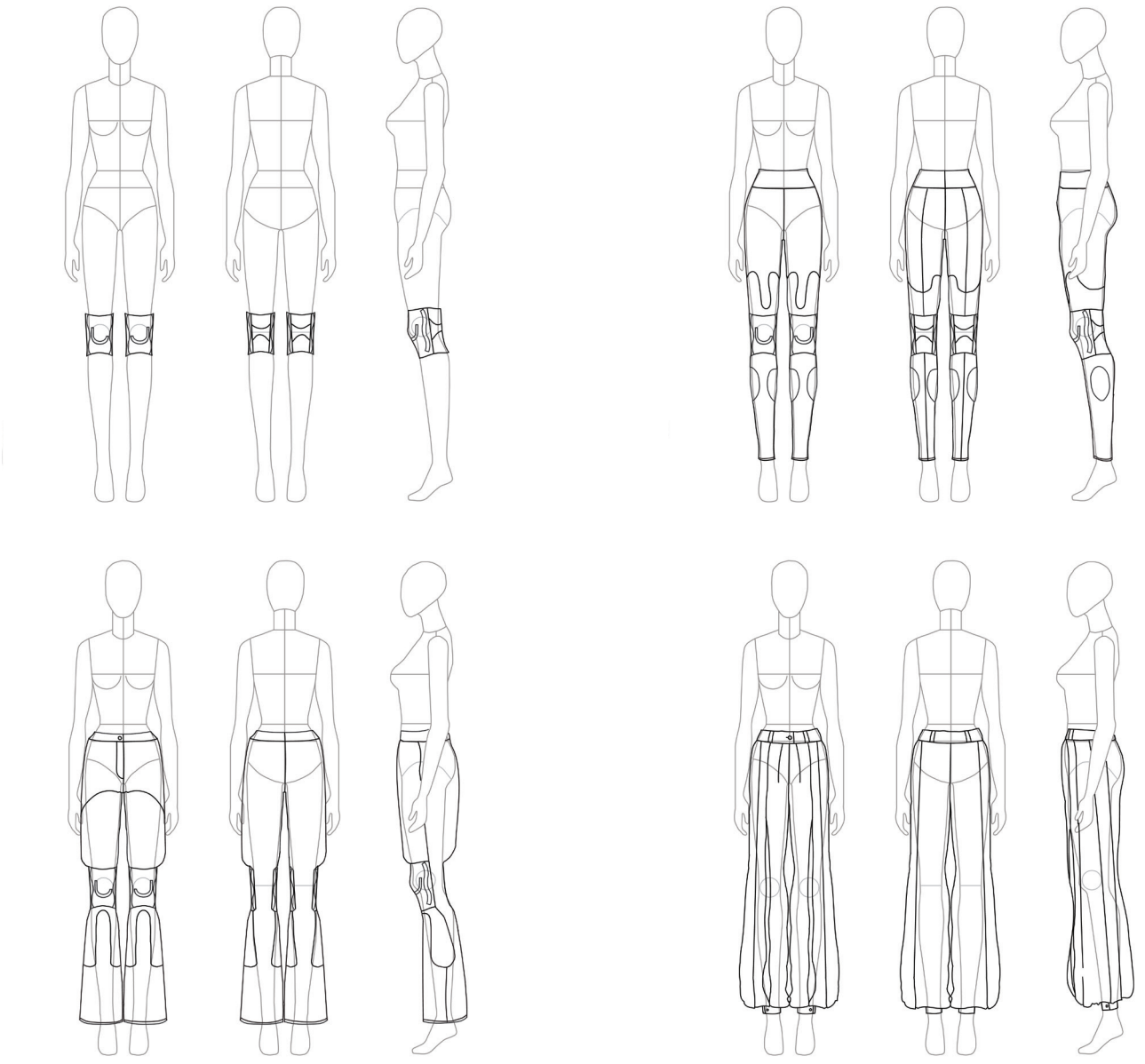




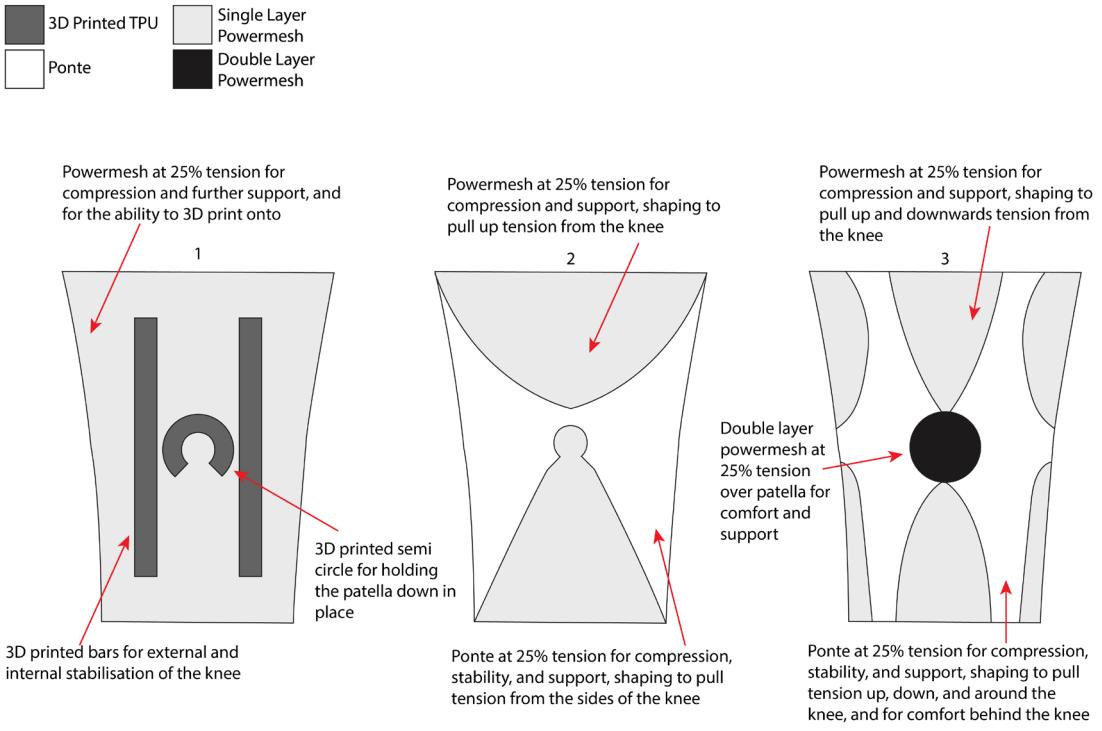


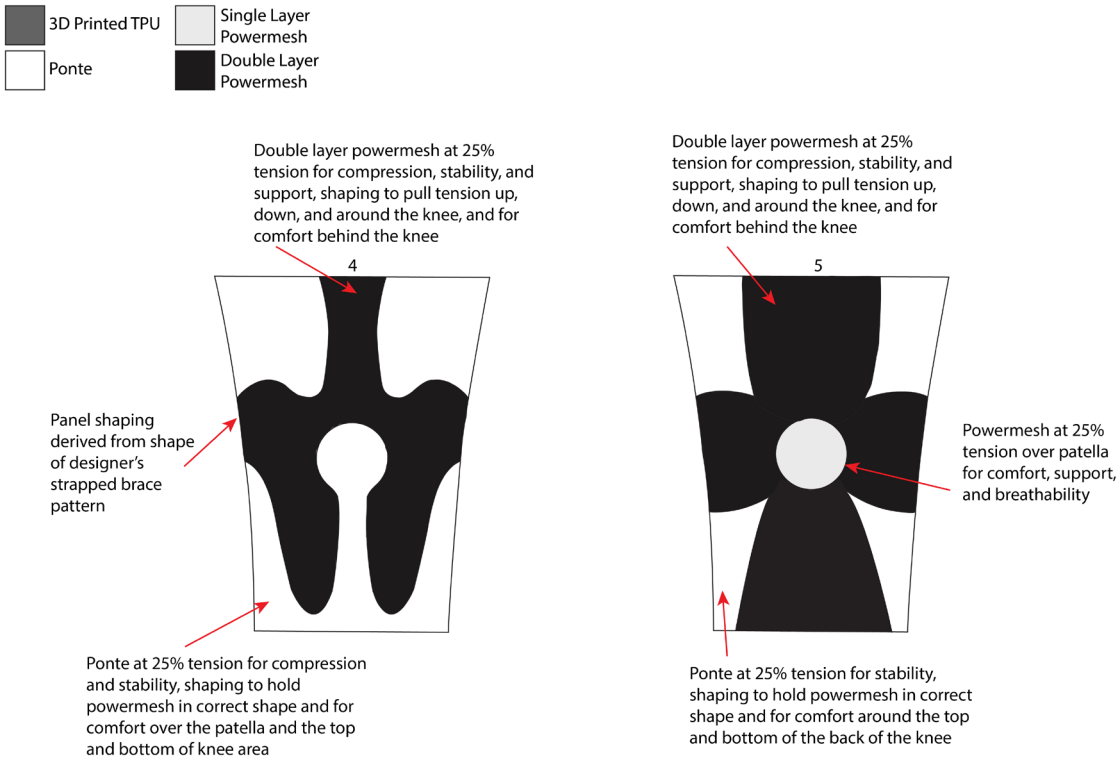


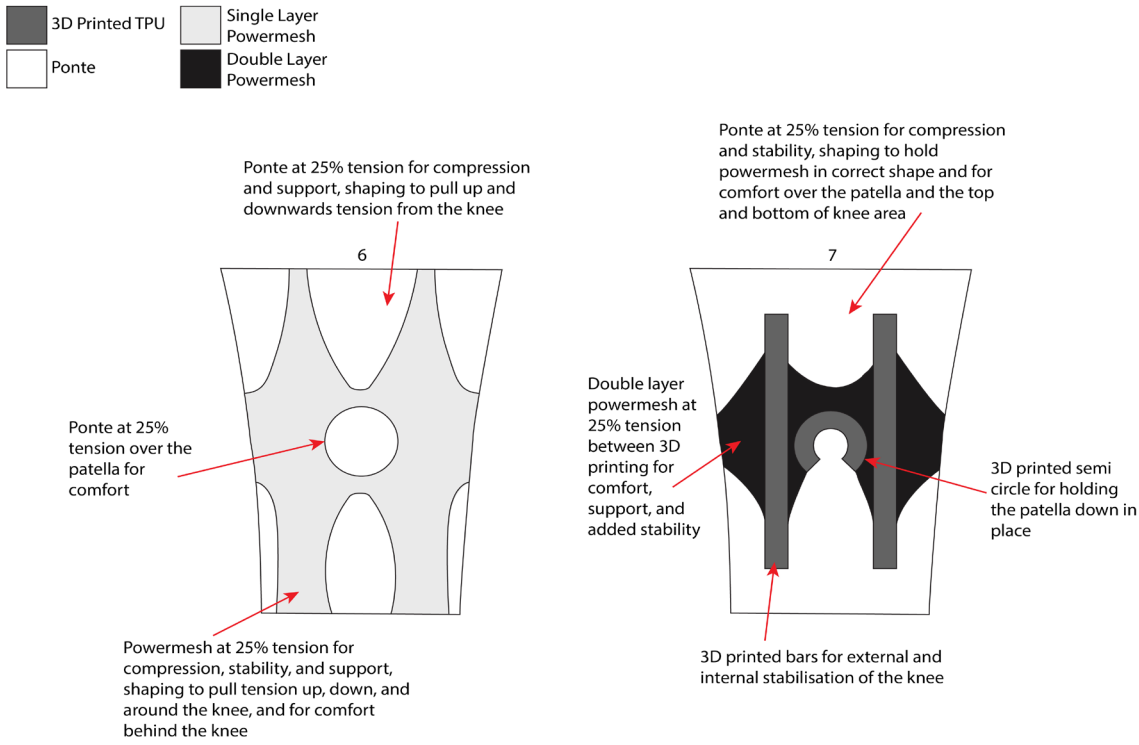


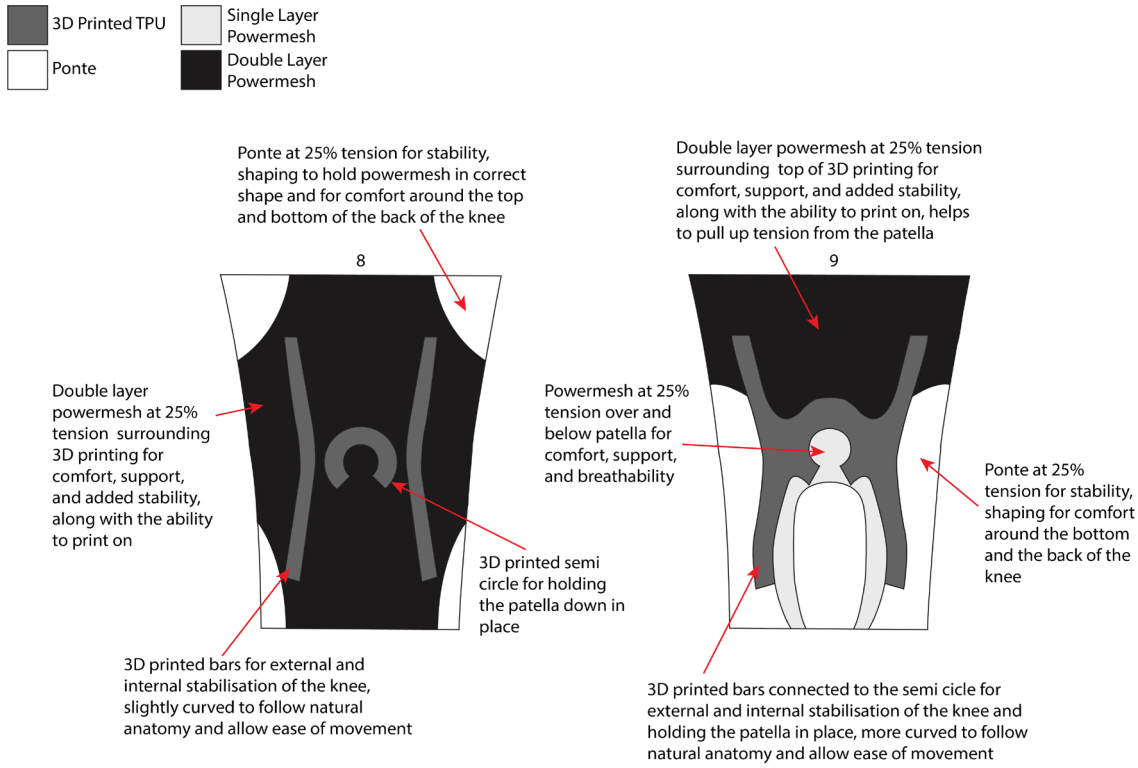


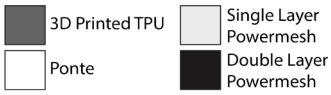
After creating my iterative sketches my focus went back to developing the brace structure. I drew up a series of potential braces to be sampled. These brace drawings were created with materials and shape kept in mind. There are thirteen drawings, each with specific panel shaping to accommodate compression, comfort, and stability, along with some of them having 3D printed structures which come in a range of shaping and connections to explore what could work best for stability and movement. Figure 80 over the following three pages show each of my drawings and their annotations detailing features and materials.

