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Master's Thesis
Academic Year 2023

Exploring Inflatable Wearable Furniture through Personal Fabrication

Keio University
Graduate School of Media Design

Yang Shen

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Yang Shen

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Abstract of Master's Thesis of Academic Year 2023

Exploring Inflatable Wearable Furniture through Personal Fabrication

Category: Design

Summary

Take a moment to think about what takes up the most space in your home and on your travels. It is undoubtedly your clothes. With the rise of a neo-nomadic lifestyle among the younger generation, there is a growing demand for more portable personal items. Inspired by the design concept of Archigram, I envision the potential of creating wearable designs that go beyond mere fashion, offering additional functional as a furniture after transformation in shape.

This research paper aims to explore the design possibilities in the context of wearable furniture with inflatable material, and to further share original design patterns and fabrication tools with creative individuals. In order to show the potential of wearable furniture, the research includes an analysis on existing inflatable works and iterations on the fabrication of inflatable material, design patterns and pneumatic structures. The research project also presents two body-scale wearable furniture designs as final proof of concept, and shows an easy-to-use fabrication method with an original design tool for designers.

This paper also documents user interviews with end users and a workshop with a target group of designers. The young participants showed a great interest in the aspect of personal fabrication, in the meantime they also shared their concerns, such as the durability of the inflatable material. For the future, we would like to discuss the potential of this concept for upcycling unused clothing.

Keywords:

inflatable material, design patterns, personal digital fabrication, design tool, speculative wearable

Keio University Graduate School of Media Design

Yang Shen

Contents

List of Figures

List of Tables

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Chapter 1
Introduction

1.1. Background: New Nomadic Age

> ”Today is a new age, I call it the ‘New Nomadic Age’. People like you and I are always moving, moving is a new daily thing, it’s not special or unusual anymore.” —— Kenya Hara(1)

The revival of “new nomad age”(1), where “nomad” has been long stands for “people who move from one place to another instead of having a permanent place to stay”(2), have been starting a growing trend among the young generation in recent years. In the era of great technological progress and enhanced transportation efficiency, the Neo-nomad lifestyle has never been that close to individuals. The way how people live and move has been rapidly changed. In contrast to the time when it took days to send even a single greeting letter, nowadays moving has become a casual daily occurrence. People have much more freedom to move easily and swiftly than ever before.

In recent years, there has been a resurgence of the nomadic lifestyle, with more younger generation opting to embrace a neo-nomadic way of living. There has been a growing trend of young men and women who would spend the majority of time in their mobile homes, such as vehicles or tents, continuously moving from one destination to another rather than residing in a permanent house.(3) In addition to that, due to the outbreak of covid-19, more and more young people choose to live as a digital nomad, which allows them to work online regardless where they truly are. According to BBC news, data has revealed that an increased amount of people are embracing a digital nomad lifestyle characterized by frequent changes in their place of residence. Until this June, there has been 58 countries that offering digital nomad visas. Not only it creates opportunity for governments to increase local consumption, but also provides people with more flexibility and freedom to work and travel in a foreign country.(4)

The shift towards a neo-nomadic lifestyle brings forth new challenges. Simply considering personal belongings, a fundamental question arises: How do we handle all of our belongings? How many times have you struggled with the size of your luggage before a flight, wishing it could magically shrink? Have you ever found yourself frustrated by the limited storage space in your apartment? Looking beyond, it leads us to ponder the great possibility that this trend of lifestyle will eventually become the norm. If so, then it raises the need to enhance the portability of our belongings, and perhaps even our living spaces in the future.

1.2. The Rise of Personal Fabrication

> “What is novel about ‘personal fabrication’ is not the ‘fabrication’ thought, but the ‘personal’.” —— Personal Fabrication (5)

Have you ever wondered how things around you has been produced today? Even though we all know that a significant portion of our everyday commodities and possessions are mass-produced in factory settings through automated machinery, but rarely do us get access to or even know about these fabrication tools by themselves. The main reason why most people hardly know about these fabrication technologies that have actually been in operation for many years is because they were patented and not easily accessible or transparent to the public. However, things is taking a rapid change in the past 30 years.

The shift from proprietary to open source, from industry to individual is affecting every sector of technology. We have witnessed similar occurrence in the history of computing which successfully made its transition from industry to individuals. As patents expiring, an increasing number of fabrication tools, like 3D printers, are transitioning into open-sources. This shift welcomes ”makers”, normally recognised as technology-enthusiasts who enjoy manufacture things on their own, to re-imagine and customize their own fabrication tools.(5) This is where the idea of personal fabrication initiates in recent years. Personal fabrication, as described by Neil Gershenfeld in 2015, as “the ability to design and produce your own products, in your own home, with a machine that combines consumer electronics with industrial tools."(5)

The significance of personal digital fabrication is not only that it engages people in the discussion about the future of production, but also that it invites individuals into the actual fabrication process. This research project aims to bring fabrication techniques and tools back to the individual in a way that contributes to the exploration of personal fabrication possibilities for the future. As more people participate in personal fabrication, we can envision a future with a more democratized market with a wider range of products.(6)

1.3. Design Pattern

Design pattern is introduced as a necessary tool for this research to bridge the gap in domain/machine knowledge and expertise.(7) In this research, the design pattern indicates for a repeatable systematic design framework for achieving specific forms. By using these design patterns as a basis, the design process becomes more inclusive and accessible to a broader range of designers, regardless of their level of expertise or background knowledge. While providing a shared pool of knowledge and experience, it also encourages designers to iterate and expand their ideas about inflatables.

1.4. The Idea of Wearable Furniture

This research focuses on exploring the new possibility in prototyping wearable, specifically inflatable wearable furniture. The notion wearable furniture, means a wearable design that can be transform into a furniture responding to the user needs in the near future. This concept is derived from the idea of wearable architecture, first raised by the avant-garde architectural group Archigram(8).

Recognizing the emergence of a new nomadic lifestyle, where our living spaces are no longer confined to static environments, I have identified a compelling need for wearable furniture. As we become more mobile and seek greater flexibility in our lifestyles, the need for adaptable and portable furniture solutions becomes apparent. Imagine a world where individuals can carry their wearable as furniture with them, transforming a raincoat into a comfortable seating arrangement, or unfold a spare shirt as a chair for impromptu work sessions. This vision of wearable furniture presents a paradigm shift in the way we perceive wearable and furniture.

1.5. Research Goal

Observing the slow yet significant societal change on lifestyle and industrial shift on fabrication technology, this research project aims to continue exploring future design opportunities with inflatable materials. More specifically, it focuses on exploring the potential of inflatable materials in the realm of personal fabrication and wearable furniture. The research goal includes three main aspects. Firstly, the primary goal is to study the material properties and validate personal fabrication method in prototyping inflatable ideas. In addition to that, by studying various design patterns and their adaptation to inflatable materials, this research particularly focuses to apply inflatable design patterns in the context of wearable furniture. In a long term perspective, ultimately, this research intents to make new design patterns and fabrication tools available as open source code to support individuals, especially designers, during their creation. This visionary concept offers a thought-provoking glimpse into the potential future where the transformative nature of wearable extends beyond mere fashion, enabling individuals to use their garments for additional functional purposes.

1.5.1 Research Question

Base on the background context and pilot research, here are the three main questions that navigated me throughout my research journey:

- Based on current research on shape-changing materials, what design possibilities arise from the intersection of existing inflatable products and wearable garments?
- How to bridge the gap between wearable and furniture with inflatable material?

- Which personal fabrication method is suitable for designers to work with inflatable materials and customizable designs?

1.5.2 Contribution

The contribution of this research can be divided into two aspects: ideation and fabrication. The challenging point in the ideation process was to propose a novel design concept amidst the saturated creative marketplace of today. Observing that existing inflatable products are either wearable or furniture, the idea of bridging wearable and furniture with inflatable material appears as a great potential for design in this nomadic age. This research also challenges people's stereotypes about clothing and fashion, expecting to unlock new potentials for the future of wearables. Additionally, the concept of wearable furniture shows potential in addressing the upcycling issue in the fashion industry. Especially for new nomads who move frequently from place to place, wearable furniture offers a more versatile and functional approach to fashion, allowing users to transform their garments into usable furniture when needed.

On the other hand, working with inflatable materials presents higher barriers and challenges for designers. After interviewing with several fashion student, they all expressed their interest on inflatable material but had limited knowledge on proper fabrication method. Thus sharing the fabrication method and providing designers with user-friendly design tools for working with inflatables became a primary goal of this research. This research aims to facilitate designers in the creation of unique and transformative designs with inflatable materials.

1.6. Structure

This research paper is structured with five chapters accordingly.
In the current chapter, I would like to give an general introduction on the research background of new nomadic lifestyle on trend, research field of personal fabrication and research topic on wearable furniture. This chapter follows with a clear interpretation on the goal of the research, research questions extending from the goal, and clarifies the targeting user group.
The second chapter includes literature review on speculative design method and

wearable architecture as inspiration for this research. It also consists of more in detail analysis on related precedents and academic papers on the design and fabrication of shape-changing material.
Base on the research information in the previous chapter, the third chapter starts with a conclusion on the design opportunity of this research topic. Then it dives into my explorations on different kinds of shape-changing materials, fabrication techniques culminating in three iterative prototyping phases. It also includes the design tool I came up with during the prototyping process.
Then, in the fourth chapter I documented the design workshop and user interview that I conducted about the future application with my targeting group. I also summarized the feasibility and limitation of this project.
Lastly, in the final chapter, I concludes this research with future plan and discussion on further application scenario.

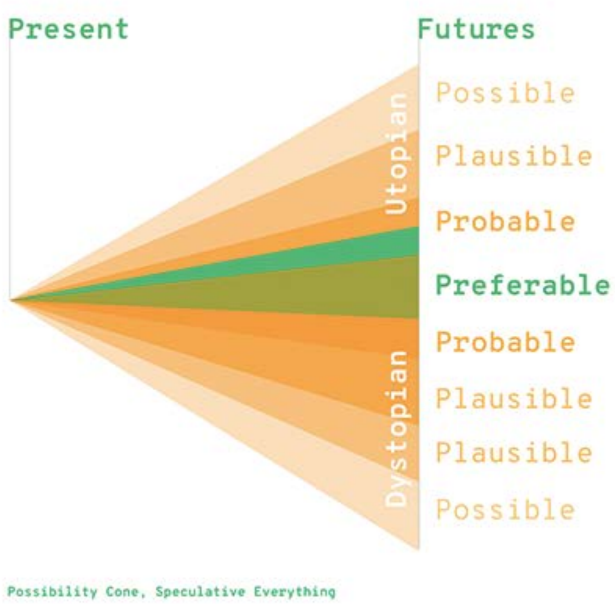
Chapter 2
Literature Review and Related Works

2.1. Speculative Design

> “ To be human is to refuse to accept the given as given.” —— Speculative Everything (9)

Speculative design methods were deployed as a foundational approach during the ideation process of this research. The inspiration of wearable architecture, also, lies underneath the spectrum of speculative design. The term ”Speculative design” was raised by design pioneers Anthony Dunne and Fiona Raby in the 1990s(9). In their book ”Speculative Everything”(9) , it explained in detail that the idea of speculative design is to embrace imagination and seeks to expand the time frame of design to the future.

As a relatively novel approach in design, speculative design prompts people to question existing norms, inspiring them to re-imagine what can be designed and fostering a broader dialogue on the potential futures we as designers can create beyond reality. The purpose of speculative design is to let designers freely wonder about how things could be again. Reminding designers that the idea of design, at its core, is not only about solving a problem, but more importantly as a pursuit of better alternatives, driven by the belief that improvements are possible. With the inherent optimism of design, speculative design fuels boundless creativity, enabling designers to reshape the world in new perspectives by surpassing the limitations in the increasingly saturated market.



