MODULAR CONNECTIVITY:

A modular approach to sustainability

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ABSTRACT

Modular clothing could prove to be an interesting solution to the ever growing amount of clothing waste. By providing consumers with the tools to easily create, personalize and tailor their own clothes, the longevity can be increased. With these tools, damaged or old-fashioned garments will not be thrown away or stored in a closet, but will be used to create new clothes.

The aim of this research is finding the most suitable modular fabric system for use in everyday clothing. Different connection methods were analysed because those are the most essential aspect of a modular system. User opinions were obtained through the Repertory Grid Technique. The results of the interviews were analysed with the Principal Components Analysis, combined with qualitative analysis. From this research, it can be concluded that system A, an easy to connect method for which no additional tools are needed, is the most suitable fabric connection method for modular clothing.

Author Keywords

Modular clothing; personalized textiles; sustainability; fabrics; modules; connection method; repertory grid technique principal component analysis.

INTRODUCTION

The average lifespan of a piece of clothing is 3.3 years. This longevity is decided by four bottlenecks, being size and fit, fabric quality, colours and styles and care, respectively from most to least important [8].

In England, 4–5% of all household waste is comprised of textiles, clothes, shoes and accessories, in 2003/2004 this would correspond to between 1 million and 1.3 million tonnes [13]. In order to reduce the amount of waste produced by the textile industry in the process of creating and 'replacing' clothes, we could resort to fabricating and repairing our own modular-made clothes. By providing consumers with the tools to create, personalize and custom fit their own clothes it might be able to raise the longevity of clothing. One approach is to create inter-connectable modules that are meant to be connected by the user. Once assembled, the modules will create a piece of clothing. If at any time the piece of clothing becomes less favourable to wear because of one of the previous mentioned bottlenecks, the user will be able to adapt the garment accordingly. Because of this there is no inherent reason to throw away the modular garment as a whole.

Also, one of the main reasons people do not make their own clothes anymore is the lack of time. By reducing the amount of time required to make a piece of clothing it could open up self fabrication of clothes among consumers. This could reduce the market for factory made clothes which would have a positive effect on the sustainability of the textile industry.

The most important part of the module in every modular system is the connection with which the modules attach to each other. Not many types of fabric connection are suitable for large quantity usage within modular systems. Because of this importance, our research focuses on finding what type of connection is the most appropriate for use in everyday-wear modular clothing.

As hypothesis we think the best approach to the connection of fabric modules is also the least limiting in interaction. Some of the connection methods require a separate tool to connect modules with each other, others can only be assembled in a specific order. These limitations reduce the potential possibilities modular fabric holds.

THEORETICAL BACKGROUND

Before diving into the connection methods, we have to clarify what the definition of modules is in our research.

Modules are pieces of textile, which can be connected and disconnected to each other. Modules can have different shapes and different methods of creating a connection. By connecting the modules it allows the user to create, for example, clothes or bags. Next to that, after the garment has been constructed, it is possible to change the shape and fit, by pulling apart some of the modules or connecting them in a different way.

Furthermore the relevance of textile waste is important to understand this research. Research is done to make people more aware of the environmental impact of the textile production. Due to the growing population in the world and the rising living standards of people, the apparel consumption is increased and thereby the generation of

textile waste, which has raised concerns about lost resources and the associated environmental damage [14].

When making modular clothes, the lifespan of clothing can be increased. There is a difference between a product's technical life and its service life. The technical life is the maximum period before the product gets stuck. The service life is the product's life in use, from the purchase of the product until the point of discard of the product [1].

In this paper, the focus is mostly on the service lifespan, the garment can be adjusted by people when they do not like to wear them anymore, this way new value of the clothes can be created, and people are able to wear them for another period. But also the technical lifespan of clothes can be increased, if a part of the garment gets stuck, this part can be replaced by new modules. With the use of modules, the life of the garment can be increased. Creating a longer lifespan is an appropriate strategy for reducing the use of resources and environmental impact [1] [2].