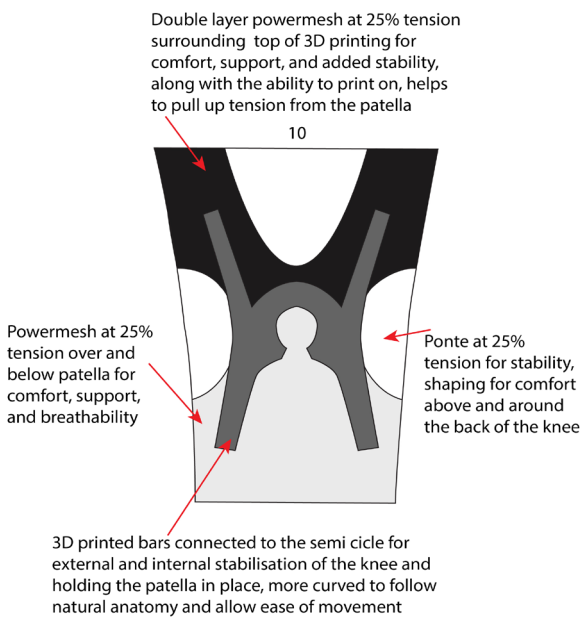

3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh
Powermesh at 25% tension for compression and further support, and for the ability to 3D print onto
1
3D printed semi circle for holding the patella down in place
3D printed bars for external and internal stabilisation of the knee
Powermesh at 25% tension for compression and support, shaping to pull up tension from the knee
2
Ponte at 25% tension for compression, stability, and support, shaping to pull tension from the sides of the knee
Powermesh at 25% tension for compression and support, shaping to pull up and downwards tension from the knee
3
Double layer powermesh at 25% tension over patella for comfort and support
Ponte at 25% tension for compression, stability, and support, shaping to pull tension up, down, and around the knee, and for comfort behind the knee

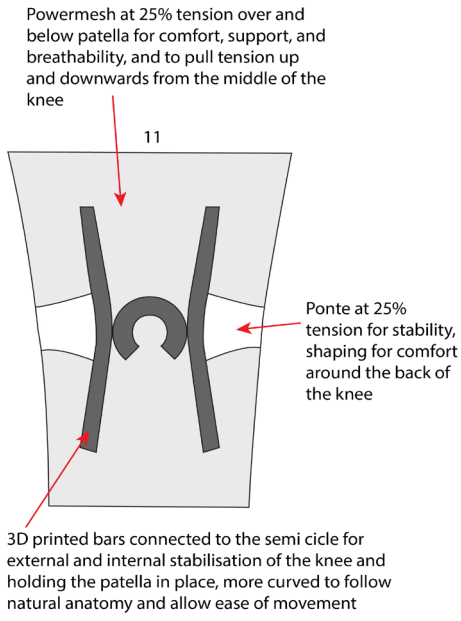

3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh
Double layer powermesh at 25% tension for compression, stability, and support, shaping to pull tension up, down, and around the knee, and for comfort behind the knee
4
Panel shaping derived from shape of designer's strapped brace pattern
Ponte at 25% tension for compression and stability, shaping to hold powermesh in correct shape and for comfort over the patella and the top and bottom of knee area
Double layer powermesh at 25% tension for compression, stability, and support, shaping to pull tension up, down, and around the knee, and for comfort behind the knee
5
Powermesh at 25% tension over patella for comfort, support, and breathability
Ponte at 25% tension for stability, shaping to hold powermesh in correct shape and for comfort around the top and bottom of the back of the knee

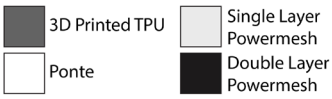

3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh
6
Ponte at 25% tension for compression and support, shaping to pull up and downwards tension from the knee
Ponte at 25% tension over the patella for comfort
Powermesh at 25% tension for compression, stability, and support, shaping to pull tension up, down, and around the knee, and for comfort behind the knee
7
Ponte at 25% tension for compression and stability, shaping to hold powermesh in correct shape and for comfort over the patella and the top and bottom of knee area
Double layer powermesh at 25% tension between 3D printing for comfort, support, and added stability
3D printed semi circle for holding the patella down in place
3D printed bars for external and internal stabilisation of the knee

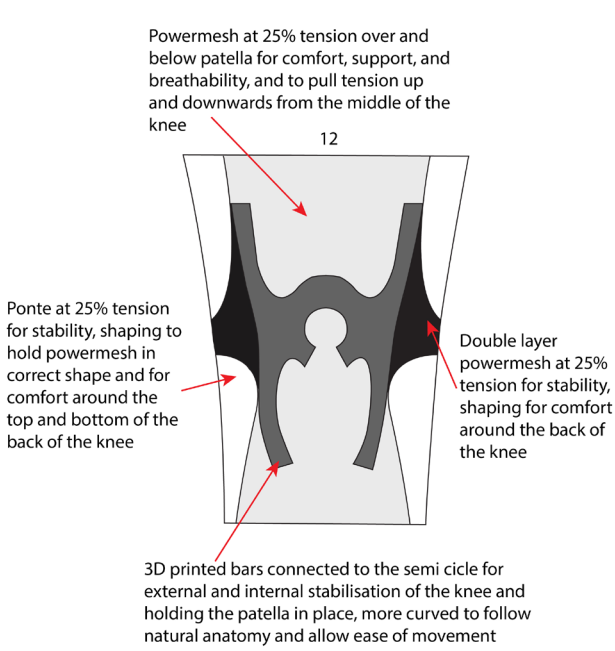

3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh
8
Ponte at 25% tension for stability, shaping to hold powermesh in correct shape and for comfort around the top and bottom of the back of the knee
Double layer powermesh at 25% tension surrounding 3D printing for comfort, support, and added stability, along with the ability to print on
3D printed semi circle for holding the patella down in place
3D printed bars for external and internal stabilisation of the knee, slightly curved to follow natural anatomy and allow ease of movement
9
Double layer powermesh at 25% tension surrounding top of 3D printing for comfort, support, and added stability, along with the ability to print on, helps to pull up tension from the patella
Powermesh at 25% tension over and below patella for comfort, support, and breathability
Ponte at 25% tension for stability, shaping for comfort around the bottom and the back of the knee
3D printed bars connected to the semi cicle for external and internal stabilisation of the knee and holding the patella in place, more curved to follow natural anatomy and allow ease of movement

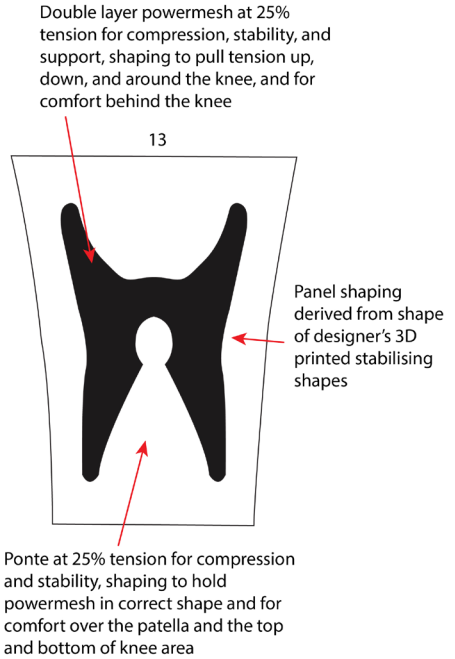

3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh


Double layer powermesh at 25% tension surrounding top of 3D printing for comfort, support, and added stability, along with the ability to print on, helps to pull up tension from the patella
10
Powermesh at 25% tension over and below patella for comfort, support, and breathability
Ponte at 25% tension for stability, shaping for comfort above and around the back of the knee
3D printed bars connected to the semi cicle for external and internal stabilisation of the knee and holding the patella in place, more curved to follow natural anatomy and allow ease of movement


Powermesh at 25% tension over and below patella for comfort, support, and breathability, and to pull tension up and downwards from the middle of the knee
11
Ponte at 25% tension for stability, shaping for comfort around the back of the knee
3D printed bars connected to the semi cicle for external and internal stabilisation of the knee and holding the patella in place, more curved to follow natural anatomy and allow ease of movement


3D Printed TPU
Ponte
Single Layer Powermesh
Double Layer Powermesh


Powermesh at 25% tension over and below patella for comfort, support, and breathability, and to pull tension up and downwards from the middle of the knee
12
Ponte at 25% tension for stability, shaping to hold powermesh in correct shape and for comfort around the top and bottom of the back of the knee
Double layer powermesh at 25% tension for stability, shaping for comfort around the back of the knee
3D printed bars connected to the semi cicle for external and internal stabilisation of the knee and holding the patella in place, more curved to follow natural anatomy and allow ease of movement


Double layer powermesh at 25% tension for compression, stability, and support, shaping to pull tension up, down, and around the knee, and for comfort behind the knee
13
Panel shaping derived from shape of designer's 3D printed stabilising shapes
Ponte at 25% tension for compression and stability, shaping to hold powermesh in correct shape and for comfort over the patella and the top and bottom of knee area

To create some of the brace series I first had to go back and refine my brace structures. To start with I focused on refining the circular piece to encase most of the patella from above as my research suggested braces are used to correct the patella placement. The refined piece no longer had the area of movement in the middle and the semi-circle was extended. I used the same technique with creating the arched pieces in illustrator and transferring them back to fusion to create a rounder shape. This particular shape was the put between the stabilising bars I had already created with a small gap between them for extra movement. This was then printed and extra panels were sewn on to create a tubular form.

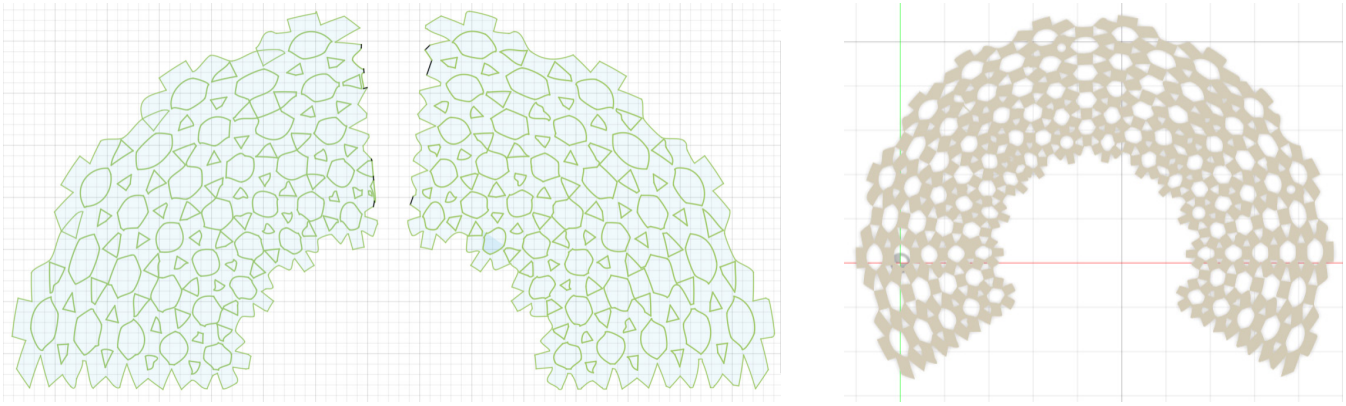


Fig. 81. Author's work. Adjusting model in Fusion, creating a circular form. 2025.

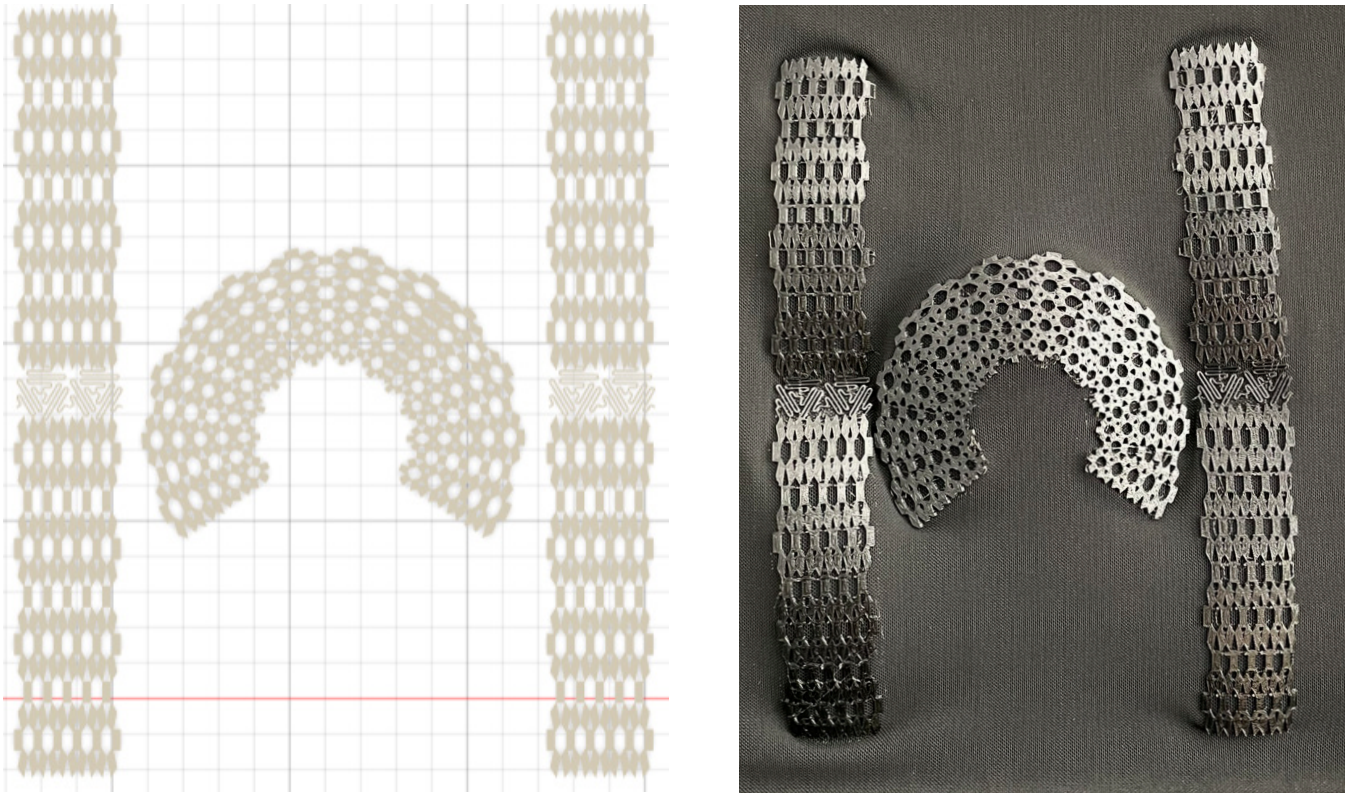


Fig. 82. Author's work. Adjusting model in Fusion, adding the circular form to the stabilising bars, then printing the sample on powermesh in TPU. 2025.