(Source: Speculative Everything, 2014 (9))

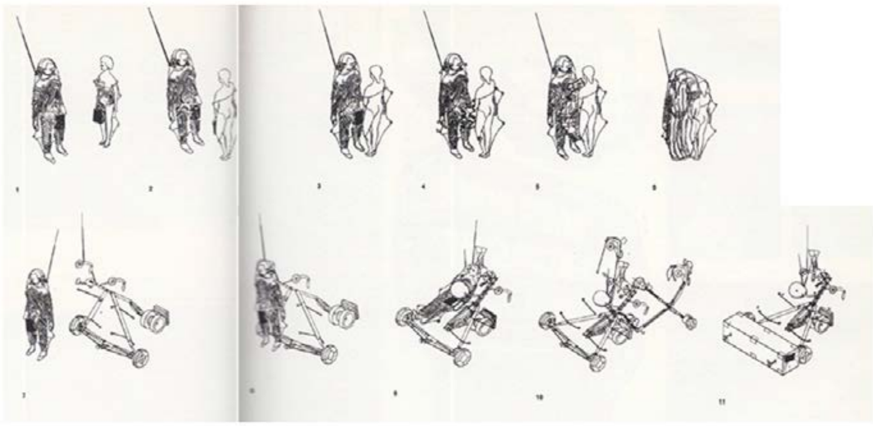
Figure 2.1 Possibility Cone from *Speculative Everything* written by Anthony Dunne and Fiona Raby

The inherent futuristic nature of speculative design poses a challenge in its practical applicability, a notable limitation of speculative design is that it is often detached from practical reality. It is often more an enlightenment than a well-grounded logical solution to current society. Which means it is rather hard for people to prove it today. Taken that in consideration, more academic researches around current digital fabrication methods has been conducted to facilitate the feasibility of the idea of wearable furniture in the near future.

2.1.1 Wearable Architecture

The research topic, Wearable Furniture, is strongly inspired by the concept of Wearable Architecture, which was first introduced by Archigram in the 1960s. The concept of wearable architecture is to merge the boundaries between clothing and architecture. The idea that our clothes could become our future homes inspires me because the conventional perception of fashion and clothing as soft, superficial, delicate and ephemeral contrasts sharply with the prevailing notion of architecture as monumental and enduring, often associated with the image of rigid, highly durable materials.

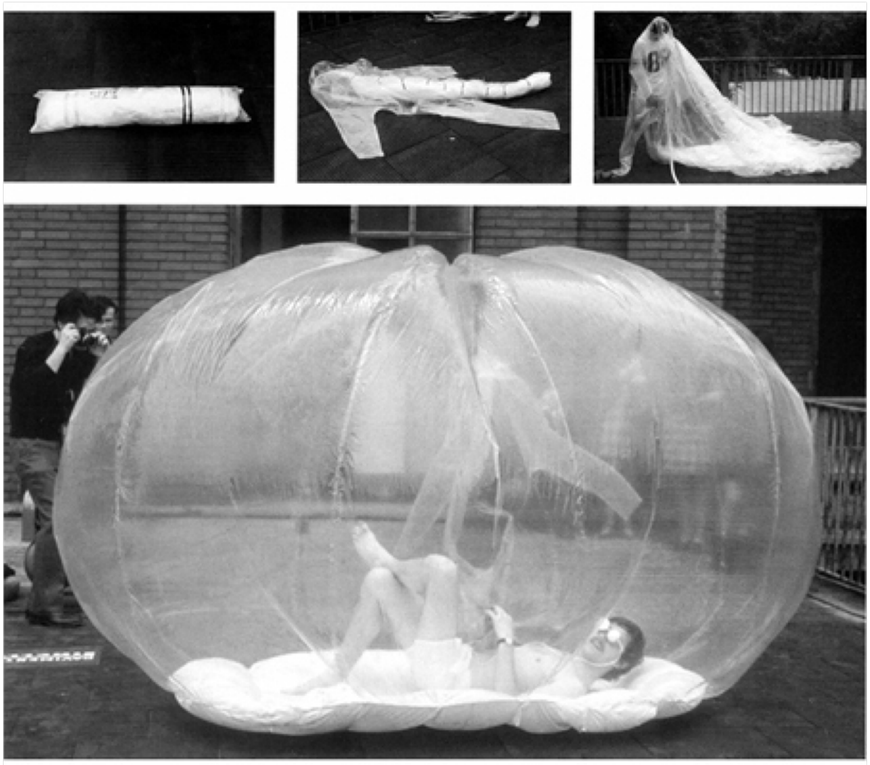
Designers from the Archigram group had been in search of the possibilities to create new living spaces with soft, inflatable materials back in 1968. For example, the following project called "THE CUSHICLE and SUITALOON" (10) was created by architect Michael Webb, who was a member of Archigram, proposing the idea of transforming mobile structures into an expandable personal space.



(Source: Cushicle, by Michael Webb, 1967(8))

Figure 2.2 Sequential drawings of Cushicle, by Michael Webb, 1967

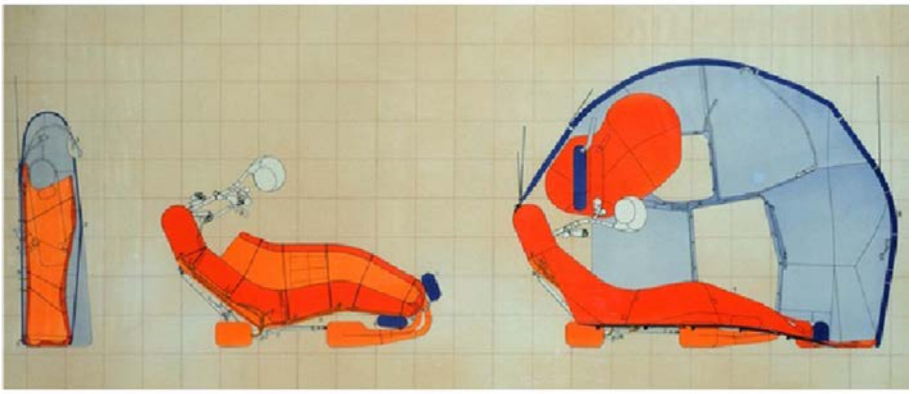
This work is composed of two parts: the Cushicle was a proposal for a human scale capsule living space published in 1964, while the Suitaloon is an updated speculative prototype that aims to portray the user case in an extremely minimalist pneumatic house.



(Source: Suitaloon, by Michael Webb, 1967(8))

Figure 2.3 Testing out a prototype of the Suitaloon.

Besides, both imaginative works concealed a transparent, ideological Utopian society that architects envisioned during the postwar period.(10) Even though the prediction of an inflatable housing system is still a concept that is yet to come to life, the potential it holds for revolutionizing the future of housing is highly intriguing. Today, there is an emerging trend that people are gradually becoming less bound to the need of physical ownership of a rigid place like a house. Taking the insight of wearable architecture, this research aims to explore a new connection between clothing and furniture by utilizing the transformative properties of inflatable materials.



(Source:Cushicle sketch, by Michael Webb, 1967 (8))

Figure 2.4 Transformation of the Cushicle, Drawn by Michael Webb, 1967

2.2. Shape-changing Precedents

Aside from the material properties of inflatable materials, extensive market research has been conducted to analyze and draw inspiration from existing shape-changing designs and past designs that have the potential to migrate into an inflatable structure. These precedents can serve as valuable sources of inspiration and guidance, providing references for the structure and fabrication of materials, as well as navigating in the pursuit of originality within this research project.

Since there is limited work on the intersection of wearable and furniture, the research on existing designs in the market was conducted separately from both perspectives: clothing and furniture.

2.2.1 Fashion, Clothes, Textile

Shape-changing design has long been a popular theme in fashion, and many designers have tried to explore its possibilities. Although not all of the works use inflatable material, the similarity in concept and transformative forms provides valuable insights for this design research.

Hussein Chalayan

One of the first design works that comes to mind is by renowned avant-garde designer Hussein Chalayan, who is known for his talent in combining philosophical ideas with clothing. In his Fall/Winter 2000 show, Chalayan presented a series that ingeniously transformed home furnishings into fashion. This collection remains a testament to his whimsical creativity and continues to attract and inspire to this day. In this show, he transformed four chair covers into four dresses and a coffee table into a skirt.(11)

(Source: AnOther, "When Hussein Chalayan Turned Furnishings Into Fashion" (11)

Figure 2.5 Chalayan Autumn/Winter 2000 part1

(Source: AnOther, "When Hussein Chalayan Turned Furnishings Into Fashion" (11)

Figure 2.6 Chalayan Autumn/Winter 2000 part2

Meanwhile, the show is curated in a Turkish living room setting, and all the transformations happened simultaneously during the show, which providing audiences with a more captivating and immersive experience. This collection was initially inspired by refugees during the war, which also ties in with his own childhood memories of the atrocities in Cyprus in the 1960s. So he created this piece with sensitivity, balancing his concept of modern nomads with form and function. The final result has a minimal and elegant aesthetic, demonstrating the harmonious fusion of concept and execution.(12)

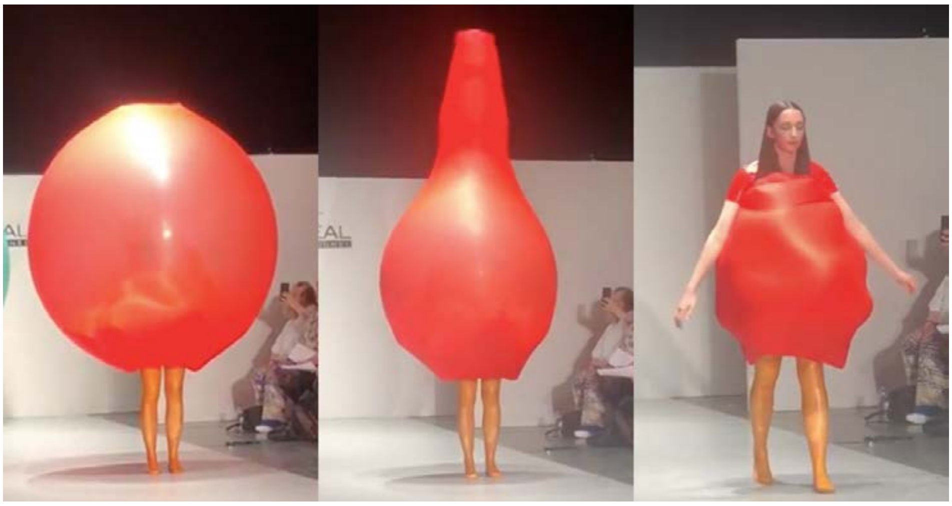
(Source: Airmail Dress, Met Museum(13)

Figure 2.7 Chalayan Airmail dress

Another notable design by Hussein Chalayan is the Airmail Dress, created in 1999 and collected in the Costume Institute of the MET.(13) The dress, as shown in the image, can be worn on the body or folded into an envelope and sent overseas as airmail. This airmail dress was originally sold with instructions to encourage people to customize it. And it was specially made from a paper-like textile called Tyvek. How he tried to communicate his idea in both material and form was a great inspiration for my thesis project. This dress can also be seen as a metaphor of the sender's emotion, representing a visceral connection from a person who misses you far away. It is obvious that the two works, created within a close period of time, share great similarity in emotion. Meanwhile, Chalayan mentioned in an interview that he liked the idea of clothes being interactive. (12) Even today, my research project is greatly inspired by his novel move of inviting consumers into the design of the dress with instructions, which makes everyone possible as a maker, a designer.

Fredrik Tjærandsen

Last but not least, there are a few designers and brands who are starting to use inflatable materials such as PVC, TPU in clothing. Inflatable materials have appeared in the fashion industry as a trendy and special material with a strong personality. One of the most impressive cases in recent years can be Central Saint Martins fashion student Fredrik Tjærandsen's balloon dress at the graduation show.