The Repertory Grid Technique

For this research we want to find out the most appropriate connection method. We want to ask the participants to define this by giving their opinion about the connection methods. For gathering data from participants, the repertory grid technique (will be referred to as RGT) is used. To make our approach more understandable, the basics of the this technique will be explained in this section.

The repertory grid technique originates from the work of G. Kelly [6]. It is used for studies in information systems [11] and studies for human-computer interaction [4] in a variety of ways. Next to that, the repertory grid technique is increasingly being used in the field of design research, for example M. Kwak, K. Hornbaek, P. Markopoulus and M. Bruns Alonso studied with this technique how people experience interaction with shape-changing interfaces [7].

In repertory grid studies, participants are presented with or asked to generate a set of elements. The participants are shown a random selection of three of the elements. Then they are asked to identify in what way two of the elements are similar to each other or different from the third. The researchers can allow the participant to label the elements in the way they want to, or they can provide a context and ask them to focus on a specific issue.

In relation to the connection methods, the technique gives the potential to compare how people experience the different connection methods (both the experience to connect the modules and the look and feel of the modules). In the user evaluation is described how this method is used for this research. To analyse the result, the PCA is used.

Principal Component Analysis

The purpose of a principal component analysis (will be referred to as PCA) is to find similar data points that form groups within large datasets.

In this research it is used to find groups of constructs that describe one aspect of the tested product. For example if the PCA shows that people who found a fabric very hard also found that fabric stiff and annoying, then the constructs Hard/Soft, Supple/Stiff and Annoying/Pleasing could belong to the component 'comfort'.

Qualitative analysis is needed to ensure that all constructs within a component do indeed describe one and the same aspect of the connections.

RELATED RESEARCH

Despite the amount of research towards modular clothing is limited, multiple fashion designers have taken modularity as a concept to design their clothes around. Even though the examples [Appendix B] take different approaches to modularity, the method of connecting the modules is very similar.

In the book 'Sustainable fashion and textile design journeys' [3] K. T. Fletcher suggests that garments could be modular, to replace or clean separate pieces and thus create sustainable fashion. This is merely a suggestion though as no actual modular fabric has come out of this suggestion.

The paper 'Re-configurable modular floor covering' [10] is about modular pieces of floor covering (which could have a textile surface), which are easily assembled and disassembled and provide flexibility in use, maintenance, removal and re-use. In this paper, the modular fabric has been produced, just not applicable for wearable clothes

Both these papers suggest the use of modular fabrics for everyday appliances because of the benefits it would hold for sustainability. But, neither of these sources have implemented their approach to create wearable modular clothes.

The paper 'Transformative Modular Textile Design' by E. S. Hur and B. G. Thomas [5] describes the development and use of identical fabric modules whose design originates from geometry. Within this modular system, there is only one structure which is used for every module. Nevertheless each module is able to connect to any other module in the system in order to create a fully modular garment. Out of the related modular systems, we consider this approach is the most modular of all. Not only does it consist of only one type of module, but it also allows for full control over fit and appearance. Even though this seems like the best approach to modular clothing, this approach has not been used for making casual everyday clothes. Instead, because of the nature of the material in combination with the type of connection being used, this is more appropriate for use in interior fabrics or showpieces.

In the field of modular fabric design, there are multiple unique approaches. The difference in these approaches lies in the purpose of the module itself. The module is either the only building block in the system or an additive to a larger single base [Appendix B].

One of the problems these modular systems all had to tackle was the method of connecting the modules which each other. With a flexible core approach, this is not a great influencing factor. With a system that consists of individual pieces, an obtrusive connection will be multiplied and more noticeable, hindering the wear and creation of these types of modules. This makes the connection of modules the weakest link in modular systems. By focusing on the different methods of attaching fabric and researching towards the best suitable connection for modules we aim to aid the development of modular systems to a point where casual clothes can be made from individual modules easily accessible to the consumer.