It was interesting to see how the 3D printing made the fabric form into a curved structure. The curving would allow the brace structure to sit against the knee without additional fabric manipulation to be added in those areas. For the next structure I looked at connecting the circular piece to the stabilising bars to see what effect that would have on movement and stability. I also widened the gap in the middle of the circle to make it fit better around the knee which in turn widened the printed arc design. I also made the stabilising bars curved to the body for better fit and to make moving the knee feel more natural and not forced due to the previous straight bars. It was then printed and the extra panels were sewn to once again create a tubular form.

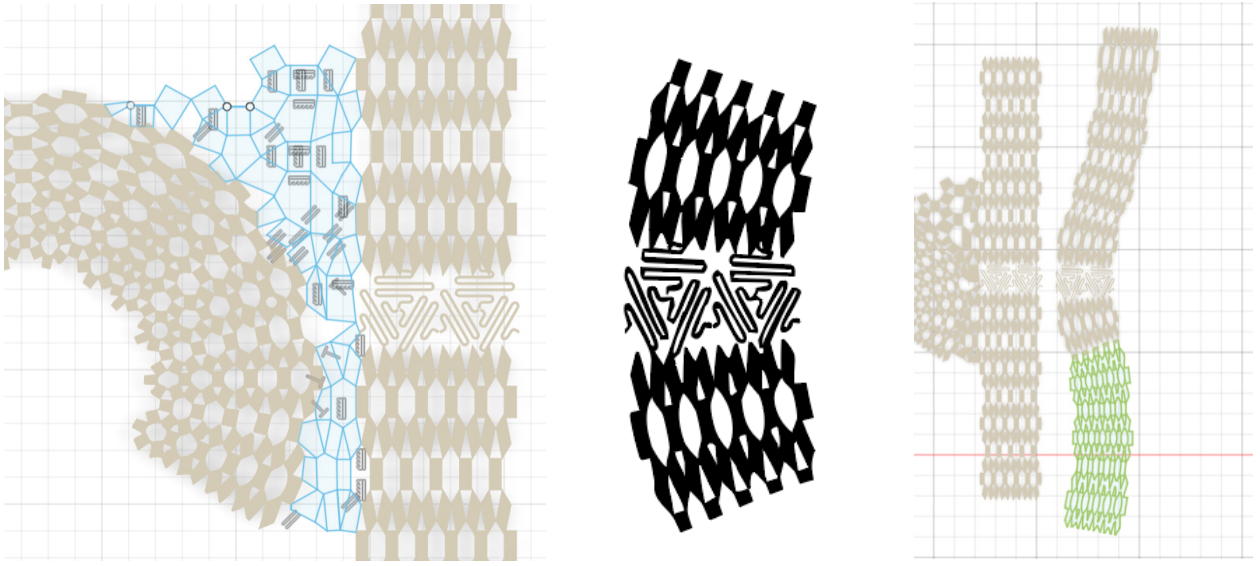


Fig. 83. Author's work. Adjusting model in Fusion, connecting circular form to bars, creating curved bars. 2025.

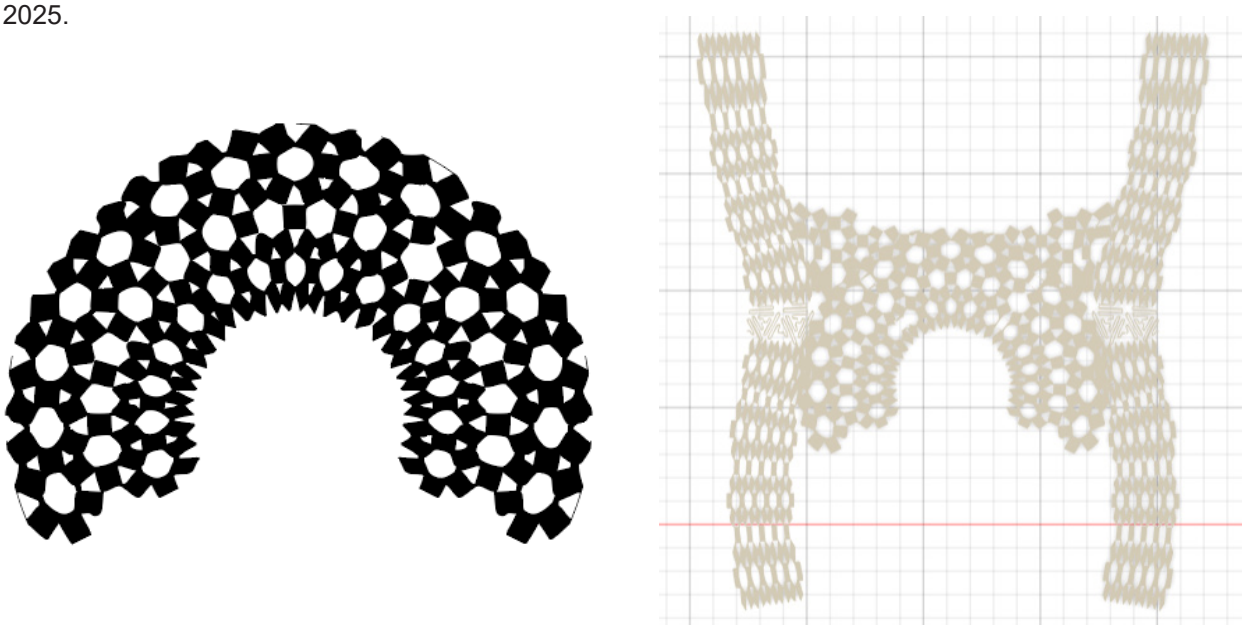


Fig. 84. Author's work. Adjusting model in Fusion, widening circular support, full model. 2025.

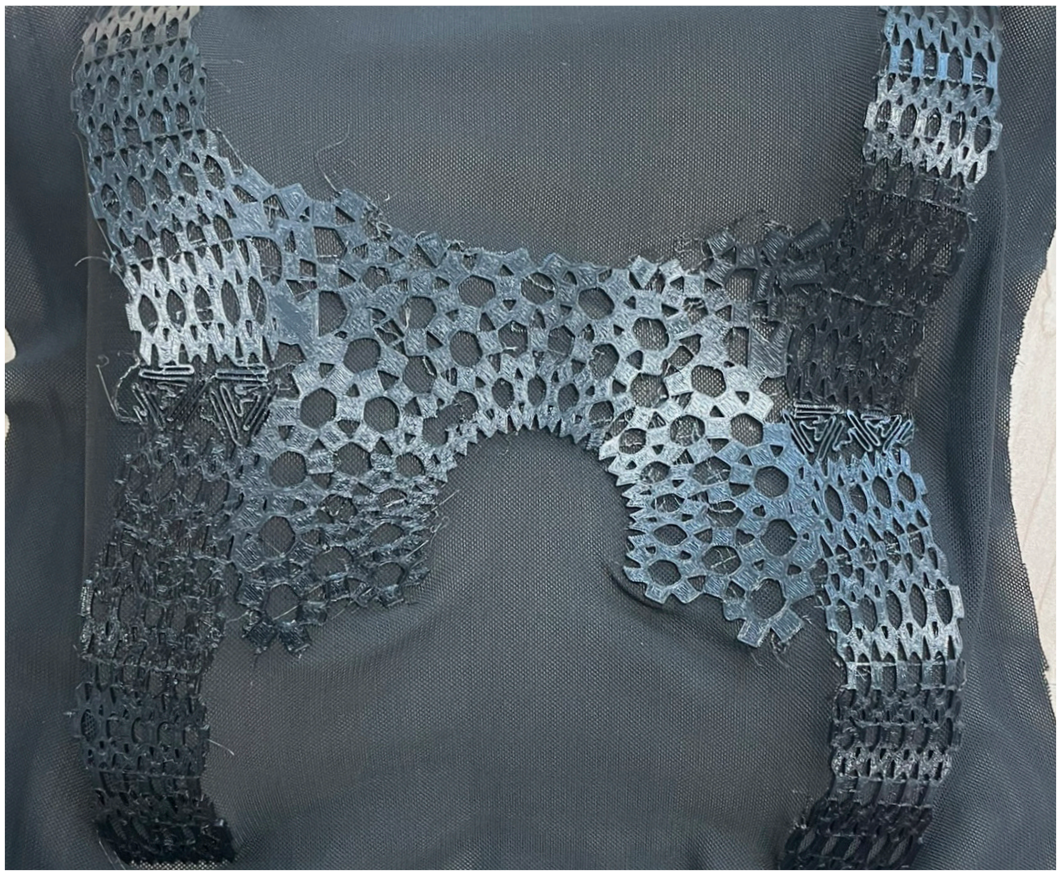


Fig. 85. Author’s work. Printed sample on powermesh. 2025.

Once I had completed the refinements to the brace structure I went back to my brace series drawings and chose six of them that I thought would work the best functionally. The brace drawings that I chose to create were numbers 1, 2, 3, 4, 6, and 12. Brace 1 is the straight barred 3D print structure on powermesh. Brace 2 is a combination of powermesh and ponte. Brace 3 is a combination of both single layered and double layered powermesh with ponte. Brace 4 is double layered powermesh and ponte. Brace 6 is powermesh and ponte. Brace 12 is a combination of single layered and double layered powermesh, ponte, and the curved bars and connected 3D printing. By choosing these six to make I was able to explore a range of panel shaping, material combinations, movement qualities, breathability, support, and comfort. I was then able to use these in my next user workshop for functional design feedback to further refine my design work and project.

Fig. 86. Author's work. Brace series 1, pattern and outcome. 2025.

Brace 1 is light and breathable with some support due to the powermesh and use of 3D printing. It is comfortable to wear and feels cool against the skin but the fabric gives little compression on its own. It has limitations when attempting to bend the knee with the straight stabilising bars.

Fig. 87. Author’s work. Brace series 2, pattern and outcome. 2025.

Brace 2 is moderately compressive and strong construction wise due to the powermesh and ponte combination. It is comfortable to wear and the compression feels very supportive. It has limitations with the ponte not covering the full area where support is needed and the powermesh seems to not be strong enough.

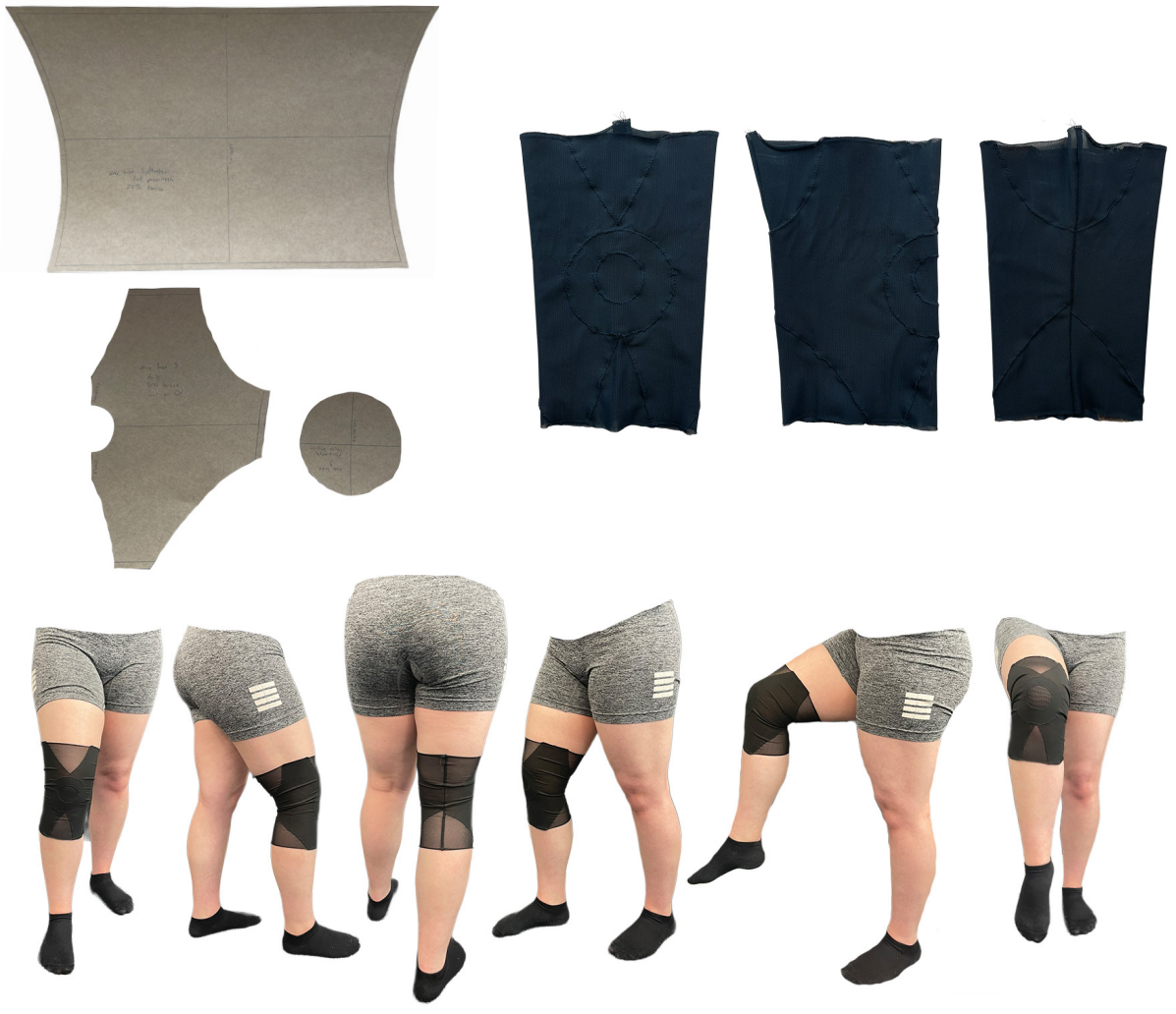


Fig. 88. Author’s work. Brace series 3, pattern and outcome. 2025.