(Source: Vogue Meets The Fashion Graduate Whose Balloon Dress Has Gone Viral, Vogue (14))

Figure 2.8 Fredrik Tjærandsen's Balloon Dress

The bubbles serve as symbolic representations of "fogginess," evoking a sense of drifting dreams. As the bubbles deflate on stage, it attempts to show the ambiguous emotions Fedrick experiences upon awakening from his childhood reverie.(14)

(Source: Vogue Meets The Fashion Graduate Whose Balloon Dress Has Gone Viral, Vogue (14))

Figure 2.9 Fredrik Tjærandsen's Balloon Dress Collection

It is particularly worth mentioning about the rubber material that he used for the collection. It is mentioned during his interview that he ordered the rubber directly from local rubber growers in Sri Lanka, and was specially customize with as much as possible from plants and was crafted to the limits to meet the draping and stretching needs in the making process. The designer's dedication to precision is incredible, not only in the transformation of form, but also in the delicate control of the material itself.

Louis Vuitton

In addition to these runway projects, Louis Vuitton's inflatable jacket vest, launched in the Spring/Summer 2021 collection, offers a more commercial and practical example of inflatable fashion. Designed by the talented Virgil Abloh, the inflatable monogram canvas jacket is available in a translucent option and a mix of transparent PVC and a classic brown monogram canvas backing. These two designs quickly created a buzz among the public, with people wondering if anyone would actually pay for this bold yet eccentric design.(15)

(Source: Hypebeast (Feb 12, 2021), "Louis Vuitton Releases Virgil Abloh-Designed Inflatable Monogram Canvas Blouson and Gilet" (15))

Figure 2.10 Virgil Abloh-Designed Inflatable Monogram Canvas Blouson and Gilet for Louis Vuitton SS21 Collectin

Although it doesn't fit the public perception of this luxury brand, and it may not be an ideal design to use the inflatable material. Louis Vuitton shows its attempt to explore new materials, which has given life to the brand and made more young people aware of it. The use of polyvinyl chloride and leather in clothing also demonstrates its modern and delicate craftsmanship. It also marked the great potential of inflatable materials in the luxury industry.

2.2.2 Furniture

In addressing the challenge of balancing the size difference of furniture and wearable, as well as fitting the structure of furniture into the wearable into consideration, the exploration in the field of furniture centered from body form structure for single person usage purpose.

Bodyform Side Chair

One design that came to me with great potential is this Bodyform side chair, manufactured by Peter Danko in the 1980s.(16) As shown below, the design of this chair not only effectively balances the dimensions of furniture and wearables, but also shows its potential as a functional inflatable piece of furniture that can be comfortably used with the human body. In addition, the simple 3D structural design of the Bodyform chair can be transformed into a flat surface, making it a possible fit for an inflatable design pattern.

(Source: MOMA, Bodyfrom Chair (16))

Figure 2.11 Peter Danko, Bodyform Side Chair, 1980

Quasar Khahn

Quasar Khahn's design caught my interest while researching inflatable furniture. Born in Hanoi and raised in Paris, Quasar is recognized as an engineer, designer and creator. The Aerospace collection, created in 1967, is one of his most famous works. This absolutely revolutionary design was inspired by the pop art culture and space exploration of the 1960s. The inventive pieces in the collection are all named after planets and names related to the solar system. The overall design gives people a sense of playfulness and imagination.(17)

(Source: Artnet, Apollo chair (model no. 15) (18))

Figure 2.12 Apollo chair (model no. 15), ca. 1968

Quasar's success not only comes from his artistic taste, but also his familiarity and mastery of materials as an engineer. The use of extra durable PVC and special welding technique, it is not hard to observe that this collection is deeply connected with Quasar's pragmatic research as an engineer. This series of inflatable furniture shows the possibility of turning vivid space dreams into realistic ideas. That is also why this visionary series quickly become highly desired.

Therefore, through an extensive research on existing inflatable fashion and furniture cases available in the market, the potential of inflatable materials has captivated my attention.

2.3. Design and Fabrication of Shape-changing Material

2.3.1 Shape changing Materials

Shape-changing materials are materials that undergo a reversible change in their physical form in response to one or more triggers such as heat, light, temperature, electricity, etc. For example, foaming materials or water absorbent polymers undergoes expansion when they are exposed to moisture. Here is a table summarizing some common cases of shape changing materials.

Table 2.1 some common shape-changing materials

material	trigger	transformation
tracing paper	water	bend
plastic film	heat	shrink
foam material	water/heat	expand
inflatable material	air	expand
shape memory alloy	heat	memorized shape

In the realm of academic research, the exploration and experimentation with shape-changing materials have yielded various pathways, and a selection of these holds relevance for the fabrication of wearable furniture. As listed above, there are a wide range of shape-changing materials. Considering that the research is related to wearable objects, inflatable materials present the most applicable option among various alternatives, because they provide a lightweight, fabric-like material that ensures a comfortable wearing experience. Moreover, a transformation, more specifically an expansion, of the structural framework is anticipated in this particular instance. For this research we envision a seamless transition from a soft garment into a stable furniture form, thereby ensuring optimal levels of both comfort and safety.

2.3.2 Inflatable Materials

The lightweight and highly adaptable nature of inflatable materials make it a suitable choice for the research at this stage. Inflatable materials are an innovative invention in the field of material science and have been adapted for use in a wide range of applications, including swim rings, life jackets, inflatable castle slides, and shipping package materials. Three of the most commonly used types of inflatable materials for rapid prototyping are thermoplastic polyurethane (TPU), polyvinyl chloride (PVC), and rubber. (19)

2.3.3 Fabrication Process on Inflatable Objects

The fabrication process of inflatable project varies base on the material applied. But air sealing is undoubtedly the most important part for fabrication. The standard industrial production line of large scale inflatable object includes the following major procedures:

1. Design. Firstly designers use 3D tools and AutoCad to solidify the technical plan.

2. Cutting. High precision cutters are used to accurately separate the parts from raw materials.

3. Stitching. Fabricating the parts into the designed shape.

4. Welding. PVC/PU material parts are fused together with great heat and pressure.

5. Testing. Check the air tightness of the final product. The machines used for industrial standard with high accuracy are hardly affordable for individuals. Thus many researchers in HCI or soft robotics field has proposed new developed tools for easily creating inflatable objects using soft material.

Manual Heat Sealing

Heat sealing method is the most widely used way for inflatables. The technique is the application of using heat to bond various thermoplastic materials, including PVC, TPU, and polyethylene. Similar to industrial welding, as the heat is applied to edges of the material, the thermoplastic material softens and melts, make the parts to fuse together upon cooling. This fusion forms a strong, continuous bond that prevents air leakage and ensures the structural integrity of the inflatable. Heat sealing offers several advantages, such as fast production time.(19)

Manual sealing is the easiest way for beginners, which can be complete with handheld heat sealer purchased, hot air gun or irons. While manual sealing can be more time-consuming and may require more skill and precision, it offers flexibility in sealing irregular shapes and smaller-scale projects.

CNC and Laser Cutting

In addition, a new heat sealing method of utilizing a customized three-axis CNC machine with a heating head has been explored in research project AeroMorph (7). This innovative method opens more space for precise and accurate heat sealing of materials in a laboratory environment. Furthermore, similar methods can also be applied on welding large scale inflatable objects as shown in the research paper Printflatable (20) and Liquid Pouch Motors project(21) . Using a customized CNC machine with numerically controlled thermal contact iron, this project achieved to produce human-scale functional objects with TPU and inflatable fabrics. In the research AccordionFab(22), it shows that the same method can also be adapt to a laser cut machine in small scale prototyping on plastic sheets.

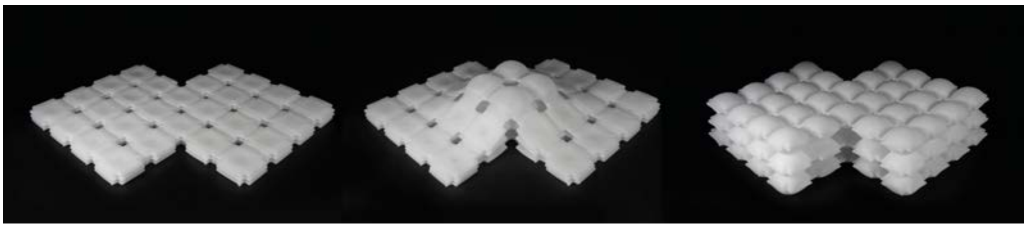
3D Printing

Recent years, with increased popularity in the 3D printing field, a new method of applying 3D printer extruder to heat-seal small scale object is proposed in research project Therms-Up (23). Comparing with the heat sealing method with CNC machine, this new heat sealing method with 3D printer is more user-friendly. Without requiring major modifications to the printer itself, it expands the design space for quick prototyping in small scale.

2.3.4 Self-Assembly Structure

In the past decades, pneumatic systems have already been utilized in various applied cases in the material science field. The self-assembly attribute of inflatable material frees people from assemble and install.

Recent research has delved into the realm of self-assembling structures using 3D printing technology, more specifically liquid printing technology. The research project, Liquid Printed Pneumatics (24), initiated by MIT's Self-Assembly Lab and BMW Design Department, created the first customizable printed inflatable material using silicone. It is worth noting that the entire material object can change in a diverse range of forms, functionalities, or stiffness attributes in responds to the amount of air supplied. On the other hand, "Liquid to Air: Pneumatic Objects" (24) explores the new craftsmanship on a variety of inflatable objects in different scales. The new way of production made it possible for individuals to customize and fabricate objects themselves in the near future.



(Source: Self-Asembly Lab, "Liquid Printed Pneumatics" (24)

Figure 2.13 Liquid Printed Pneumatics Self-assembly Structure

2.3.5 Design Patterns

The pneumatic pattern plays a vital role in the fabrication process of inflatable materials, particularly in creating shape-changing structures. Here, the design pattern, indicates for a repeatable design solution for achieving specific forms. Observing from afar, nature provides an abundant source of inspiration for such patterns. Not limited to natural inspired origami, today computational origami has been a popular research direction in material engineering and soft robotic fields. The shape-changing materials combining with origami patterns enables robots to mimicry movements like a living organism, or even human muscles. (25) One particular fold that caught my attention is the miura-ori fold, known for its ability to increase paper stiffness, rigidity, and compressibility. (26) This fold shows the potential to form wearable furniture with inflatable material. Additionally, I have also delved into bending structures for flat surfaces and geometric primitives. The research paper "AeroMorph" (7) documents single surface bending simulations and illustrates different surface curvatures in detail. These investigations have broadened my understanding of inflatable design patterns and their applications in creating innovative and functional designs.

Chapter 3
Design

3.1. Design Opportunity

Through extensive academic research and existing precedents in the market, a compelling design opportunity for wearable furniture in the near future has become evident.

Firstly, after interviewing several young fashion designers in pilot survey, it is not hard to notice that there is a lack of awareness on user-friendly prototyping methods with inflatable materials.

There is also a need for design tools that can demonstrate the application of various inflatable design patterns to designers. Such tools would enable designers to realize the full potential of inflatable materials and facilitate the creation of innovative and customizable wearable structures.

Lastly, there is a notable opportunity lies in the utilization of inflatable materials for creating futuristic wearable designs. While existing inflatable products primarily serve functional or high-fashion purposes, there is a limited exploration of the material's lightweight and transformative nature with the idea of wearable furniture. More specifically, inflatable clothing and inflatable furniture has been long existing products in the market. However, rarely do designers think of using the transformative nature of inflatable materials to connect wearables with furniture.

By addressing these challenges and opportunities, this research aims to bridge the gap between material science and wearable design, exploring the creative possibilities offered by inflatable materials, particularly with the idea of wearable furniture.

3.2. Concept

The concept of this design project is to explore the potential of personal fabrication with inflatable material. By embracing imaginative and forward-thinking design approaches, coupled with the practical considerations of usability, this research aims to extend the potential of inflatable material in wearable.As the design process continues, the concept can be broken down into two designing scenarios:

3.2.1 Design Scenario 1

The first design scenario is to explore the idea of wearable furniture. By using inflatable materials and design patterns, the ultimate goal is to inspire design creation with the concept of wearable furniture as explained. The user cases of Design Scenario 1 can therefore be outdoors or when frequently moving from place to place to live.