DESIGN PROCESS

The modules we tested are designed during the brainstorms about connection methods. In part of the modules, existing connection methods are processed, for example in system B and D (Image 2 and Image 4) in which buttons and zippers are clearly used. All modules of the systems consist of a fundamental triangular starting shape. Triangles allow the user to construct a vast amount of different tessellations. Triangles also lead to the possibility of creating a hexagon, which further increases the amount of creative possibilities.

Connection method A is inspired by the paper of E. S. Hur and B. G. Thomas, they use modules to encourage user participation in the design process by giving them an interactive and playful experience [5]. When exploring their last iteration, we experienced how these modules could be improved, which is processed in the module we used for this research (Image 1). There are three different sizes for this module, which are all composed of the base module of this system. The modules can be connected to each other by pulling the ‘arrow’ of one module into the ‘slot’ of another module. These modules only require fabric to create their connection, no tool is needed in order to make the connection.

The modules of connection method B (Image 2) can be connected to each other by pressing a ‘positive’ and a ‘negative’ side of the push buttons to each other. The push buttons are sewed on the fabric. There are two different modules, modules with three ‘positive’ sides of the buttons and modules with three ‘negative’ sides of the buttons. The modules are in the shape of a hexagon, the buttons are placed in the shape of a triangle.

Connection method C (Image 3), is inspired by weaving and sewing methods.The modules can be connected by going there and back through the modules with the cord. The modules are made by sewing loops on the modules. There are three different shapes of the modules, two small shapes, and one shape with the size of two small modules together. The two small shapes differ in the amount of loops (four or five), the modules should be connected on a way that the loops continue each other.

Connection method D (Image 4), was conceived during a brainstorm with two fashion students from the Tallinna Tööstushariduskeskus in Estonia. During the brainstorm they came up with the idea of using zippers as connection method for the modules. The slider is used as a separated tool to connect the modules, it has to be disconnected in the end.

Image 1: Connection Method A

Image 2: Connection Method B

Image 3: Connection Method C

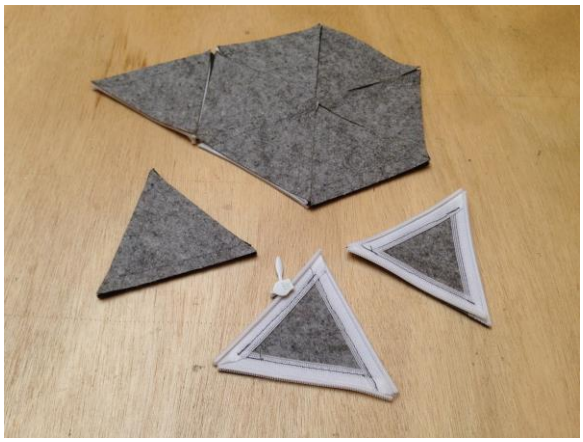


Image 4: Connection Method D

USER EVALUATION

The user evaluation existed out of four parts. First the target group had to be defined. A survey is setup to define this target group. Then the RGT is used to test the modules. The RGT existed of two phases, first a pilot test to define the cluster, afterwards exploring the clusters with the participants. Then the PCA is used to analyse the data.

Survey Target Group

The expected target group for this research were people who just got children, it was expected that these people were too busy to make their own clothes, but had their own style and were interested in new ways to create their own clothes. To verify this target group, a demographic survey was used. 14 people filled in the survey (half were men, half were women; half of them were below 25 years old the other half were above 25 years old; they had different occupations). It turned out that the answers did not differ that much, only the people below 20 stood out. Teenagers turned out to be more interested in trends instead of having their own style. This can be confirmed by the paper of S. Lim and M. Lee [9], this age group has a strong conformity with their friends and are very sensitive to the development of fashion trends.