Brace 3 is very compressive and soft due to the layering of powermesh and ponte combination. It is comfortable to wear and the compression provides a lot of support. It has limitations with the ponte not extending directly above and below the patella so the support pulls sideways instead of all around.

Fig. 89. Author's work. Brace series 4, pattern and outcome. 2025.

Brace 4 has a low amount of support due to the shaping of the panels. It is mostly comfortable to wear but has limitations with uneven support and light compression.

Fig. 90. Author’s work. Brace series 6, pattern and outcome. 2025.

Brace 6 is moderately compressive with comfort areas and breathable areas due to the panelling of the powermesh and ponte combination. It is comfortable to wear and the panel shaping provides a lot of support. It has limitations with the ponte in the back at the bottom being too small to provide adequate comfort.

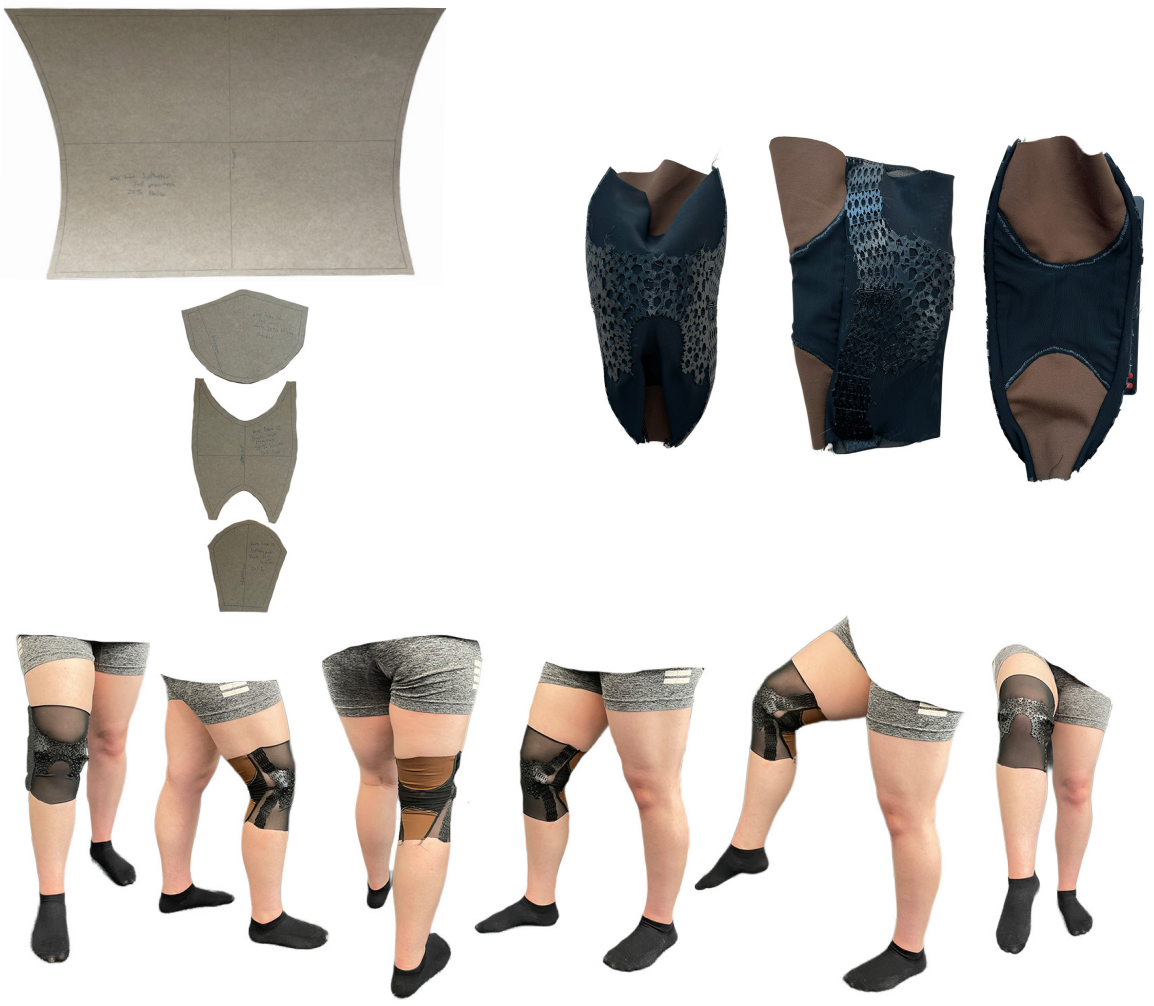


Fig. 91. Author’s work. Brace series 12, pattern and outcome. 2025.

Brace 12 is highly compressive, soft and breathable, and has a lot of support from the 3D printed structures. It has limitations with the printing being connected as it provides extra support but limits movement too much.

4.3a User Workshop Two

The second workshop with my user was used to gain feedback on the knee brace series samples and how well they would work functionally for support, compression, and stability, along with whether they would be suitable for everyday use and what kind of activities could be completed while wearing them. Feedback was also given for possible improvements in terms of function and possibility.

This workshop included a semi-structured interview and design feedback with the trouser leg samples, knee brace series planning and samples numbered 1 to 4, two drawn garment ideas, and the open ended questionnaire, *see appendix*, being used as resources.

The questionnaire asked:

- Response to the materials, shape, and function of the knee brace series samples
- Response to the materials, shape, and function of the knee brace series drawings
- Response to the shape, and function of the trouser leg samples
- Response to the function of the drawn garment ideas

The workshop was set up as shown below:

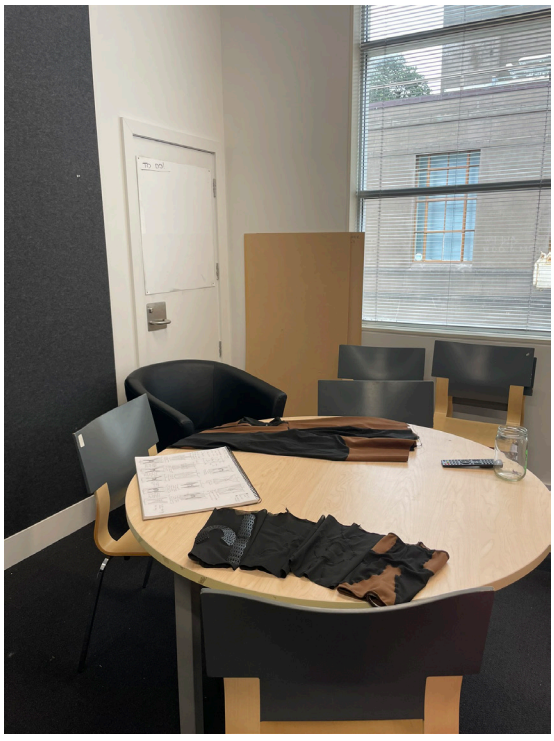


Fig. 92. Author's work. Workshop two set up. 2025.

Fig. 93. Author's work. Workshop two set up - table set up. 2025.

4.3b Refined Design Criteria - Function

Material Features (Ponte and Powermesh)	• Breathable, spongy in a good way, intricate • Compression 3-6/10, good for light everyday wear and standing up all day • High-moderate stretch, good for low physical effort
Suitability for Use	• Highly suitable for function, would compete in the market • Could be multi-use, possible applications for other conditions • Seems comfortable enough for everyday use
Further Recommendations	• Wider patella hole • Using flat seams • Turn semi circle upside down and make it ‘J’ shaped

Fig. 94. Author’s work. Table of key themes and responses given by workshop participant. 2025.

For this workshop the participant gave crucial feedback about the material features, suitability for use, and further recommendations for the design in terms of functionality. The participant chose braces 1-3 as the most suitable for everyday wear and thought they would be able to compete in the market. They also mentioned that there could be a possibility that the braces could be used for other knee conditions. It is important to note one of the further recommendations they gave; turning the patella support upside down and creating a ‘J’ shape. They mentioned the purpose of that support for them is to prevent dislocations and not to push the patella down to where it should be, hence the need for a ‘J’ shape which sits under the patella and extends up the outer side of it. They also mentioned the drawings of brace 6 and 12 looked like they could work well functionally, which led me to making them.

4.3c Refined Brace

After considering the workshop feedback and my own analysis of each of the brace samples I made, I chose brace 12 to further refine to become my final outcome. I went back to the drawing I completed and created a refined drawing based on what the user said would work best for functionality. The differences of the refined drawing include a ‘J’ shaped support which is applied under the patella, disconnected supports, and stabilising bars that reach the edge of the fabric. After planning how to create the refined brace I went back to the 3D modelling stage and used illustrator to create a slightly curved shape that could be used in connection to the circular shape to form a ‘J’. I then removed the connections between the structures and turned the shape upside down as suggested by the user. I also added a thin line around the inside of the shape to create a smooth edge against the knee. In terms of patternmaking I also made the width of the panels wider and taller by 0.5cm in each direction to allow for a better fit against the body and for finishings.

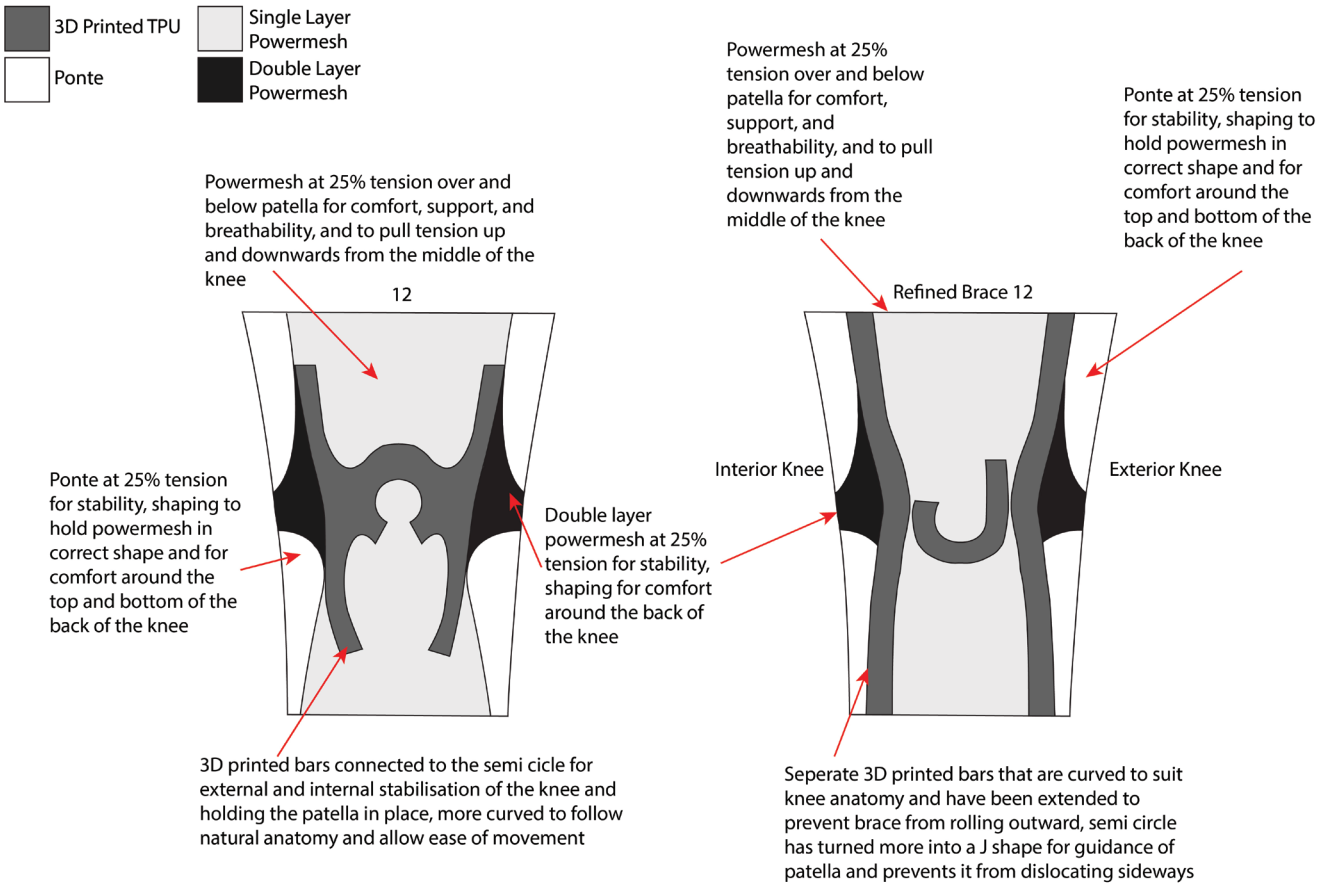


Fig. 95. Author’s work. Brace drawings, left is brace 12, right is planned refined brace to make. 2025.

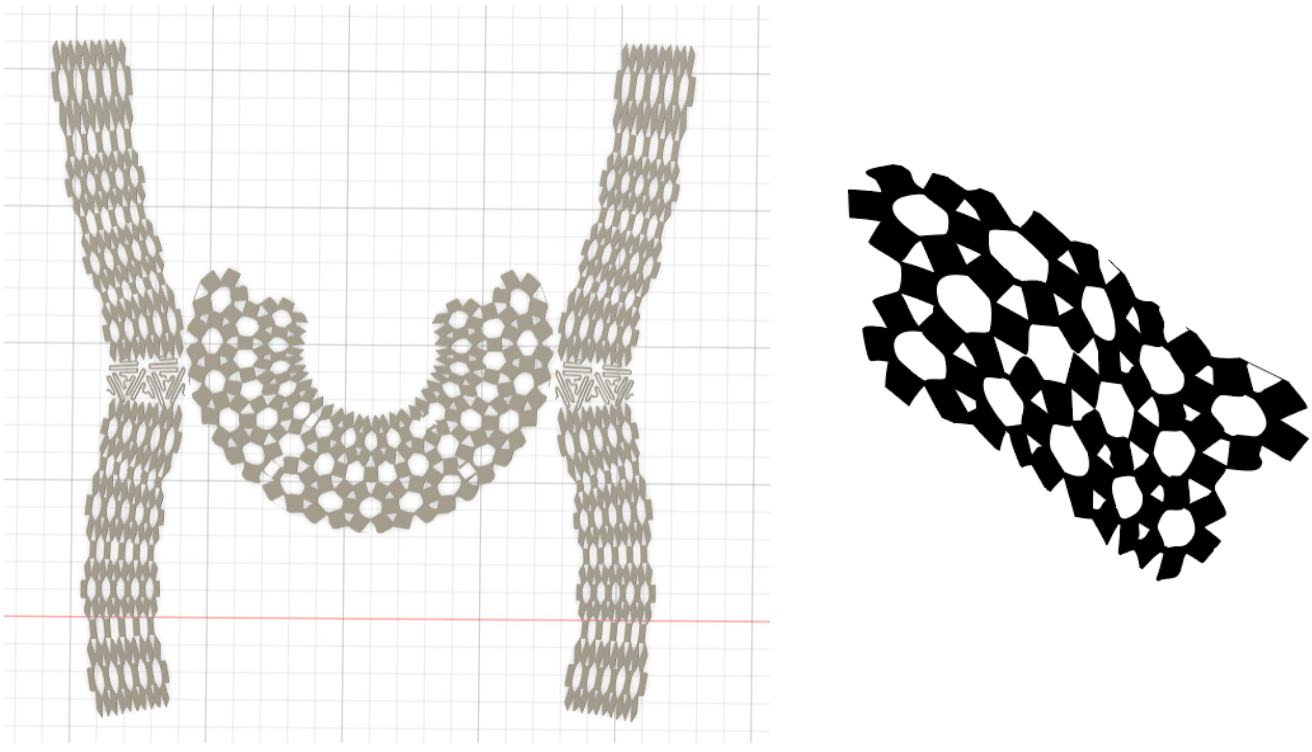


Fig. 96. Author's work. Turning circular support upside down, creating additional piece in Illustrator to extend the 'J' shape. 2025.