3.2.2 End User

When designing wearable furniture for design scenario 1 , we need to take consideration on the end user. The end user of design scenario 1 can be anyone who embraces a new nomadic lifestyle. The design propositions of wearable furniture are portable, lightweight and self-assembly. According to recent data on digital nomads recently, the age group is concentrated in the 20s and 30s.(2) So the young generation is our main target end-user at the moment. For the future, we envision that everyone will be used to the idea of wearable furniture.

3.2.3 Design Scenario 2

As the research progresses, I am aware of the need to consider another design scenario: from the designer's perspective. One of the goals of this research is to push the idea of wearable furniture and the boundaries of inflatable material in wearables. In the process of prototyping with inflatable material, I realized that if I want to push this idea, I need to implement easier design tools for prototyping and I also need to get more design talents on board. Thus the design scenario 2 focuses more on design patterns, design tools and fabrication method that can be shared with designers as open source. The user case can be a fashion designer who wants to experiment with inflatable material in his or her design. Or an interior designer who wants to create a portable soft structure for a space.

3.2.4 Target Group

The target group for design scenario 2 are new generation designers, especially creative young designers who has interests in the interdisciplinary field of apparel, furniture and speculative design area. So more specifically, this research focus on new generation designers, aged from 15-30 years old. Even though, it is still hard for individuals without basic knowledge on design tools and hands-on experience with hardware equipment to start digital fabrication by themselves. It is no doubt that people will be much more adaptive on digital fabrication in the near future. So eventually the target group will be limited to designers, but anyone who aims to bring their idea into life.

3.3. Prototype 1

The first iteration of prototype is to determine the material choice of this project and testing different heat seal methods. Simple thin PVC sheet and aluminium sheet are daily materials that first be chosen to be test with. For heat sealing process, traditional heat sealer clip and soldering machine are utilized. However, these existing machine has many limitations.

Firstly, heat seal clips are often limited in terms of the size and shape of the materials they can effectively seal. In this case, the heat seal clip used can only create straight lines heat-sealing. Similarly, soldering machines, although widely used in various industries, may not be suitable for all types of inflatable materials due to their high heat intensity, which easily causes damages and deformations on thin PVC sheets. Even though these two materials are easy to find, and aluminium sheet is good heat insulator, their suitability for larger prototypes are limited due to their fragility and lack of flexibility.

Figure 3.1 Heat sealing methods

Realizing that the materials and method weren't working as expected, I looked for other material alternatives available for prototyping. I found PU heat transfer rubber sheet to be an ideal inflatable material for prototyping on fabric. The material is commonly used to create graphics and slogans on T-shirts or other garments in the market.

3.3.1 Fabrication procedure

The fabrication process using PU Heat Transfer Vinyl Sheet with baking paper to make inflatable is an easy way to make inflatable even for beginner. The material I used for prototype is the white matt heat transfer vinyl from HVRONT brand, with a recommended heat setting at 305°F -310°F(27). Taking a simple radiant snowflake shape pneumatic system as a model, the general fabrication method is demonstrated as following:

1. Firstly, preparing the design pattern on baking paper and two vinyl sheets that slightly greater than the whole design pattern (5mm margins between edge). The design pattern represents the part that will be inflated, so it is necessary to consider about how air can go through it and the position of the air hole. Then cutting out the design on baking paper or using a laser cutting machine. Depending on the complexity of the design, you can choose the suitable tool. In this case I laser cut a simple six-square pneumatic system.

2. Secondly, heat sealing. As shown in the picture, placing the three layers: Top TPU, baking paper and bottom TPU together for heat sealing. Plastic carriers should always facing outsides with adhesive sides facing towards the baking paper. Then passing the iron around 150 degree and press gently to on both surfaces, especially edges for 10-15 seconds. A heat press is also recommended if size matches the design pattern.

3. Then the vinyl will be sealed where there is no baking paper, and if necessary cut the outline after the surfaces cool down. It needs at least 5mm margins between edge. Make sure there is an air hole or place for air valve.

4. Finally, pealing off the plastic protection layers and testing the inflatable by connecting the air pump or using a hand pump.

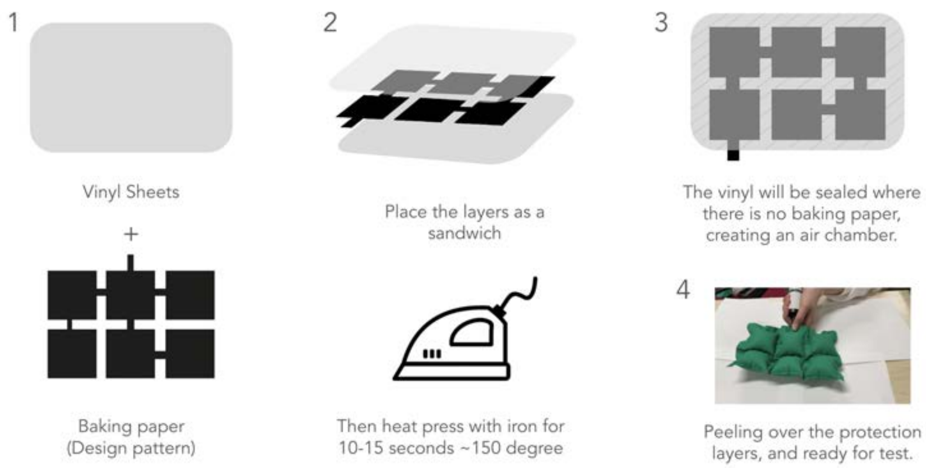


Figure 3.2 Fabrication process, starting from top-left corner (1) to bottom-right corner (4)

3.3.2 Material Testing

Based on the initial round of prototyping, I have decided to further investigate the use of heat transfer TPU vinyl sheet for inflatable prototyping. This material possesses several advantageous characteristics that make it well-suited for this purpose. First of all, in comparison to PVC, it exhibits enhanced flexibility, stretchability, and reduced fragility. This light weighted material enables greater adaptability and durability in the inflatable structure. Additionally, the material is specifically designed to be compatible with soft fabrics and can be seamlessly integrated onto clothes. Moreover, it allows user to fabricate with iron, which is a more accessible tool in daily life. I foresee the potential of applying this material for personal fabrication.

However, the use of heat transfer vinyl also presents certain challenges. Firstly, the affordance of the material can be one concern, as it may limit some design possibilities. Secondly, this first round of prototype is mostly manually air-pumped. By considering the opportunity for self-assembly structure, I would like to find other ways to pump the structure. Gaining a deeper understanding of the behavior of inflatables is crucial for taking next step in design. Thus in the second round of prototyping, I aims to explore various design patterns using this material.

3.4. Prototype 2

Based on the first iteration of prototype, the second iteration consists of two parts. It begins with a more hands-on exploration of customizable design patterns that expand upon the existing patterns.

3.4.1 Pattern Design

To begin with, I started by translating various design patterns from research papers into tangible inflatables, and aimed to derive from the existing patterns. By bringing these design concepts into the realm of practical implementation, I sought to explore their new potential.

One of the main goals during this second iteration is to find ways to make the 2-dimensional inflatable interface into a more 3-dimensional structure. Based on the related work mentioned in the previous chapter, the research project Aeromorph(7), draws great inspiration when I started exploring around inflatables.

Initially, I experimented with simple geometric structures. Based on the controllable bending direction, these textures form a self-folding structure as a triangular pyramid and octahedron shape. The transformation from a flat surface to a 3D object and its deconstruction back to a flat surface corresponds to the concept of a future wearable that can expand and compress based on the user's choice.

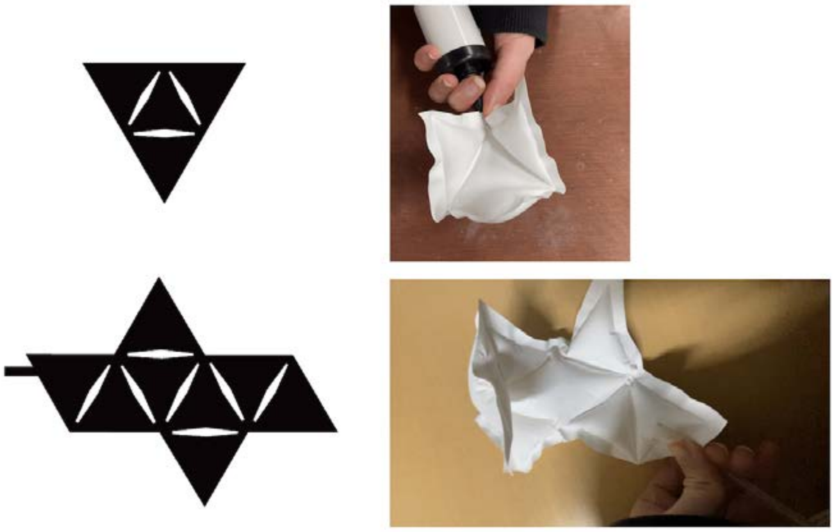


Figure 3.3 Foldable Triangular Shape

Thus by implementing the hinge mechanism and controllable bending structure(7) discussed in Aeromorph, I created the following prototype with Arduino. This display is created as a small demonstration of the future vision of self-assembly wearable for KMD forum.

Figure 3.4 Inflatable Wearable Demo

Next, inspired by the Miura(26) fold pattern, I modified and re-applied this origami pattern as the inflatable shape and created the following sample.

Figure 3.5 Inflatable Miura Pattern

In the meantime, I experimented with another variation of the Miura form, creating a star-shaped inflatable structure inspired by the Miura pattern. The pattern shrinks and lifts from the surface when inflated.

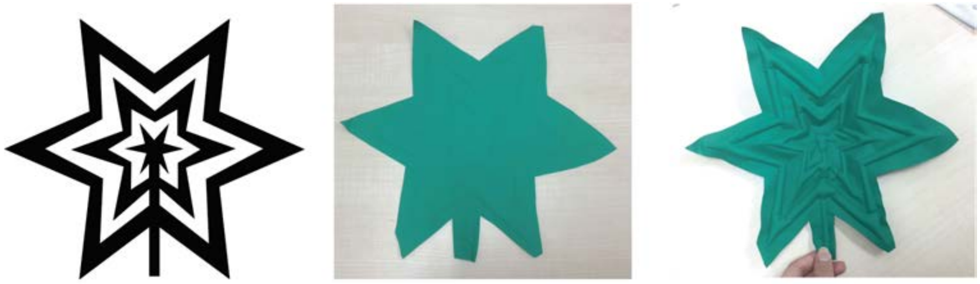


Figure 3.6 Inflatable Star Pattern

While exploring the modular unit design thinking perspective, I recognized the potential to replace the square shapes in the six-unit pneumatic structure with alternative shapes, such as circles. This inspiration leads to this parametric egg structure as a viable circular shape alternative. Also, to increase the flexibility of the inflatable structure, the adhesive negative space that will not be inflated is cut out later. However, since the egg shapes are all uniform in size and length, the final structure does not have much transformation.

Figure 3.7 Inflatable Egg Pattern

Then, with the goal of creating a more dome-shaped load-bearing structure, I modified the egg structure again with more variations in the size of the circles and the length of the paddles. By adopting a parametric approach to the circles, the design can be further customized and adapted to different shapes and forms, allowing for greater flexibility and versatility in creating the dome shape.

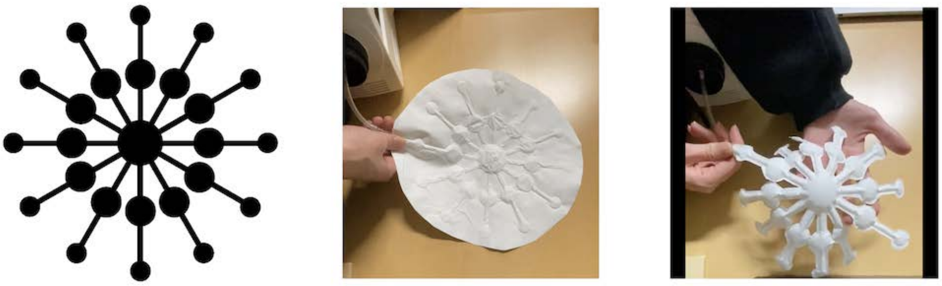


Figure 3.8 Inflatable Dome Pattern

Furthermore, inspired by Chalayan's(11) Table Dress structure. I tried out with the circular ring shape design pattern, however without extra extension between layers, it can only form this arc shape after inflation.