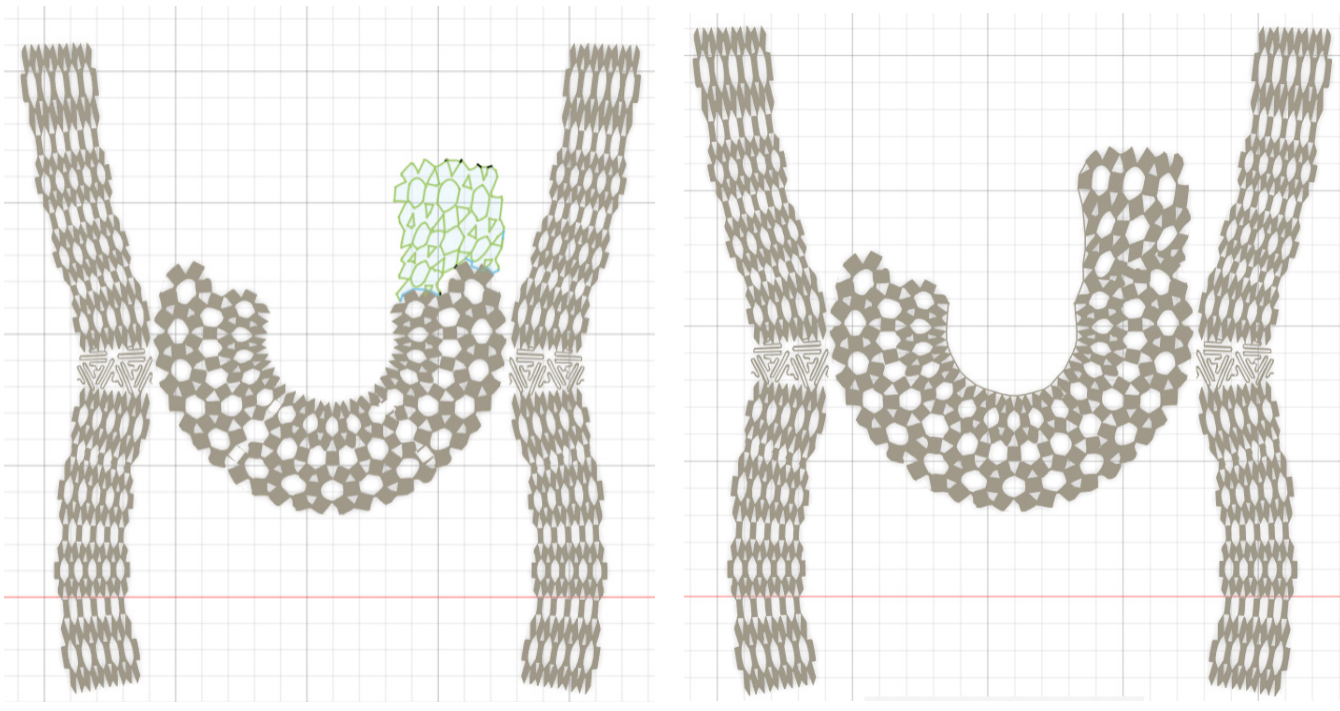


Fig. 97. Author's work. Applying additional piece to extend the 'J' shape, adding thin line around the inside to smooth the edge. 2025.

Fig. 98. Author’s work. Printed refined brace sample on powermesh. 2025.

After completing the refined brace I decided the way it looks, feels, and functions was meeting all of the criteria that I had set from my contextual, designer-orientated, and user research. To gain further validation that it was meeting this criteria, and for validation about what feedback the participant had given me, I decided to reach out to a physiotherapist, which also allowed me to further understand the condition, the braces, and what impact they have on users.

4.3d Medical Expert Consultancy: Physiotherapist

The medical expert consultation with the physiotherapist was used to gain validative feedback on some of the knee brace samples and the refined brace based on the information given from the user with patella alta. Feedback was also given for possible improvements and recommendations for post study.

This workshop included a semi-structured interview and design feedback with the knee brace series samples numbered 1, 2, 3, and 12, the refined brace, expected garment outcome drawings, and the open ended questionnaire, *see appendix*, being used as resources.

The questionnaire asked:

- Validation of design feedback given by user for shape, placement, and other application of braces
- Response to materials, size, and 3D printed design for use and functionality
- Further recommendations or improvements

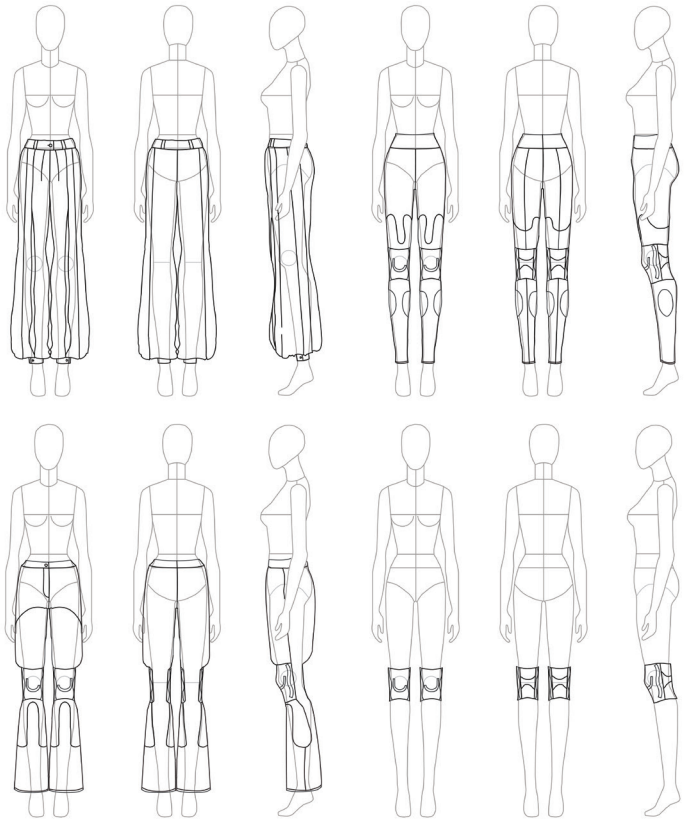


Fig. 99. Author's work. Expected outcome drawings that were shown to physiotherapist. 2025.

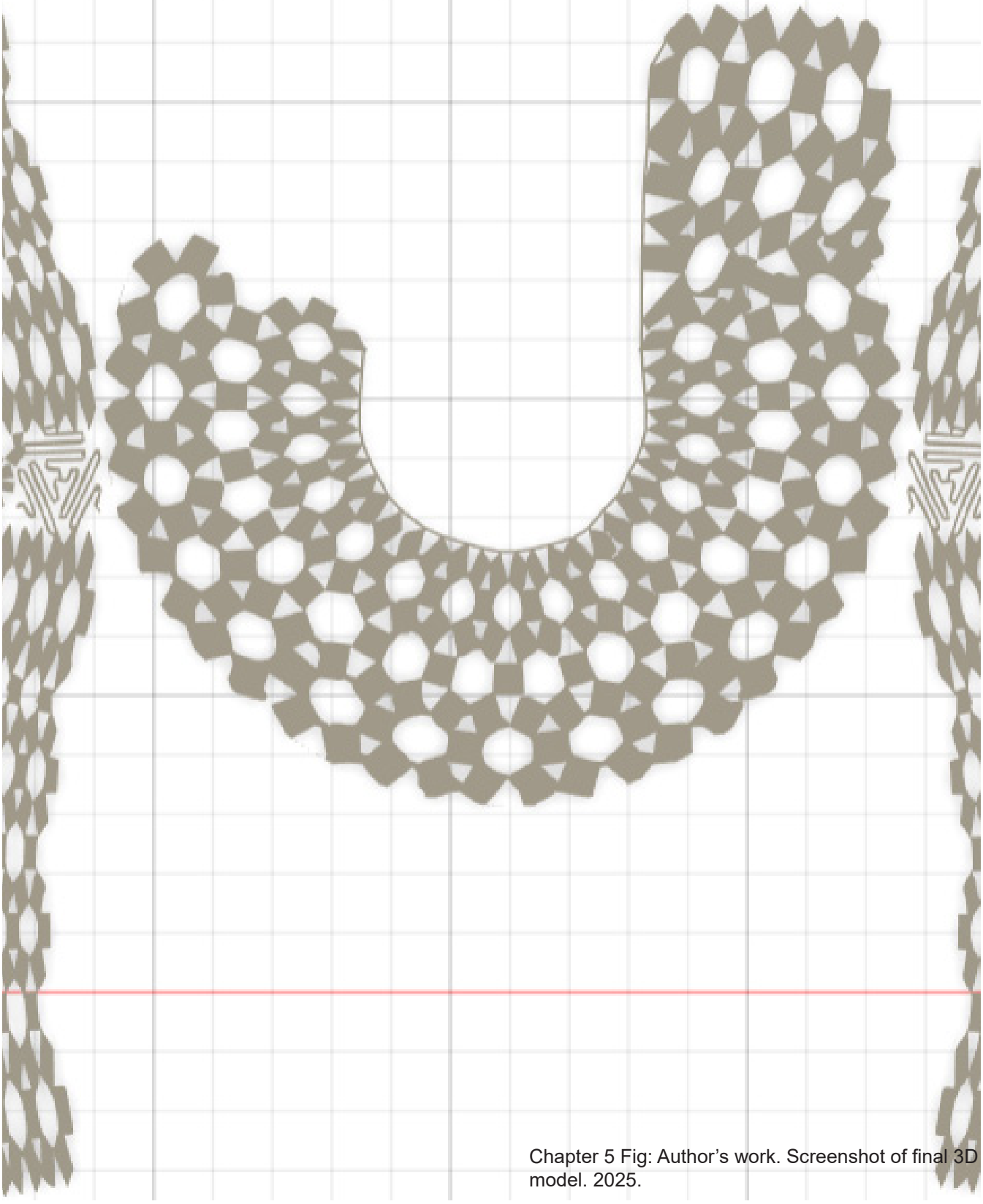
4.3e Medical Expert Validation

Validation of Design Feedback	• 'J' shape is optimal to prevent dislocations, some options already exist but don't look nice or are breathable • Stabilising bars being connected vs disconnected to 'J' shape is down to individual needs and feel • Width of circular support is down to individual needs and size of the knee of the user • Further development can make them suitable for other patella instability's, post surgery, and early stages of injury
Material Features (Ponte, Powermesh, 3D printed TPU)	• Materials feel comfortable enough to be worn for a full day • Powermesh is compressive, stable, lightweight, breathable • 3D printing is beautiful, innovative, and should give enough support for everyday use
Further Recommendations	• Consider the mental impact and state how these will improve user ability • Think about the ability to create tailored braces to each specific person through recommendation of medical professionals post study

Fig. 100. Author's work. Table of key themes and responses given by physiotherapist. 2025.

The answers from this questionnaire validated the need for a 'J' shape support structure and having it under the patella, along with the use of powermesh and ponte due to their compressive abilities and the way powermesh is lightweight and breathable. Comments about how the 3D printing was innovative, beautiful, and would give enough support for everyday use were also made. Their further recommendations included thinking how users' mental state is affected by the improvement of ability given from the braces, as the main reason people don't do the thing that made them injured in the first place is fear. The knee braces work as a device that not only supports the area but is also mentally considered as a way to keep safe and feel protected. They also mentioned keeping in mind how these could be developed to be created for individual needs post study as the differences in my range of sampling have the ability to suit differing needs.

5. Final Outcomes



Chapter 5 Fig: Author’s work. Screenshot of final 3D model. 2025.

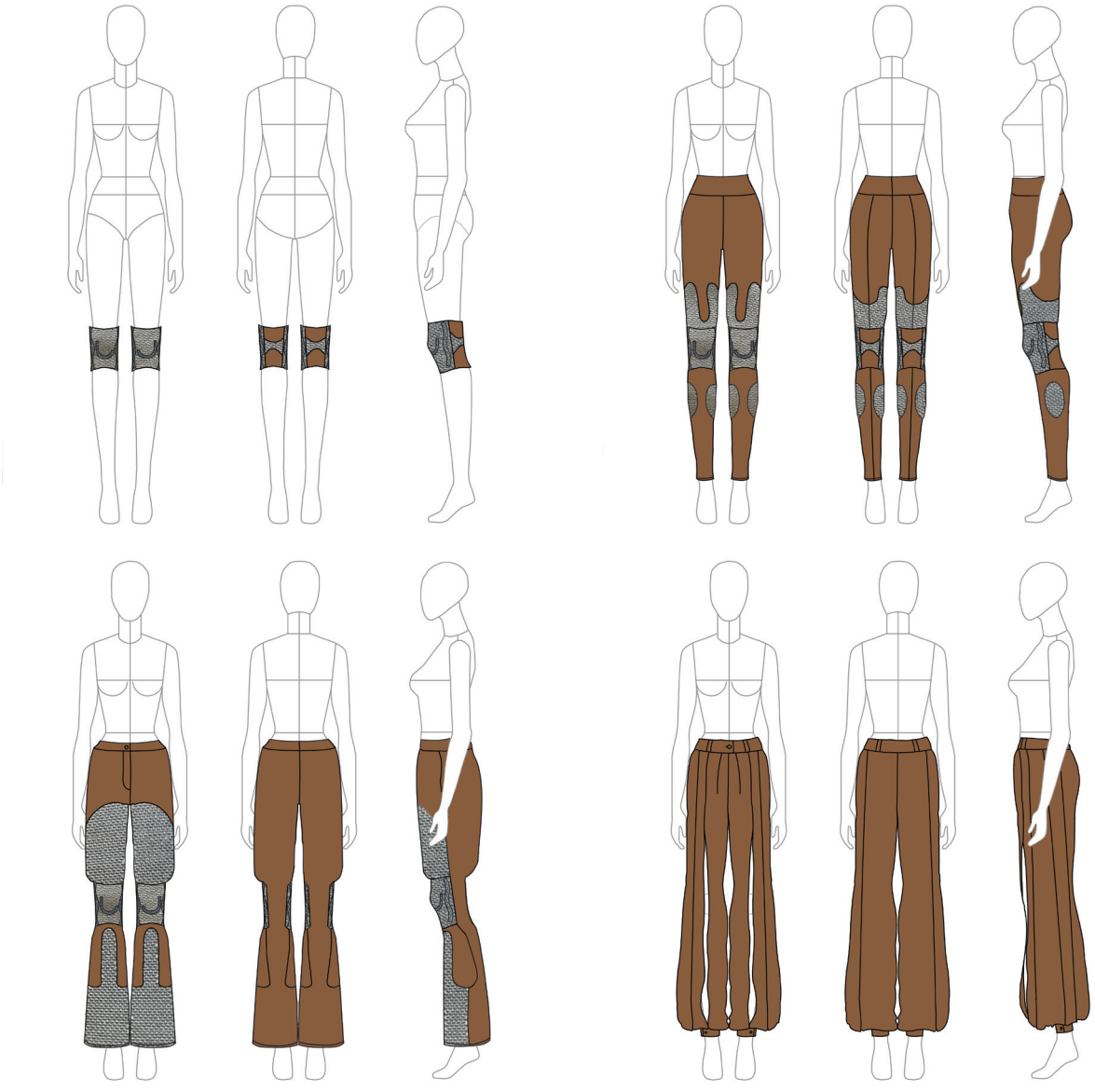


Fig. 101. Author’s work. Rendered outcomes, left to right: knee brace, fitted trouser/legging with built in knee brace, bootleg trouser with partial external and internal knee brace, balloon pants with opening to reveal brace. 2025.

I decided to make the brace and the fitted trouser/leggings to show how the processes that I have created can be applied to garments for medical conditions and use the drawings of the other trousers to provide further potential applications. The following pages show the making process of the brace and fitted trouser/leggings before showing the finished prototypes on the body.

5.1 Making the Brace

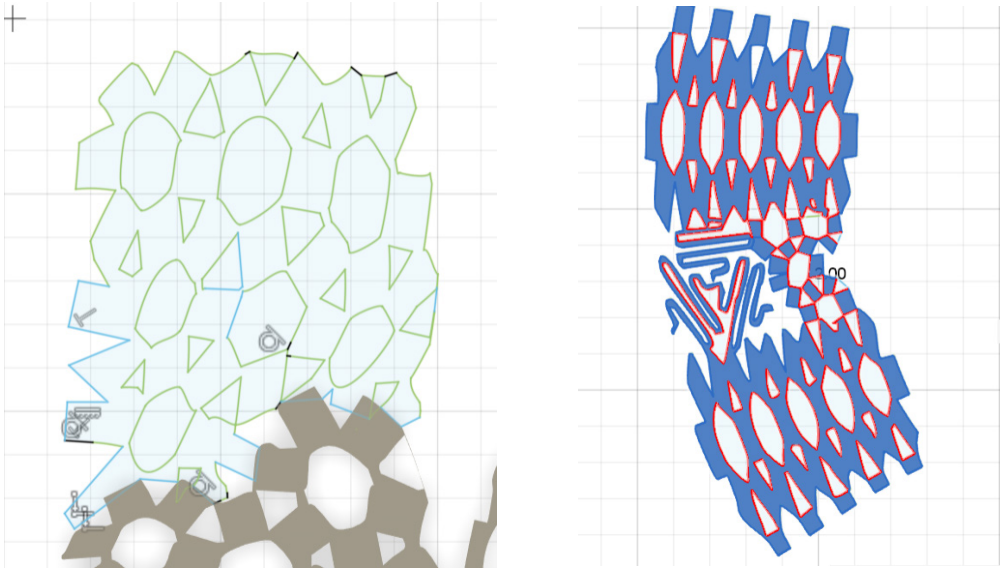


Fig. 102. Author's work. Adjusting 3D printed support structures for comfort before final print, straightening inside edge of 'J', removing one of the moving shapes in the bar and replacing it to prevent extra bubbling at the side. 2025.

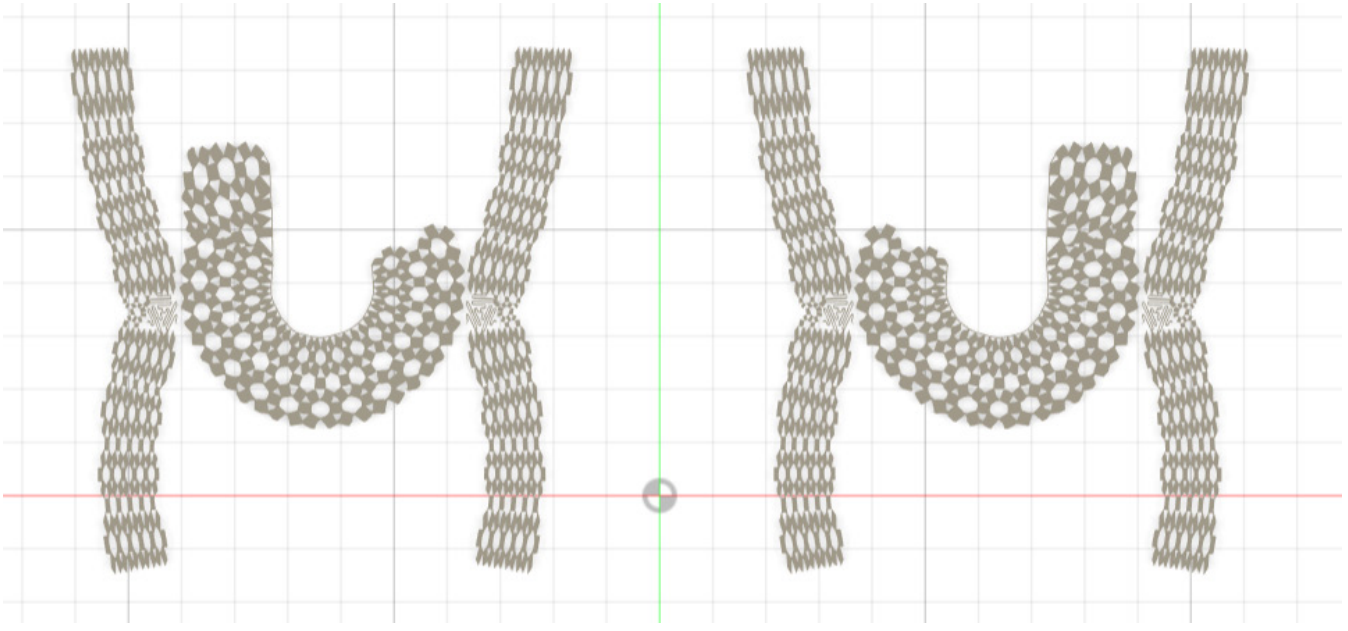


Fig. 103. Author's work. Duplicating the finished model, mirroring it to create a model for the left and right knee. 2025.

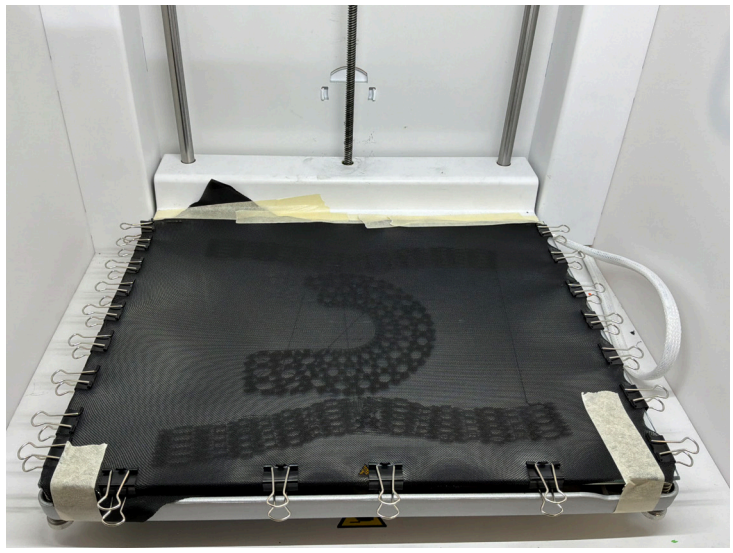


Fig. 104. Author's work. Cutting out fabric for brace, 3D printing set up for brace support structures. 2025.

Fig. 105. Author's work. Finished 3D print on fabric, overlocker set up for construction. 2025.

Fig. 106. Author's work. Constructing panels for behind knee, attaching the combined panels to the main brace structure. 2025.

Fig. 107. Author's work. Machine sewing stretch binding to top and bottom edges of brace for finishing. 2025.

5.2 Making the Fitted Trouser/Leggings

Fig. 108. Author's work. Adjusting the pattern from a previous pattern master, cutting out pattern pieces, cutting out patterns in fabric for trousers. 2025.

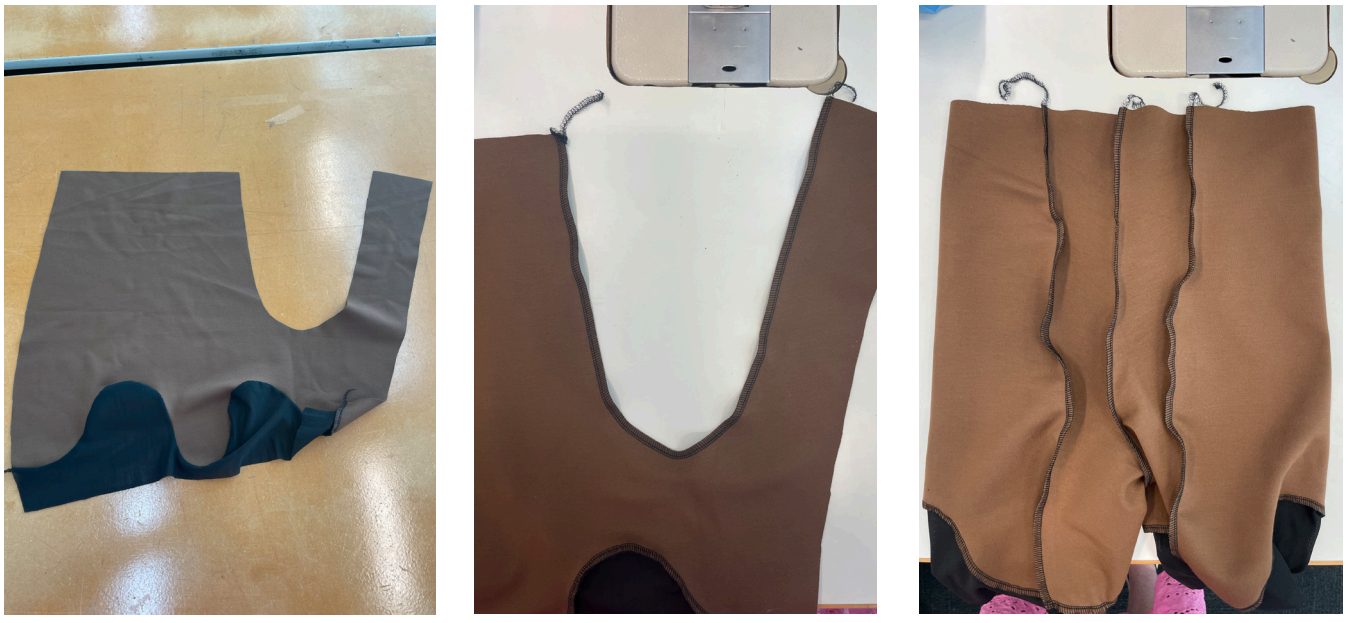


Fig. 109. Author's work. Constructing the top panels of the trousers, they had to be constructed from the top first due to the design lines of the knee area. 2025.

Fig. 110. Author's work. Forming and applying waistband, overlocking circular panels on lower leg and sewing the back seam together. 2025.

Fig. 111. Author's work. Using a twin needle coverstitch to hem the legs, sewing in the knee brace area between the top and bottom leg sections. 2025.

5.3 Final Prototype - Brace

Fig. 112. Author’s work. Final brace front. 2025.

Fig. 113. Author’s work. Final brace outside knee. 2025.

Fig. 114. Author’s work. Final brace back. 2025.

Fig. 115. Author’s work. Final brace inside knee. 2025.

5.4 Final Prototype - Fitted Trouser/Leggings

Fig. 116. Author’s work. Final fitted trouser/leggings front. 2025.

Fig. 117. Author’s work. Final fitted trouser/leggings outside leg. 2025.

Fig. 118. Author’s work. Final fitted trouser/leggings back. 2025.

Fig. 119. Author’s work. Final fitted trouser/leggings inside knee. 2025.

6. Concluding Reflection

Chapter 6 Fig: Author's work. Final fitted trouser/ leggings prototype. 2025.

Through an empathy-centered design research process I was able to create two prototypes which provide comfortable and aesthetically pleasing everyday fashion design solutions for those with patella alta. By researching aspects of the condition, current adaptive and functional fashion design, and empathic and user-centered design methodologies, I was able to create design processes following the Functional, Expressive, Aesthetic framework and apply them to form prototypes meeting user needs and wants.

The topics covered in my context review and method/methodology sections directly informed my design and user research processes and choices. Looking at existing adaptive and functional fashion design examples and understanding their strengths, weaknesses, and processes allowed me to identify design features that would need to be considered when designing for medical conditions and how they could be applied. Investigating material innovation, the condition, treatments, and issues, led to a thorough iterative sampling process using a range of materials such as knit fabrics and TPU to find solutions for comfort, accessibility, support, and aesthetics. To understand functional and aesthetic issues, and gain user feedback throughout my project, I applied techniques suggested in holistic approaches to fashion, and user-centred and empathic design through the use of the Functional, Expressive, Aesthetic model.

The final prototypes formed by this project include the design features of 3D printed lace inspired stabilising bars and a ‘J’ shaped patella support, a combination of knit fabrics to give support, compression, comfort, and breathability, and panel shaping inspired from existing brace patterns to provide fashion aesthetics.