Figure 3.9 Inflatable Ripple Pattern

In addition to the structural aspects, I also tried to incorporate Arduino as an air supply mechanism in the experimentation. This allowed for the implementation of intermittent inflation towards the prototype, which facilitated a more comprehensive observation on the transitional inflatable behavior. By using this approach, I aimed to observe and gain a deeper understanding of how these structures change and adapt over time.

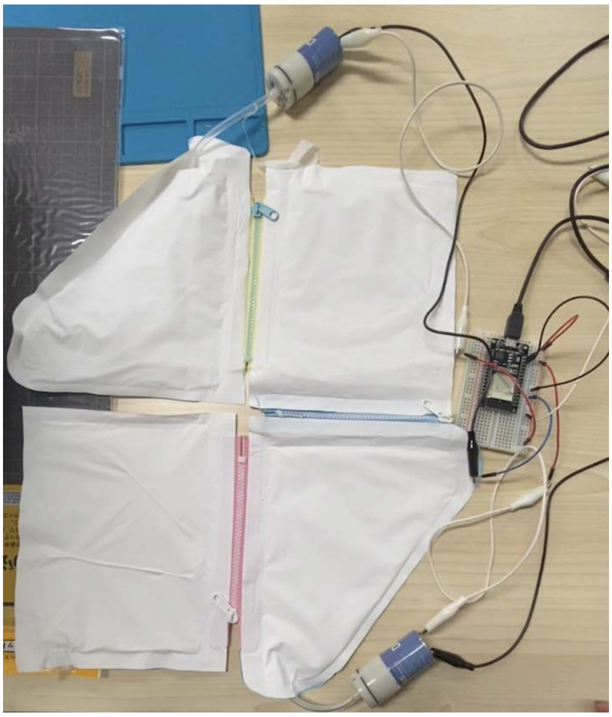


Figure 3.10 Arduino Air Pump module with modular units

However, the main issue regarding to air pumping with Arduino is that the volume of air as well as pressure of air supplied by the unit is not capable to support prototype in greater size. Although Arduino is really handful for quick prototyping and easy to carry for demonstration at events such as KMD forum. But since only air pump motors are used for this prototype, without vacuum pump module, it takes more time for the prototype to be deflated. To make the form even closer to self-assembly design, I also looked up research paper milliMorph(28) which showcased prototype using fluid-driven method, also known as liquid pouch motors(21), to inflate shape-changing materials. But still, the structure is in a much smaller scale which can hardly be applied in my design scenario.

Figure 3.11 Showcase in KMD forum with Arduino air pump

In addition that , another attempt for the second iteration is to explore the possibility on modular unit. Research project such as Pneubot(29) and Liquid Printed Pneumatics(24) presented how modularity allows for easy customization, better adaptability and versatility. By breaking down the wearable into smaller inflatable units, each unit can be individually designed, fabricated and inflated, enabling greater flexibility in terms of size, shape, and functionality. So I did a rough prototype to test out modular unit by using zipper and velcro as connection.

Figure 3.12 Modular inflatable units

3.5. Prototype 3

For the third iteration of prototype, the focus shifted to improve the design patterns from the previous iteration with visual programming software Processing, so that user can make changes more easily. Also, based on my previous design research, I tried to experiment on the integration of these design patterns into the concept of wearable furniture.

3.5.1 Pattern Design Tool

The goal of the third prototype is to explore design patterns in detail and utilizing effective design tools to achieve greater parametric control over the patterns.

While prototyping the dome structure in the second iteration, I found that make variation on parameters for a similar design pattern, for example only changing the size of modular shapes, in current design tool, illustrator, is rather time-consuming. In order to improve the efficiency and more possibility for personal fabrication, I used Processing, a flexible visual coding software, to facilitate this process.

To find the ideal dome shape, I created the following design tool based on the dome shape design pattern showed before. The sketch aims to allow users to modify the pattern on three parameters: the size of circle(A), the position of the circle in the middle of each paddle(B) and the number of paddles(C).

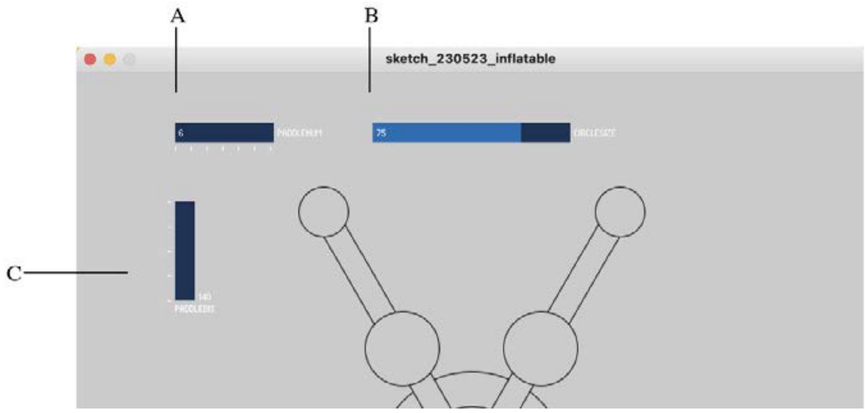


Figure 3.13 User Interface of Processing Sketch

Users can make changes with the sliders on the interface.

After determine the structure, the user can export the shape in SVG form by pressing ”s” key.

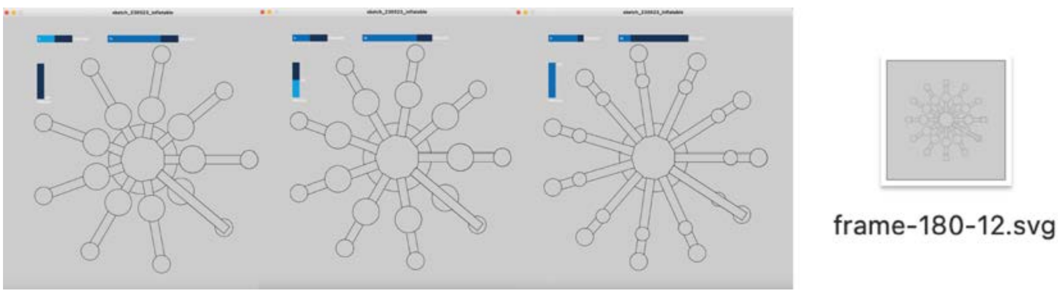


Figure 3.14 Patterns Generated with the Sketch

Then user can import it into illustration to expand the border with <Pathfinder>/ <Merge>and make slight modification before laser cutting.

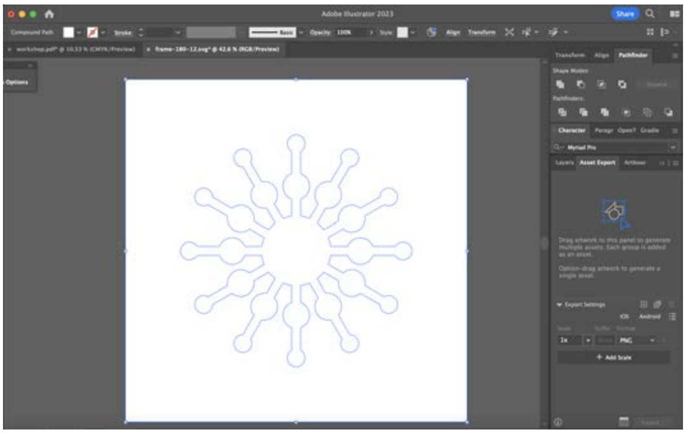


Figure 3.15 Using Illustrator to merge the svg for laser cutting

Comparison on the shape

Here are a set of shape that I created in order to compare on the structure. The comparison of the dome structure is showcased as below:

9 paddles 160 paddle distance	9 paddles 180 paddle distance	9 paddles 200 paddle distance
		
		

Figure 3.16 comparison of changing the distance of the paddles

From observation, with lower paddle distance, the dome structure shrinks more, while the greater paddle distance will make the structure more spread out.

3.5.2 Cloth Making

Stepping away from the design patterns, understanding the structure of wearable, specifically clothes, is also crucial for developing the idea of wearable furniture. As a non-fashion background student, I tried the first time to sew a skirt from its pattern.

Figure 3.17 Making skirt from pattern with sewing machine

Through the pattern making process, there are two points that is worth-noting. Firstly, the draping of the skirt proved to be more complex than I initially anticipated, requiring multiple fabric pattern parts to achieve the circular shape. Also, normally fabrics covers body softly with many curves but in order to transform it into an inflatable furniture, a rigid structure needs to be attached on it. So I realize that the alignment of the furniture shape with the silhouette of clothes is a crucial key towards approaching the wearable furniture idea.

3.6. Final Prototype

For the final prototype, I want to get closer to the application of wearable furniture. Aiming to transform a soft cloth into a practical furniture, I started to design considering the most conventional furniture objects: chair and table,

3.6.1 Wearable Shirt Chair

Ideation

Inspired by the design of the Bodyform chair, the concept of a wearable chair emerged during the ideation process. This idea builds on the simplistic design mentioned earlier in the related work, which is able to transform from a 3D chair to a 2D flat surface. Meanwhile, chairs, as furniture for one person to use, have similarities in scale to certain garments, such as coats and one-piece outfits.

Figure 3.18 pattern for bodyform chair

As implied by its name, the wearable chair design embodies a shape reminiscent of the human body. This unique form opens up possibilities for transforming a one-piece garment into a practical chair by incorporating the aforementioned bending structure into the clothing. Here is a small-scale prototype using heat transfer vinyl.

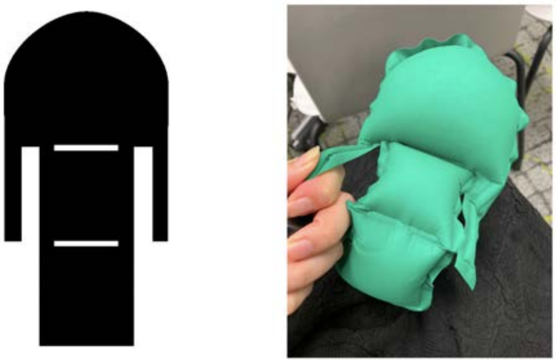


Figure 3.19 inflatable bodyform chair first prototype

Fabrication

In order to explore this concept further, I first created a small scale prototype with children's cloth to proof that this fabrication method works well on fabric.

Figure 3.20 inflatable bodyform chair form on children's clothes

Although the folding form was not as the bodyform chair, because the children's cloth is too short to form a chair with a backrest structure. By attaching bending folds on three sides, the cloth can successfully transform into a stool after inflating.

Figure 3.21 Final prototype - Shirt Chair

I created the final prototype using a full-size women's shirt dress, which was chosen for its ample space to accommodate the inflatable chair structure on the back. The Taking into consideration the affordances of the material, I designed and fabricated the prototype in the following form.Since the form is greater than the size of laser cut machine, I cut and assembled the deign patterns with baking paper manually except for the bending structure on two arms which were laser cut in the first place. Velcros are attached on side arms so after inflation user can set them in place.

3.6.2 Wearable Skirt Table

Ideation

When considering the closest form with table, the forms of a skirt and a dress immediately come to mind. After researching existing works, Chalayan's furniture dress greatly inspires me, as well as the following images

Figure 3.22 Strolling Table Dresses (left) and Table Dress (right) by Chalayan

It is worth noting that the majority of table-shaped dresses featured in previous designs are constructed in solid materials underneath such as wood, resulting in a heavy structure. Recognizing this opportunity, I wants to create a similar table design in a lightweight inflatable form for single-person use. Also, there is an opportunity to extend the dome design pattern from the previous iteration into use.

To be sure about the structure, I made a small scale prototype of the portable table on a figure model. The material I used is also heat transfer vinyl.

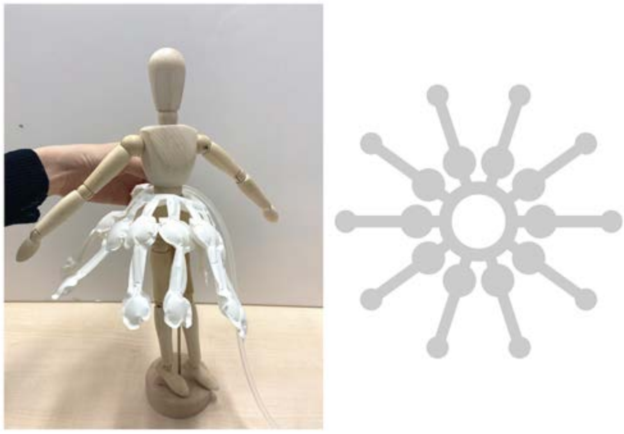


Figure 3.23 Inflation demo on figure model - Table Dress

Fabrication

Based on the comparison of dome pattern shown in the previous iteration, I chose to use the following design pattern as it would create more flat surface around the body. But as the scale of the skirt greatly exceeds the size of laser machine. So I deconstruct the paddles of the pattern into parts and lasercut them as individual pieces. To prevent air leakage issues, I decided to fabricate each paddle individually which allows me to check the air tightness before assembling them together.

Figure 3.24 Fabrication and details - Table Dress

To make it easier to put on and put off during user testing, I decided to use veclro at the waist edge. Finally, the inflatable skirt-table structure is attached inside the handmade skirt from the previous iteration.

Figure 3.25 Final Prototype - Skirt Table

Chapter 4
Evaluation

4.1. Overview

The evaluation consists of two parts: an in-depth analysis of the feedback received from end-user interviews on the design concept and prototype, and a summary of the workshop with young designers (target group) on the use of inflatable material. The purpose of the user interview session was to gather valuable insights from the user's perspective and to validate the effectiveness of the design. While the workshop session aimed to explore the personal fabrication possibilities around the topic by engaging with a group of young creative individuals interested in the topic.

4.2. User Interview: Exploring User Perspective on Wearable Furniture

The user interview was conducted with 18 potential end users of design scenario 1. The participants are focused in the age group of 18-30, 6 people were interviewed online after experiencing it. The whole user interview includes two surveys: context survey and feedback survey, with a total of 11 questions and 4 open-ended short answers. I also conducted a short face-to-face interview with some of the respondents during the user testing sessions about their experiences and suggestions about wearing the design.

Procedure

The user interview is conducted with the following procedure:

1. The interview begins with a general context survey, which guides users into the scenario and prompts them to reflect on their current storage situation regarding their belongings, particularly on clothing. The survey includes a series of questions listed below:

    - What takes the most storage in your luggage when you travel to live in a new place?
    - Do you think clothes is occupying a significant amount of storage space at your home now or when you move to a new place?
    - Would you be interested if clothing could serve additional functions when not being worn?
    - What comes to your mind when thinking about the term wearable furniture? (short answer)

2. Then, I would give participants an introduction on the concept and design of wearable furniture

3. After that, participates would wear the prototype, sometimes a brief interview or short discussion is conducted.

4. Finally, participants are asked to fill out the feedback survey prepared, including assessment on the functionality, suitability, aesthetics and user experience of the design. Below are the questions:

    - As shown in the picture, it is a rough prototype of a shirt dress that can transform into a simple chair. On a scale of 1 to 5, how interested are you in this design ?
    - After seeing the prototype, how would you rate this design ?
    - As shown in the picture, it is a rough prototype of a skirt dress that can transform into a small table. On a scale of 1 to 5, how interested are you in this design ?
    - After seeing the prototype, how would you rate this design ?
    - After seeing the prototypes, how would you rate your concerns for this design ?

- comparing these two designs, which one do you prefer?
- Why do you prefer that design?

Participants were also asked to provide open-ended opinions on the potential of this design concept. Below are the questions:

- If there is any opportunity to make this kind of inflatable structure on unused cloth of yours would you like to participate
- Can you name other design combination you expect to see? (eg. hat+lamp etc.)
- What would you expect to see as the next step of this concept?

Figure 4.1 User Tests and Interviews

4.2.1 Result Analysis

Context Survey

According to the survey result, all participants agrees that clothes took the most storage in their luggage when travel to live in a new place. And 94.4% of them incline to the view that clothes is occupying a significant amount of storage space at their home.

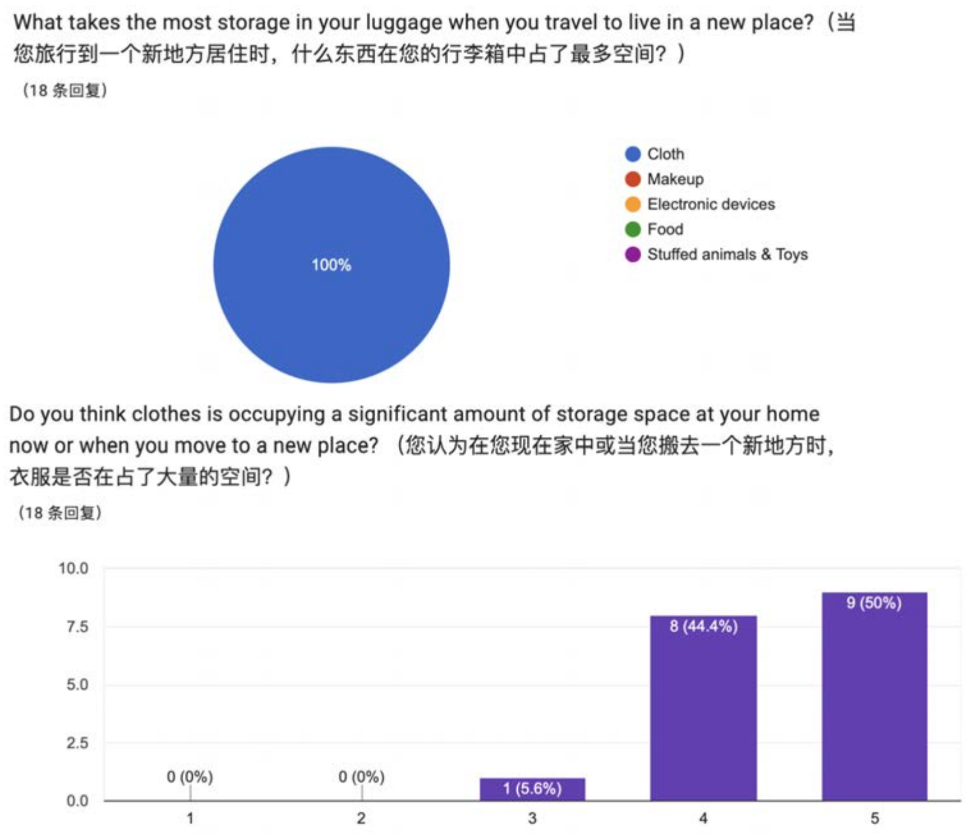


Figure 4.2 Context Survey Q1, Q2

Among these participants, 61.1% showed with direct interest on the idea that clothing could serve additional functions when not being worn. While 33.3% of the participants fence with the idea and one participant refuses to the idea.

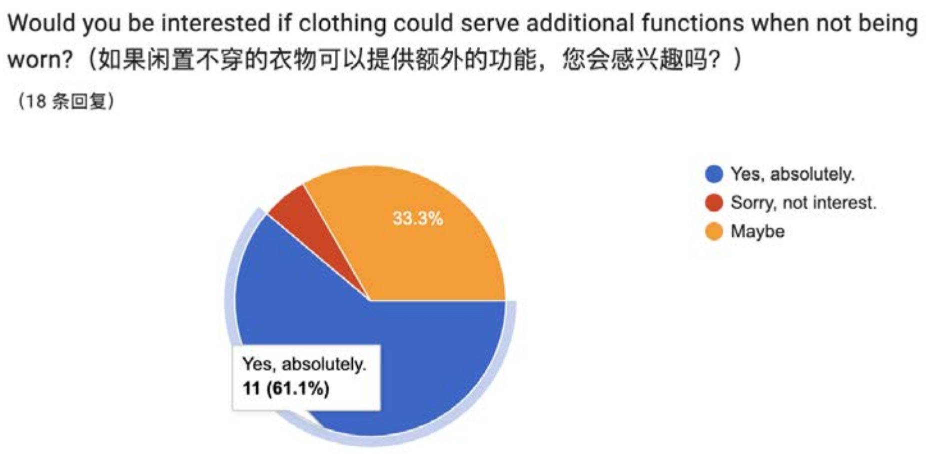


Figure 4.3 Context Survey Q3

Then about the short answer "What comes to your mind when thinking about the term wearable furniture?" Participants gives feedbacks as following:

- "I never think about wearing the furniture on my body before, because I think it will be very heavy."
- "a portable sofa so I don't need to stand all the time?"
- "Inflatable or foldable clothing"

By analyzing the users' response, all participants expressed their association with "wearable furniture" is for resting, in terms of its functionality and purpose. We can also see that 23% mentioned inflatable or foldable in terms of the form. And In terms of the furniture mentioned, 50% participants' answer is related to sofa and seating, and 23% of the participants' responses include bed and lying down.

In summary, we can see that the context situation as well as the user need is quite clear.

Feedback Survey

The first portion of the feedback survey reveals participants' assessment on the designs after user testing.

For the shirt dress/chair design, 50% of the participants showed great interest on the design, while 44.4% of participants showed somewhat interested. As for the skirt/table design, 33.3% of participants showed great interest on it, while 50% of participants showed somewhat interested to the design. Overall, we can see the chair design gains more interests. When comparing these two designs later, we also observed the same user tendency that the shirt dress/chair design is more attractive to participants.

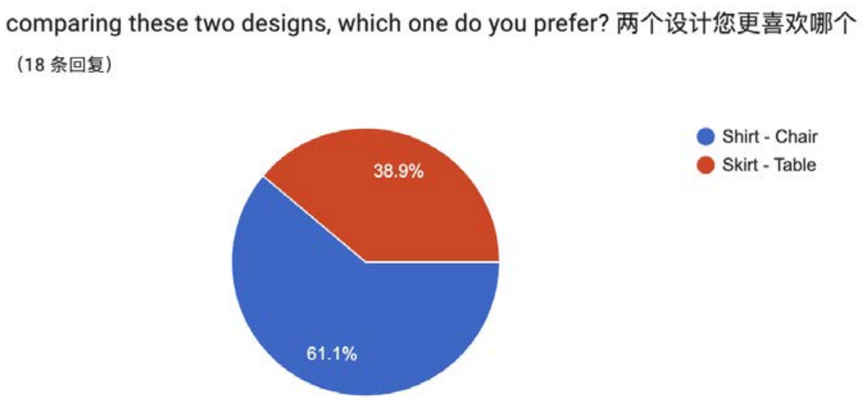


Figure 4.4 participants preference on two designs

The top diagram visualized in detail on the rating of the prototype of chair design. As we can see, participants are generally satisfied with the functionality and aesthetics, but unsatisfied with the user experience and suitability.