Prototype features which fit the Functional, Expressive, Aesthetic model:

- Functional - 3D printed stabilising and support structures with some movement, combination of lightweight and heavy knit fabrics for comfort, compression, and breathability
- Expressive - Ability for brace structure to be placed into other garments, panel shaping and design lines to promote confidence and emotional strength, and empowerment
- Aesthetic - 3D printed structures inspired by lace fabric structures, panel shaping and design lines to promote confidence and emotional strength, and empowerment, fashion contemporary aesthetic

I was extremely grateful to have a participant with patella alta who was able to give their lived experience with the condition and clothing. It made it a lot easier and more meaningful to observe and address issues and empower them and others who use knee braces everyday. The feedback given from the participant was also able to be validated by a physiotherapist in the final stages of the project leading to a more

everyday wear that are comfortable, easy to wear, allow for movement, and don’t look out of place in a casual setting, providing aesthetic value to the wearer.

I hope my exegesis provides an innovative example to the fashion design industry on how processes can be modified to consider those with medical conditions through empathic design. I also hope that it inspires all designers alike to experiment with processes found outside of their speciality, and to consider and empathise with users continuously to ensure what they create works best for the users.

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8. Appendix

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

5/06/2025

Dear: Claire Johnson

Re: Low Risk Notification - 4000030796 - User-Centred Design for Patella Alta: An Exploration of Adaptive and Functional Design Solutions

Thank you for submitting a low risk notification for your research/teaching/evaluation.

This email is to acknowledge receipt of the low risk notification and to inform you that the details of your project have been recorded in our database for inclusion in the annual reports to the Health Research Council Ethics Committee (HRCEC) and the Massey University Research Committee (URC).

You may proceed with your research, though it is advisable to provide a couple of weeks before commencing, as all low risk notifications are checked for completeness and clarity by a Research Ethics Advisor. You may be contacted if your application is incomplete and/or further clarification is required.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis.

If a sponsoring organisation, funding authority (e.g., the Health Research Council) or a journal require evidence of ethical approval from a Human Ethics Committee (with an approval number), you need to complete a full Massey University Human Ethics application to be reviewed and approved by one of our Human Ethics Committees. Applications must be submitted and approved prior to the commencement of the research.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact the Research Ethics Office, email humanethics@massey.ac.nz. "

Please include the following statement on all public documents (e.g., information sheet, consent form) related to your project:

> ***This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.***
>
> ***If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.***

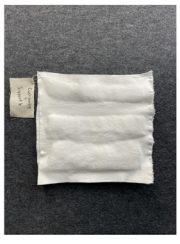
I wish you all the best in your research, teaching or evaluation activities and appreciate your thoughtful consideration of ethics principles and practices.

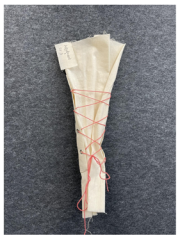
Ngā mihi nui,

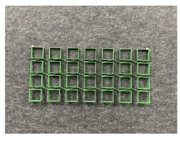
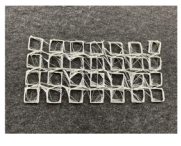
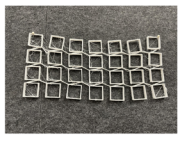
Professor Tracy Riley
Acting Chair, Research Ethics Chair's Committee

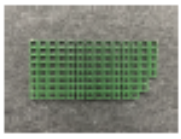
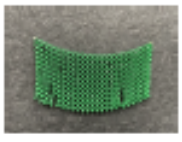
Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 951 6840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

Sample Diary

Sample:	What is it:	Why is it important:	How could it be applied :	Where to next:
	Cushioning and stability, plastic boning, wadding, woven/non stretch	Finding ways to incorporate a hard area for support but making it soft and flexible for comfort	Could be added into the side seams to give support on the outer and inner knee	Remake but attempt to make it more uniform and softened
	Cushioning and stability, plastic boning wrapped in wadding, woven/non stretch	Finding ways to incorporate a hard area for support but making it soft and flexible for comfort	Could be added into the side seams to give support on the outer and inner knee	Make a similar sample but use other materials and take a shape from the brace
	Cushioning and support, neoprene, fusing, stretch	Finding ways to incorporate a firm area for support but making it soft and flexible for comfort	Could be added around the knee, specifically around the patella area	Take the same application but use an arrangement similar to the previous sample to this one
	Cushioning and support, neoprene, stretch	Finding ways to incorporate a firm area for support but making it soft and flexible for comfort	Could be added around the knee, specifically around the patella area	Do the same thing but use other materials to make it softer
	Cushioning and support, wadding, stretch	Finding ways to incorporate a firm area for support but making it soft and flexible for comfort	Could be added around and over the knee, specifically around the patella area	Do the same thing but use more uniformity
	Cushioning and support, wadding, stretch	Finding ways to incorporate a firm area for support but making it soft and flexible for comfort	Could be added around and over the knee, specifically around the patella area	Could look at applying to a pre-existing garment or try making different shapes that are in the knee

	Adjustment and fit, elastic, string, woven/non stretch	Finding ways to offer adjustment to ensure comfort and a better way of dressing	Could be added to a side seam or hem to adjust sizing and ease with dressing	Could attach to a tube or a larger area of fabric and use multiple to see how the adjustment changes
	Adjustment and fit, plastic hardware, stretch straps, woven/non stretch	Finding ways to offer adjustment to ensure comfort and a better way of dressing	Could be added to a side seam to adjust sizing and ease with dressing	Do the same thing but with different materials
	Adjustment and fit, eyelets, string, woven/non stretch	Finding ways to offer adjustment to ensure comfort and a better way of dressing	Could be added to a side seam to adjust sizing and ease with dressing	Do the same thing but with different materials
	Adjustment and fit, metal hardware, cotton tape, stretch	Finding ways to offer adjustment to ensure comfort and a better way of dressing	Could be added to a side seam to adjust sizing and ease with dressing	Could try adding an opening of some sort or even other hardware like buckles
	Closures, buttons, woven/non stretch	Finding ways to offer a better way of dressing	Added to a seam to adjust sizing and ease with dressing	Same thing with a different closure type
	Closures, velcro, woven/non stretch	Finding ways to offer a better way of dressing	Added to a seam to adjust sizing and ease with dressing	Same thing with a different closure type

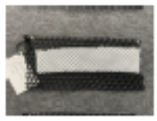
	Closures, metal hook and eyes, woven/non stretch	Finding ways to offer a better way of dressing	Added to a seam to adjust sizing and ease with dressing	Same thing with a different closure type
	Closures, metal snaps, woven/non stretch	Finding ways to offer a better way of dressing	Added to a seam to adjust sizing and ease with dressing	Same thing with a different closure type
	Closures, magnets, woven/non stretch	Finding ways to offer a better way of dressing	Added to a seam to adjust sizing and ease with dressing	Could find other types of closures to try or explore different materials
	3D printing, large connection, Kiwifil PLA	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels to give support on the outer and inner knee	Do the same thing but in a different material
	3D printing, large connection, deconstructed, TPU	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels or a full structure to support shape and movement	Do the same thing to see if the layer adhesion can be fixed
	3D printing, large connection, slight deconstruction, TPU	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels or a full structure to support shape and movement	Do the same thing to see if the layer adhesion can be fixed
	3D printing, large connection, TPU	Finding ways to incorporate a hard area for support but making it flexible for	Could be added panels or a full structure to support shape and movement	Go back to the PLA but adjust the model so that the squares are smaller to find more

		comfort		movement
	3D printing, small connection, Kiwifil PLA	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels to give support on the outer and inner knee	Do the same thing but in a different materials
	3D printing, small connection, TPU	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels or a full structure to support shape and movement	Could print multiple and find a way to weave them together to create a spacer fabric
	3D printing, structure and movement, stretch fabric, Kiwifil PLA	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels to give support on the outer and inner knee	Do the same thing but in different materials
	3D printing, structure and movement, stretch mesh, TPU	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels or a full structure to support shape and movement	Could try printing different things using the same method or potentially looking at using a different printable material
	3D printing, small hard and movement, Kiwifil PLA	Finding ways to incorporate a hard area for support but making it flexible for comfort	Too small and fragile to be used	Do the same thing but make the scale larger by at least 50%
	3D printing, large hard and movement, Kiwifil PLA	Finding ways to incorporate a hard area for support but making it flexible for comfort	Could be added panels to give support on the outer and inner knee	Could take this and use other forms of shapes or joints to create something new

Material Combination Analysis

No:	Sample:	Materials:	Stretch:	Feel:	Compression:	Difference from base fabric on it's own:
1a		Ponte Ponte	Moderate all ways	Firm, thick	Some when stretched	Increased thickness
2a		Ponte Poly Double Mesh	Moderate parallel to grainline	Soft, textured, spongy	Minimal when stretched	Extra softness, increased stability
3a		Ponte Athletic Poly Mesh	High parallel to grainline, minimal against it	Light, warm, smooth	High when stretched	Thicker, more stable, warmer
4a		Ponte Woven Mesh	Moderate parallel to grainline	Rough, unpleasant	None, tightness	Warmer and thicker
5a		Ponte PP Nylon Mesh	High all ways	Slight squish, soft but scratchy	Moderate when stretched a lot	More stable
6a		Ponte CR Poly Mesh	None	Spongy, soft, textured	None, tightness	Added softness
1b		CR Poly Mesh Ponte	Minimal all ways	Spongy, soft, textured	Minimal/none, tight	Added sponginess and texture, less stretch
2b		CR Poly Mesh Poly Double Mesh	Minimal parallel to grainline	Spongy, textured, lightweight, stiff	Minimal/none, tight	Added sponginess and texture

3b		CR Poly Mesh Athletic Poly Mesh	Minimal parallel to grainline	Spongy, textured, lightweight	Minimal/none, tight	Added sponginess and texture, less stretch
4b		CR Poly Mesh Woven Mesh	None	Rough, spongy, textured, lightweight	None	Added thickness, sponginess, less texture
5b		CR Poly Mesh PP Nylon Mesh	Minimal all ways	Spongy, textured, soft but scratchy	None, tight	Added thickness, sponginess, less stretch
6b		CR Poly Mesh CR Poly Mesh	Minimal on bias	Spongy, textured, stiff	None, tight	Increased thickness
1c		Woven Mesh Ponte	Moderate parallel to grainline	Thick, rough, warm	Minimal when stretched	No stretch against grainline, more stable
2c		Woven Mesh Poly Double Mesh	Moderate parallel to grainline	Rough, slight squish, lightweight	Minimal/none, tight	More stable, less stretch
3c		Woven Mesh Athletic Poly Mesh	High parallel to grainline	Rough, lightweight, cool	None	More stable, less stretch, more texture
4c		Woven Mesh Woven Mesh	Minimal parallel to grainline	Rough, unpleasant, stiff	None	Increased thickness and stability
5c		Woven Mesh PP Nylon Mesh	High parallel to grainline	Scratchy, textured, lightweight	Minimal/none, tight	Increased stability, less stretch

6c		Woven Mesh CR Poly Mesh	None	Rough, spongy, textured, unpleasant	None	Increased stability, added softness
1d		PP Nylon Mesh Ponte	High all ways	Soft, slight scratchy, heavy, warm	Moderate when stretched	Added stretch and stability
2d		PP Nylon Mesh Poly Double Mesh	High parallel to grainline	Lightweigh t, slight scratchy	Moderate to high when stretched	Added stability
3d		PP Nylon Mesh Athletic Poly Mesh	Very high parallel to grainline	Lightweigh t, cool, slight scratchy	High when stretched	Added stability
4d		PP Nylon Mesh Woven Mesh	Moderate parallel to grainline	Rough, stiff, lightweight , cool	Minimal/non e, tight	Added thickness
5d		PP Nylon Mesh PP Nylon Mesh	Very high all ways	Slight scratchy, lightweight , cool	High when stretched	Added thickness and stability
6d		PP Nylon Mesh CR Poly Mesh	Minimal parallel to grainline	Rough, spongy, thick	Minimal/non e, tight	More coverage
1e		Athletic Poly Mesh Ponte	Moderate parallel to grainline	Thick, warm, soft	Moderate when stretched	Less stretch opposite grainline, thicker
2e		Athletic Poly Mesh Poly Double Mesh	High parallel to grainline	Soft but scratchy, thick, lightweight	Minimal/non e, tight	More stable, thicker
3e		Athletic Poly Mesh Athletic Poly Mesh	Very high parallel to grainline	Soft, lightweight , cool	High when stretched	More stable, thicker

4e		Athletic Poly Mesh Woven Mesh	Minimal parallel to grainline	Thick, soft but rough, heavy, warm	Minimal/none, tight	Thicker, less stretch
5e		Athletic Poly Mesh PP Nylon Mesh	Very high parallel to grainline, minimal opposite	Soft, slight scratchy, warm, lightweight	High when stretched	Thicker, added stability
6e		Athletic Poly Mesh CR Poly Mesh	None	Spongy, thick, soft, heavy	Minimal/none, tight	Added coverage and softness
1f		Poly Double Mesh Ponte	Moderate parallel to grainline	Thick, scratchy, warm	Moderate when stretched	Added texture and structure, less stretch
2f		Poly Double Mesh Poly Double Mesh	Minimal parallel to grainline	Thick, spongy, scratchy, lightweight, stiff	Minimal/none, tight	Added thickness and structure
3f		Poly Double Mesh Athletic Poly Mesh	Moderate parallel to grainline	Thick, spongy, soft, lightweight, cool	Moderate when stretched	Added thickness, texture, and stability
4f		Poly Double Mesh Woven Mesh	Minimal parallel to grainline	Rough, unpleasant, stiff, spongy	Minimal/none, tight	Added thickness, texture
5f		Poly Double Mesh PP Nylon Mesh	Moderate parallel to grainline	Spongy, soft but scratchy, cool, lightweight	Moderate when stretched	Added stability, thickness, structure
6f		Poly Double Mesh CR Poly Mesh	None	Squishy, soft but rough, dense, cool	None	Added thickness, coverage, smoothness

Data Visualisation

User group

How long have you been diagnosed with patella alta for?	Officially clinically diagnosed last year, before that had about three different diagnoses that none of them lined up with the correct treatment. Kept having more and more dislocations up until found a physiotherapist that then passed onto a surgeon. Spent about 8 or 9 years with dislocating knees and not getting the right answers. A lot of it was immediately going to hypermobility and Ehlers-Danlos Syndrome, but doesn't show any of the other symptoms, was overlooked by many specialists, took a lot of nagging medical fields to find correct diagnosis. Dislocations were happening sporadically, first dislocation happened just by standing.
What is the severity of your condition e.g mild, moderate, extreme?	Moderate, patella sits above where it should be but not completely on the thigh bone.
Does it affect both knees?	Yes, one more severely than the other, one has had about 8 dislocations and the other has only had 1.
Do you use any other form of treatments apart from knee braces?	Physiotherapist/PT grouped together. The sessions focus on rehabilitation through stabilisation of muscles around the knee. Had appointments with private orthopaedic surgeons to consider surgery but doesn't look like the right option at the moment.