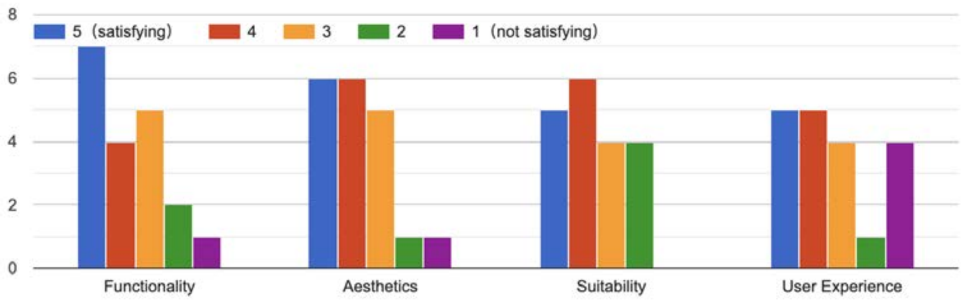


Figure 4.5 participants rating for shirt dress/chair design

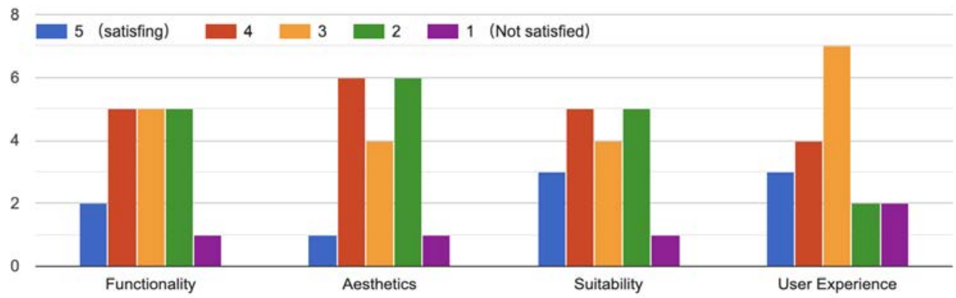


Figure 4.6 participants rating for skirt/table design

The diagram at the bottom visualized in detail on the rating of the prototype for the table design. As we can see, participants are generally satisfied with the user experience, but unsatisfied with the aesthetics. Also more participants showed neutral on the satisfaction.

By surveying participants why they prefer the chair design, people reviewed as following:

- "The shirt - chair looks more functional. There could be various design ideas depending on the clothing material."
- "Chair is more functional"
- "I think chair is more needed than a table"

The responses aligns with the rating on functionality of chair design, which is much higher than the table design. Meanwhile participants also showed their concern that the soft material may not able to hold things steadily as a table.

The survey also invited participants to rate about their concerns for these inflatable wearable designs from the aspect of air leaking, air pumping, material and aesthetics. Around 60% participants are concerned with air leakage and Aesthetics.

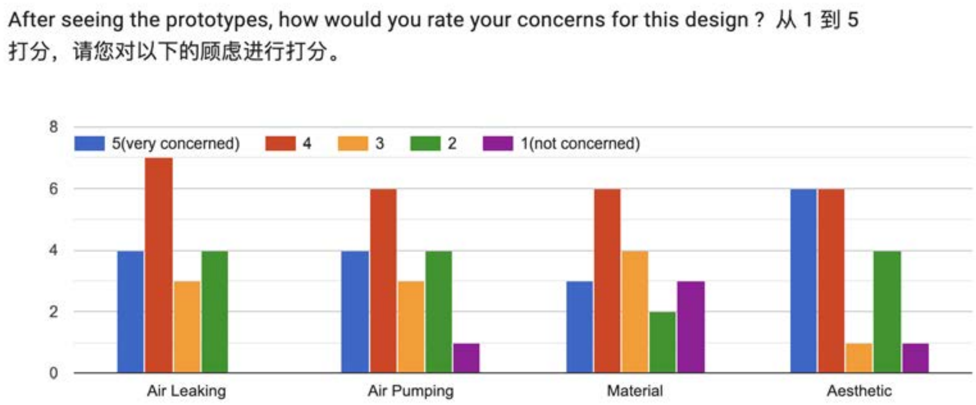


Figure 4.7 participants concerns for the designs

The second portion of the feedback survey questions more open-end questions for further applications and suggestions for further development. Here are a few responses I got on the question of other new design combination you expect to see?

- "I think hats are a good choice, or umbrellas or something (it is really necessary for the rainy season recently "
- "wool sweater + cushion"
- "jacket+bag(eg. rucksack etc...) Sometimes when I go out and I am not sure if I need a bag or not, it would be convenient to have an inflatable bag. And, since the bag and clothes are integrated, it may be able to prevent theft."
- "Maybe attach hook on the sleeve for easy carrying things."
- "Dress or gown becomes mural or screen"

Also, to the question of next step, over 72% of the participants are expecting to see improvement on aesthetics. Interactivity with body follows the next, with 61.1% participants choose this direction. And improvement on structure(55%) comes as the third.

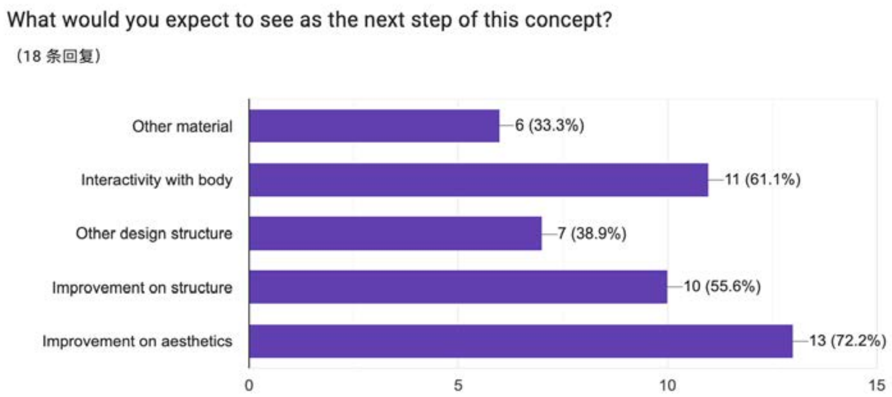


Figure 4.8 participants expectation

4.2.2 Discussion

When conducting the user testing session, I also raised some short discussion with a few participants.

- The first question is about their experience with the material. All participants give positive feedback on the material, they think it give a "cozy, soft, hugging" feeling that bring relaxation for them.
- We also discussed about various application scenarios that they envision this design can fit in the future. The answer that comes up the most was the use of this design in restaurants and cafes, especially for food trucks in outdoor fields. Another noteworthy response highlighted the sustainable potential of this design practice. The participant expressed enthusiasm about the concept's ability to address the historical recycling problem within the fashion industry and address that by repurposing clothing into functional furniture, the design promotes a circular economy and reduces waste.
- Furthermore, one of the participants, who happens to be a dancer, provided insightful feedback regarding the Table dress design. She mentioned that it could serve as an excellent stage prop for performers due to its lightweight nature.

Figure 4.9 participant dancing around observing the movement

4.3. Workshop: Trial of Inflatable Materials with Young Designers and Evaluation of Personal Fabrication Tools and Methods

The purpose of this workshop is to discover the opportunity for personal fabrication design tools related to inflatable material. On the other hand, the workshop also aims to discuss the possibility of wearable furniture with young designers as target group for design scenario 2.

4.3.1 Procedure

- Time: 17:00 - 18:00, Friday, June 16, 2023, 17:00 - 18:00, Sunday, June 18, 2023
- Place: Keio University, Hiyoshi Campus
- Participants: 5 students with design or prototyping experience. The following diagram shows the overall skillsets of the participants.

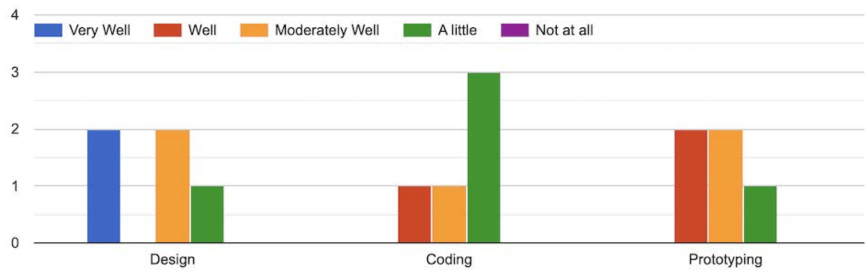


Figure 4.10 Participant backgrounds

Also it is worth mentioning that this workshop marked all participants' first experience working with Heat Transfer Vinyl. While one participant may know about this material before, she had never personally used it before. So all the participants are at a level playing field.

- Materials: Drawing Tools, Baking Paper, Scissors, Iron, Heat Transfer Vinyl and Fabrics.

- Workshop Agenda:
17:00 - 17:10 Introduction to the workshop objectives and participants. Demonstrating material, samples and applicable design pattern.
17:20 - 17:30 Choosing design pattern and brainstorming ideas
17:30 - 17:50 Fabrication time, with guidance
17:50 - 18:00 Showcase and Documentation

4.3.2 Showcase

Participant A

- Idea: Participant A chooses the design pattern of dome structure and come up with the idea of making a hat that can transform into an umbrella. When it is deflated the paddles hang as decorations or hide inside the hat; when inflated the paddles keep user off the rain.

- Thoughts: "Free your hands from a rainy day."

Figure 4.11 participant A's prototype

Participant B

- Idea: The participant B also choose the design pattern of dome structure. They were inspired by the shrinkage behavior of the triangular inflatable and decided to combine it with the dome structure. The idea is that each paddle will have the function of grabbing.

- Thoughts: "Grab things with your clothes!"

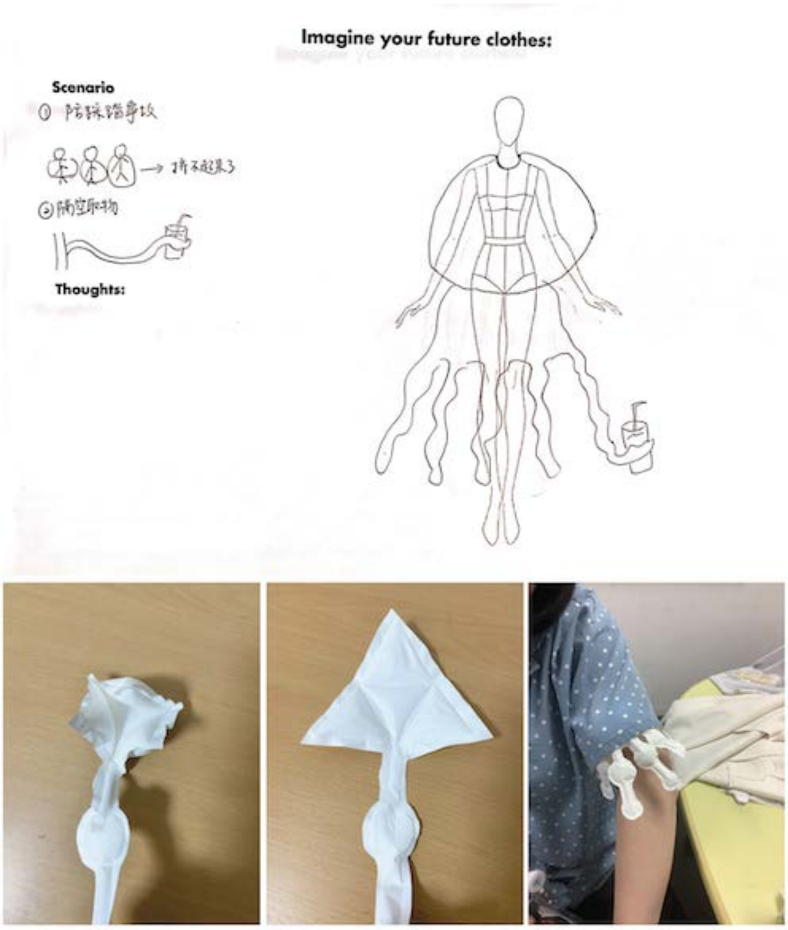


Figure 4.12 participant B's prototype

Participant C

- Idea: Participant C wants to design a pure costume design for Halloween. Originally C wants to make a variation on the dome structure with the processing tool as well. Later C realize that a spiky shape will be a better fit so user can choose the length of the octopus skirt by herself.

- Thoughts: "Eye-catching but also easy to carry costume"

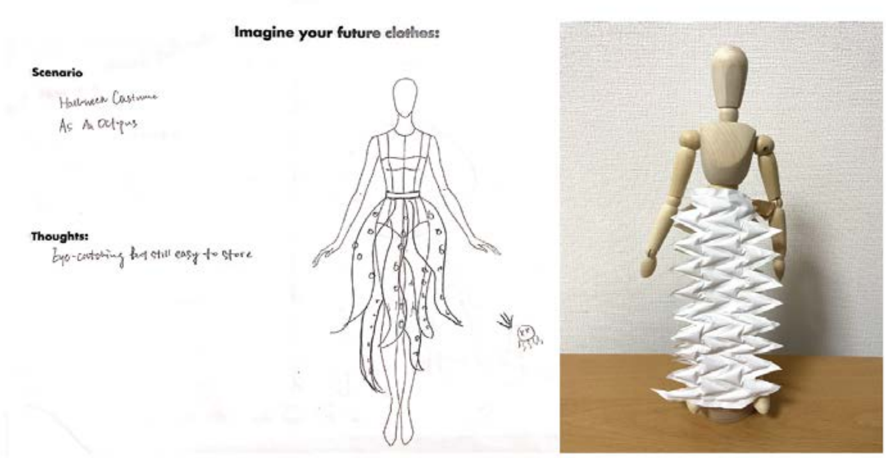


Figure 4.13 participant C's prototype

Participant D

- Idea: Participant D also choose the bodyform chair design pattern. D think that design pattern fits with a long one-piece dress. So D designed it with fabric as a dress.
- Thoughts: "Bring clothes 3-dimensional."

Figure 4.14 participant D's prototype

Participant E

- Idea: Participant E choose the bodyform chair design pattern. E thinks it is the most effective pattern for the idea of wearable furniture. E comes up with the scenario of going for outdoor picnic or casual hiking. So E designed it as a cloak that can transform into a chair at the destination.
- Thoughts: "Fashion outfit for outdoor trip."

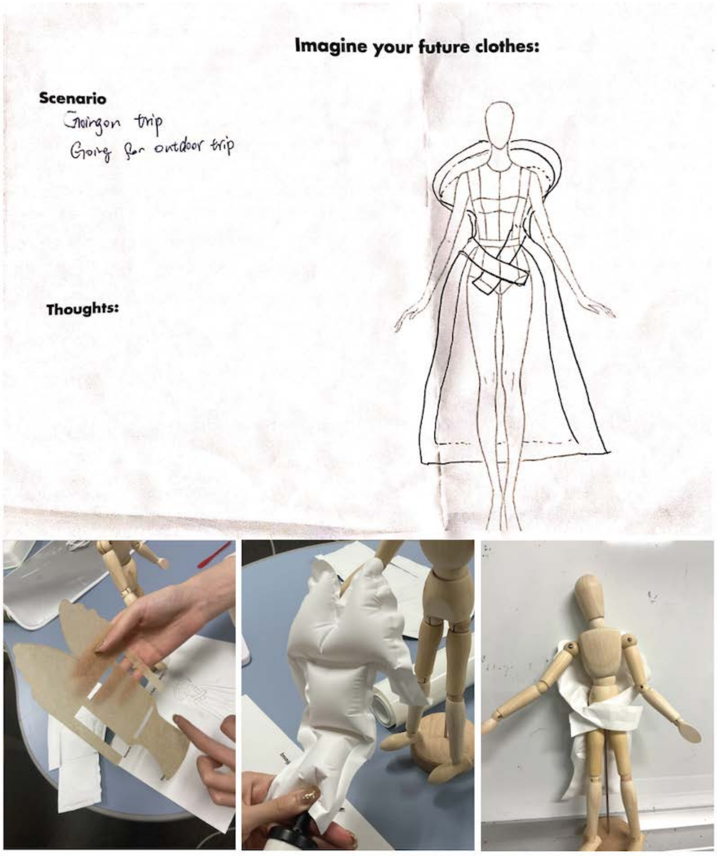


Figure 4.15 participant E's prototype

4.3.3 Discussion and Feedback

Figure 4.16 Workshop in Progress

- During the design process, participants come up with the question that how can we pump the clothes if we are in a outdoor setting. I looked up on the design of life jacket on the plane and found that it was completed by gas-generating pressure cylinder included within the jacket. But because the gas is generated from chemical reaction, the process is irreversible. But I think this is a great issue to research further into.

- In addition to that, I found that even though participants can easily navigate through my design tool in Processing, they actually prefer to see real physical demos. It gives them more intuitive demonstrations. Also from the feedback we can see that they need more guidance on pattern design part and 60% people agrees that there is a need for a dedicated design software that specifically enables quick modification and construction of inflatable shapes. It seems rather hard for them to think the wearable form and the functionality of the design at the same time, which I also think is quite challenging. Thus I would like to see how to make design tool that can help designer in this new field.

- On the other hand, participants shows great curiosity and patience during the fabrication period. The feedback also revealed positive or neutral responses to the beginner friendly fabrication method. But participants also complained that it is time consuming to cut the shape manually, especially if they want to make it in a greater scale. So we would like to see if there is opportunity to try customize a cutting machine to help with cutting large scale parts.

- Meanwhile, participants encountered some challenges when sealing the air pumping hole due to its uneven surface. So they asked if there is alternative methods for sealing the air pumping area that could offer improved results.

- Last but not least, according to surveys, participants are more interested in using this fabrication method to make wearable furniture from their existing unused clothing, rather than buying a ready-made new product. The main reason is that they think it is more sustainable and they are interested in recycling it with new functionality. So there is a lot of personal fabrication potential in this concept.

4.4. Summary

Overall, user interviews and the workshop session provided valuable insights, which can be summarized as follows:

- Interests on the concept and needs for the design

- Expectations on more design patterns and guidance on creating design patterns by themselves.

- A compelling application scenario for this concept is the re-attachment of the inflatable structure to unused or old clothes, transforming them into wearable furniture.

User Interview

To sum up, the user interview of exploring user perspective on wearable furniture and prototypes, revealed a positive understanding and recognition on the design context. Regarding to the effectiveness and satisfaction towards the two designs (shirt-chair and skirt-table) presented, most users showed interests on this design concept and preferences towards the design of shirt-chair due to functionality. There are three main issues that can be further improved upon:

- The air leakage problem of inflatable material. Besides trying other airtight material, it is also important to find methods to guide users to fix leakage by themselves or providing help service on this issue for the future. The material needs to be updated with more durable ones.
- The user experience of the design needs to be more carefully considered with the scenarios. Perhaps an outdoor setting can be a better environment for conducting the user tests next time. Also, more specific functionality ratings need to be added into the test.
- Users expressed a desire to see more structural design patterns under the idea of wearable furniture as well as development in aesthetics of style.

Workshop

During the workshop, participants gained a strong understanding of the concept of personal fabrication and expressed that the fabrication methods were easy to learn. However they also identified the following problems:

- It is challenging for designers to come up with original design patterns in a limited time frame, considering both furniture and wearable at the same time.
- The current tool only facilitates on transforming design to fabrication, but not flexible enough for assisting designers on ideation. Also, with more design patterns added to it, the efficiency of fabrication can be further improved.

- The material is good for designer to work with prototyping inflatable idea but not really suitable for real application.

Chapter 5
Future Application

5.1. Future Opportunity

For this thesis project, I explored the personal fabrication opportunities for wearable furniture by studying inflatable materials and design patterns. This visionary concept seeks to push the boundaries of conventional notions about wearables and furniture, offering a fresh perspective on their potential integration.

Throughout the evaluation process, I engaged with a group of talented young designers who demonstrated interest in this design concept. They also showed a willingness to actively participate in the fabrication process by presenting their design attempts to bring these ideas to life on their own. This fabrication method may be a good way for designers to create inflatable prototypes for future wearable furniture creations, but a new material should be used to support the functionality of body scale projects. The experiment and discussions generated fascinating insights and sparked conversations about potential future application scenarios.

5.1.1 Aesthetics

This research primarily focuses on the exploration of structure form and fabrication in wearable furniture design. However, there is a significant opportunity for further development and aesthetic improvement on this research outcomes. Although inflatable jackets have been around us for a long time, despite their functionality, they are rarely explored as a fashion item. During the user interview, it is evident that users have high aesthetic expectations for clothing. Additionally, while experimenting with design patterns and fabrics, it shows possibility on amplifying graphic patterns on textiles, which can transform a flat surface into a relief pattern.

5.1.2 Sustainability

Beyond aesthetics, there is a significant opportunity to address sustainability concerns. The fashion industry, particularly fast fashion, has long struggled with recycling issues. With the increasing severity of global warming, it is crucial for individuals to take responsibility in their daily lives. The concept of transforming unused wearables into furniture offers a solution for recycling. Buy giving designers improved tools to design with inflatable material, we expect to see more creation around wearable furniture. Drawing inspiration from the modular inflatable research project Pneubots, another possible application is to create a design patterns kit for designers to explore through creation.(29) Furthermore, wearable furniture is portable, making it a practical alternative for digital nomads in the future, eliminating the need for unnecessary purchases.

5.1.3 Interactivity

Last but not least, one of the key goals of this design is to enable the wearable furniture to inflate and deflate according to the user's needs. While the current design only considers two states: inflated furniture and deflated wearable, there is potential for further on human-centered interactivity. (30) For instance, the addition of sensors, such as a UV detection sensor, could allow specific parts of the wearable furniture to open up automatically when using outdoor. Moreover, by incorporating digital sensors, such as temperature sensors, the air inflation could be adjusted based on the ambient temperature. I believe that these interactive elements would enhance the functionality and user experience of the wearable furniture design.

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Appendices

A. Processing Code For Dome Structure Design Tool

```
import processing.svg.*;
import controlP5.*;

ControlP5 cp5;
int paddleNum = 6;
int paddleDis = 130;
int circleSize = 30;
//int sliderTicks2 = 30;
Slider abc;

int myColor = color(204);

boolean record;

int x;
int y;
int outsideRadius;
int insideRadius;

void setup() {
  size(800, 800);
  x = width/2;
  y = height/2;

  cp5 = new ControlP5(this);
```

```
  cp5.addSlider("paddleNum")
     .setPosition(100,50)
     .setRange(6,12)
     .setSize(100,20)
     .setNumberOfTickMarks(7)
     ;


  cp5.addSlider("paddleDis")
     .setPosition(100,130)
     .setSize(20,100)
     .setRange(140,220)
     .setNumberOfTickMarks(5)
     ;



  cp5.addSlider("circleSize")
     .setPosition(300,50)
     .setSize(200,20)
     .setRange(30,90)
     .setValue(75)
     ;

}

void draw() {
  float outsideRadius = 300;

  if (record) {
  beginRecord(SVG, "frame-"+paddleDis+"-"+paddleNum+".svg");
  }
```

```
background(204);


int numPoints = paddleNum;
int insideRadius = paddleDis;
rectMode(CORNER);
fill(paddleNum);

fill(myColor);


float angle = 0;
float angleStep = 180.0/numPoints;


circle(width/2, height/2, 150);
circle(width/2, height/2, 180);



beginShape();
for (int i = 0; i <= numPoints; i++) {
  float px = x + cos(radians(angle)) * outsideRadius;
  float py = y + sin(radians(angle)) * outsideRadius;
  float sx = x + cos(radians(angle)) * insideRadius;
  float sy = y + sin(radians(angle)) * insideRadius;




  angle += angleStep;
  circle(px, py, 50);

  circle(sx, sy, circleSize);
  angle += angleStep;
```

```
    pushMatrix();
    translate(width/2,height/2);
    rotate(radians(angle));
    rect(60,-12.5,250,25);
    popMatrix();
  }


  endShape();

    if (record) {
    endRecord();
    record = false;
  }


}


// Use a keypress so thousands of files aren't created
void mousePressed() {
  record = true;
}




void slider(float theColor) {
  myColor = color(theColor);
  println("a slider event. setting background to "+theColor);
}
```