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The medical definition of patella alta is a congenital condition of the knee where the patella is abnormally high in position in relation to the femur, tibia, and trochlear groove. What is your understanding of the condition?	Pretty much the same as the clinical definition, the kneecap is not where it needs to be. Partner calls them hobbit knees because they're going on an adventure.

Knee brace use

What kind of knee brace do you use?	Is a hard one to answer. Have been surgically recommended and patella stabilising brace but conversations with surgeon didn't go well in regards to practical day to day use. Went behind surgeon's back and trialled a whole bunch to find ones that actually worked. Ones given by surgeon were 2-3cm too wide so just walking was knocking knees together because of the bars down the side of them that stick out and the support piece around the patella. Best ones that work are thermoskin compression braces that have two stabilising bars down the outside and are compressive rather than stabilising. Uses them in a way to be aware of not doing movements that will compromise knees, they're so tight on legs that they can't be forgotten and have enough compression that if something did happen the knee should stay fairly stable. Pushes patella into place so it has less freedom to slide around.
Have you used more than one kind of brace? If so, what other kind of brace did you use?	Tried a lot of different kinds, tried McDavid knee braces, tried supermarket braces, tried professional surgical braces.
How often do you have to wear a brace/s?	Everyday at work, don't have to wear them outside of work because of progress from physiotherapy and PT training. Will wear them if wearing a long formal dress for an event just in case.

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Are there any issues that you have with the knee brace/s themselves? (any issues with the brace as a standalone medical device, issues with clothing will be asked later)	Velcro strap ones from surgeon cut off circulation and slide down, also can't bend the knee because they hold it straight in place. Ones that are used are not funded, goes through a pair once a month because the compression gives out. Can only get them from rebel sport and sometimes don't have the right size -small, medium, and large.
How do you wear your brace/s in relation to clothing? (on top of/underneath clothing)	Wears under clothing, tried to wear them over tights in high school but got made fun off and constantly asked questions. Have to wear long pants because they don't really want people to see them. Wears wide legged pants because the compression means there's a bulge at the thigh and at the calf which doesn't look very flattering. Throws a spanner in the mix when it comes to choosing clothing.

Response to samples on the wall:

Visually straight away the cushioning and stability 1 and the cushioning and support 3 work well, looks natural and sort of skin like, looking at it it looks just like part of a leg, they're slimline and you wouldn't be able to see it which is awesome because an issue is with seeing the braces when you're trying to wear cute fits.

Likes adjustment and fit 3, it's just like tying your shoes which is something you do everyday. Visually adjustment and fit 4 looks nice but then would probably get tired of it everyday trying to slide the adjustments.

Likes the hook and eye and metal snaps closures, feels like they can be trusted the most. Hook and eyes are reminiscent of a bra and bras hold through a lot. Velcro isn't very reliable, in a stabilisation and compression setting it's the most likely to give out. The magnets would be a no, mainly because of airports and inconvenience, would have to be pat down which is already done because of the knee braces and is quite scary because someone is patting down and if they touch the wrong place they could pop out the knee.

In terms of fabrics and comfortability, visually and texturally the white stretch fabric is better. Mainly because of aesthetics, it looks nicer and helps in the way of not being afraid of people seeing knee braces being worn because it looks like a cute little thing instead of a medical device. Texture wise the white stretch would feel nicer for everyday wear rather than the brown stretch, the brown feels like it would be more itchy and it seems rough and dry where the white feels softer and less abrasive, its like if linen and wool had a baby, seems breathable and the whole leg wouldn't be drenched in sweat after an 11 hour work day.

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Issues with clothing

What is your experience with putting on/taking off clothing with the brace/s?	Because the braces aren't worn full time anymore they sometimes get forgotten when get ready for work, then pants need to be fully taken back off to put them on unless it's a wide legged pant then the braces can be slid right up the leg. But when the braces are at the end of their lifespan they start sliding down the leg a bit because the compression has worn down, so then every time you go to the bathroom the braces have to be pulled back up. By the end of the day you're ready to just get them off. Braces have to be put on first before any clothing usually.
What is your experience with putting on/taking off the brace/s?	Fairly easy to put on and take off and they slide. They can't be taken off over shoes which can be annoying, especially if knees are sore after work. Have to awkwardly reach into pants to slide braces down after taking off shoes if don't want to go do it in the bathroom.
What is your experience when it comes to adjusting the brace/s throughout the day?	The braces can slide or sometimes just feel slightly off where they should be so they need to be adjusted. Has to be done in the bathroom because pants have to be pulled down to move braces around or try going up the pant leg which doesn't work very well. Have tried grabbing the brace through the fabric and pulling it up but that also doesn't work well because the fabric of the pants gets stuck under the brace which makes the brace slide down more.
What is your experience with wearing the brace/s and clothing together, e.g tightness, movement issues?	It depends on materials, braces don't get stuck to fabric very easily unless it's a really static fabric like satin. Would never wear braces under leggings because they tend to rip holes in them. Have only really had issues with the surgeon recommended braces because they were bulky and had velcro which sticks to everything. Sometimes with skirts the friction between the braces and fabric can slowly lift your skirt over time which you then have to keep pulling down.

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What is your experience with the visual impact of wearing the brace/s and clothing together? (e.g. brace visibility, odd shaping, etc.)	Just the leg thing from the compression, calls it the leg muffin top because of the thigh and calf bulging out over the edges. Don't wear short skirts or shorts with braces because you have this weird looking fabric thing sticking out from the bottom of them. Have to go with a wider leg pant so it doesn't have a weird bow look.
What is your experience with the feel of the brace/s and clothing? (e.g. the way the fabric feels against the brace)	The surgical braces have an industrial seat belt feeling material that's plasticy and really hard with velcro, the most uncomfortable things known to man. You can get eczema and sweat build up from them. Clothing and fabric wise tend to go for things more breathable and versatile, things that are slimline opposed to bulky and industrial. Lightweight and natural fabrics are better, usually go for linen and cotton but also things that have a bit more elasticity. If going to wear a skirt often go for a skims type material. Hemp is a great fabric to wear because it keeps cool and doesn't cling to anything. Can't really wear denim because of the thickness and how it traps the heat.
Has using the brace/s changed the way you choose clothing and what you wear/buy? Could you give an example?	Kind of, avoids satin and silk because of static but also because they're quite flowy and tend to outline everything. Buys garments because of the fabric they're made out of.
Has using the brace/s changed the way you get dressed each day? If so, could you give an example?	Yes, have to put the braces on first thing everyday otherwise morning is going to be very rushed. With work have to look very professional so can't really have the braces showing visually.

Possible improvements

Are there any garments that you don't wear but would like to? What are they?	A lot of shorter lengthed skirts, being big on fashion would love to have a basic short black dress, something very basic but glam. If there was a way that knee braces could be worn to stylise them so that they can be worn with anything. Or tights or leggings that have the support of the braces without

	having to wear the braces themselves, anything that could be worn with shorter length garments, that way could wear something really cute to work.
What recommendations would you suggest are made to the brace/s and/or clothing to make dressing and wearing easier?	Looking at the previous designs, love that it's almost a cross between a cargo pant and more chic. Gives Schiaparelli vibes, where they've done collections that are a natural tone but are really sleek. Likes to have something that has a clean style to allow tattoos to stand out. Feels like previous collection is very industrial, sleek, but quite fashionable and that they can be worn either quite edgy or that clean girl aesthetic, but at the same time there's that practical aspect of being able to tighten and adjust knee braces throughout the day. Having things that can be hidden, something so it's not very noticeable that there's a difference underneath. Any garment that has stabilisers and compression like the used braces would be able to be worn and would be great. From a viewers point the previous collection is a very Schiaparelli and Balenciaga kind of vibe with being militaristic but also futuristic at the same time. Slimline is a big part, the worst part about wearing a brace is the bulkiness. If it's slimline it feels more comfortable and gives more motivation to wear it.
Are there any particular non-negotiables that you would expect to find in a garment made for knee brace use? (e.g. a specific pocket, an opening of some kind, use of zips or buttons, etc.)	Compression in some sort of way because the knee needs to be compressed whether it's underneath, above, or on the knee. Any kind of compression is used as stabilisation. Easy to use, don't want to be fiddling with heaps of straps when there's only five minutes to pull on an outfit. If humans are going to use it it's going to be user centred. 50/50 about having an opening because of using slide on braces but it would make it easier to adjust them throughout the day. Using hook and eyes and metal snaps as closures would work the best for this. Having a way to access the brace without

	having to go to the bathroom. Velcro sticks to everything and wears out so wouldn't work. Magnets aren't that reliable. Zips would work well. Buttons might not work because of movement, it could make the buttons come undone or pop off and will create tightness in some areas and looseness in others. This could make the area slide up.

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Workshop Feedback:

Material Combinations/3D brace structure series

What do each of the samples feel like? (e.g. soft, spongy, warm)	**1:** Breathable, spongy in a good way, intricate **2:** Strong, active everyday fabric, internal seam could be a comfort issue would be better as a flat seam **3:** Softer than the others, feels ultra soft and buttery, would be very hot **4:** Soft
What is the level of compression of each sample? (e.g. none, minimal, moderate, high)	**1:** 3-4/10 good for light everyday wear **2:** 5-6/10 good for recovery and standing up all day **3:** 7-8/10 high level of support, would be good for something like a reformer pilates class **4:** 1-2/10 barely any support
What is the level of stretch of each sample? (e.g. none, minimal, moderate, high)	**1:** High - good for low physical effort **2:** High-moderate **3:** Moderate **4:** High-moderate
Would any of the samples be suitable for compression and support of the patella?	Samples 1 to 3 due to the level of compression and the strength/stability of the materials
How suitable would the samples be for compression and support of the patella compared to an existing brace?	Highly suitable, would compete in the current market, especially with the ability of samples 2 and 3 to be multi-use. The amount of compression given from them could be used for people with patella alta but could be used for other conditions like arthritis to help with swelling - provide both comfort and pain relief
How comfortable would it feel for everyday use if the samples were used as an alternative to wearing a brace?	Something that is different between peoples conditions. Personally, it would be very comfortable to wear them all day. The mesh is good because it would keep the skin cool

	and prevent excessive sweating so would help keep your skin dry too. The ponte is good for the functions but could make them quite hot to wear, but would compromise the heat for support and comfort in other areas
Are there any improvements that you would recommend in terms of brace function?	Making the hole around the patella wider, using flat seams, turning the semi circle upside down and making it more of a J shape so that it doesn't rub on the patella and instead steadies it so that it doesn't dislocate - the top of the J would be on the external side as that is the side that the patella would go to in a dislocation, making the bars go all the way up to the edge of the brace so that the fabric doesn't flip over because of the tension, using a silicone strip like what is used on seamless underwear could be good for holding the top and bottom edges against the leg

Garment Sampling and Developments to Show

Based on the physical samples in front of you, are there any drawings that stand out as being the most suitable for everyday use?	12 - would be great because it looks really supportive and it has interesting shaping to it, but would turn it upside down like previously mentioned and would also separate the bars and the circle so that there is still the ability to move your knee and do it comfortably 6 - because it has the support from both fabrics and the panel shaping, but would make the mesh double layer for extra support through the middle of the knee, the mesh going around the back of the knee is good for comfort and keeping cool
Are there any drawings that stand out as being the least suitable?	4 - because of the unsuitability of the compression and support 11 - because the ponte going around the back of the knee would tighten and feel suffocating and could cause issues with rubbing throughout the day
What are your thoughts about the 3D printed structures being built into these garments? Would they be functional for everyday use?	They would be functional built into garments, and they would look really cool with the lace pattern of the print. The balloon pant idea with concealing braces but also being able to show them is

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	awesome.
What are your thoughts on cut out areas? Would they compromise the stability and support of the knee areas?	They are a cool idea but it could feel a little unstable. They would be fun to wear and if combined with the brace samples that have been seen could work really well if further developed
Are there any improvements that you would recommend in terms of function and accessibility?	Same as what has already been said, the 3D printed bars need to go right to the top and bottom edges to stop flipping and the separation between the bars and the semi circle like what is in the first brace sample is good
What are your thoughts on creating garments that integrate with existing braces instead of garments with brace features? (e.g. garments with openings and panelling for braces like honours collection)	Both would be good, the balloon pant idea could work with the beautiful 3D printed lace brace and with already existing braces so that area is already covered. Would be the best of both worlds for people with patella alta and others with different conditions.

Discussion with physiotherapist

My original 3D printed designs had the semi circle sitting above the patella like brace 1 and 4, however my user said they would be better if it were sitting under the patella with an extended piece on the external knee to prevent dislocations and to not force the patella down. Do you agree with this? Why?	In terms of patella alta and knee dislocations yes as the patella is most likely to dislocate laterally to the external knee. Some current options have this shaping already and work well but they don't have the benefit of looking nice or being made from a lightweight and breathable material.
What are your thoughts about the stabilising bars being connected vs disconnected to the circular piece?	It's individualised, depending on feel movement, either of them could work depending on user preference and what tasks they will be completing while wearing it
What are your thoughts on the width of the circular support piece? Would the wider or the thinner size be more functional?	Again it's individualised and dependent on the size of the knee of the user, both are equally functional they will work the same
What are your thoughts about the materials in terms of how comfortable and supportive they feel? Would they be able to be worn for long periods of time?	The materials both feel comfortable to be worn for a full day. The mesh in particular is compressive, stable, lightweight, breathable, and gives a form of adjustment because of the stretch when applied to the body. The 3D printing is innovative and it should give enough support for the every day use.
What are your thoughts about these being able to be used for other conditions? Are there any other conditions that they could be used for?	Yes they could be, other patella instability's, further development of them could lead to working post-surgery and in the first stages of injury
What further improvements or recommendations do you have for the designs in terms of functionality?	Limitations of current braces - restrictive vs not restrictive enough, where the support is felt vs applied, current braces can not be

Discussion with physiotherapist

	tailored to specific people whereas this project has potential to do it Consider the mental impact and state how these will improve user ability - when people are injured the most common thing stopping them from doing what got them injured is fear of re-injury, the mental impact of that leads to people not wearing their braces and not doing the rehabilitation properly, along with more pain. The braces are going to make them safe and protect the knee and previously injured area which improves mental and physical well-being at the same time, as they are not just made to be pretty, but made to protect and support.

Further recommendations, things to think about post masters:

-The ability to tailor braces to each specific person through recommendation of physics/surgeons/doctors

-Swapping around fabric shaping, 3D printing shaping and connections to make specific tailored braces depending on user needs

-Research into the background of users injury's especially if they're reoccurring, is there a pattern to injury causes

-Researching/measuring users knees to create a sizing guide and to make the correct sizes for New Zealand

-The application into garments is interesting, can't really comment on it but thinks it would be best suitable for people when their knees are back to pre-injury/baseline state