Because modular clothes don't fit any current fashion trends, the resulting target group for this research is people above the age of 20.

Repertory Grid Study

In this research, the RGT gives the potential to compare how people experience the way they have to connect and modify the modules and how they experience the look and feel of the modules. To identify the different elements, users were interviewed to obtain constructs in their own words, instead of giving them constructs to choose from. This is more reliable because it eliminates the chance of accidentally influencing the opinion of the users by the way the questions are formulated.

Because interviewing every user during the test takes a lot more time than providing them with a set of constructs, obtaining these constructs is done in advance, in a smaller pilot study. This enabled the researchers to still test with a larger sample of people. The obtained constructs were used for the user test. This way of applying the RGT is also used in the study of P. Turner and S. Turner [12].

To identify the elements for the constructs, the following steps are taken for the pilot study, which was done with six participants (three men, three women, of different ages between 20 and 62 years old). All participants had to connect three modules to a larger set of the same modules which were already connected. This way they had an impression how the modules had to be connected. While they were connecting the modules, the duration to connect the modules was timed. The modules are all made of the same fabric felt, and the same basic colour, grey. This will ensure the participants are only judging the connection methods and not the fabric itself. Afterwards the following question was asked, each time about another set of three modules (four sets in total): How would you describe two modules on an different way than the other module? This way the participants had to compare the connection methods, if the answers were not clear enough, laddering techniques were used, questions as why and how were asked to identify clear elements.

From the repertory grid pilot, 139 constructs were obtained. All of these constructs were pairs of words to describe how the different fabrics feel, such as: Hard/Soft, Thick/Thin, Heavy/Light etcetera. More emotional qualities were also described by constructs, such as: Satisfying/Frustrating, Inviting/Repelling, Pleasant/Annoying.

To limit the amount of time needed to conduct the user test, the list of constructs was narrowed down to 50. Constructs that were too similar to each other were eliminated, as well as constructs which only described very obvious physical differences between the different fabrics where no perceptive differences could occur.

Procedure User Test

In the second phase, user tests were done with 22 participants, from which 11 men and 11 women of different ages within our target group. Each session lasted one hour on average. On arrival, the participants were asked to take place at the table, they were briefly explained what they were supposed to do and what the goal of the test was. First they were asked to assemble three individual modules to a larger pre-assembled piece of modular fabric and to explore the modules in general. This experience provided them with sufficient information to fill in the survey.

After the participant had the experience of connecting the modules, they were asked to fill in a survey, which exists of three parts. The first part is a demographic questionnaire, to gain some basic knowledge about the participants and their interests in creating clothes, new methods and sustainability. The second part is a list of 50 constructs about the four different modules. The participants were instructed to rank the four different modules on the 50 constructs on a scale

from one to five. The final part of the survey concerns the qualitative part, which exists of two overall questions: Which modular system appeals the MOST to you for creating and wearing your own garments, and why?; Which modular system appeals the LEAST to you for creating and wearing your own garments, and why? [Appendix A].

The results of the user test were analysed both quantitatively and qualitatively.

Principal Components Analysis

The opinions that the users gave on the 50 constructs were analysed using the PCA [Appendix E]. This analysis method aims to find constructs that are similar to each other. For example when users found a fabric very stiff, they also perceived it as a long-lasting fabric. The groups of constructs obtained from the PCA were qualitatively analysed on their content, to ensure that each component would indeed describe one aspect of the fabrics. After adding or removing some constructs from the components, the correlation value within each of the different components was calculated [Appendix G]. This was done to check whether the modified components were still describing one aspect according to the statistics.

Then the correlation between the components was calculated in order to see if they all describe different aspects of the systems [Appendix G].

From the PCA, five initial components were found. After analysis these were combined to form three principal components relevant to this study: Emotion, Quality and Accessibility.

FINDINGS & DISCUSSIONS

Quantitative Findings

Output from PCA: Scores on the three principal components.

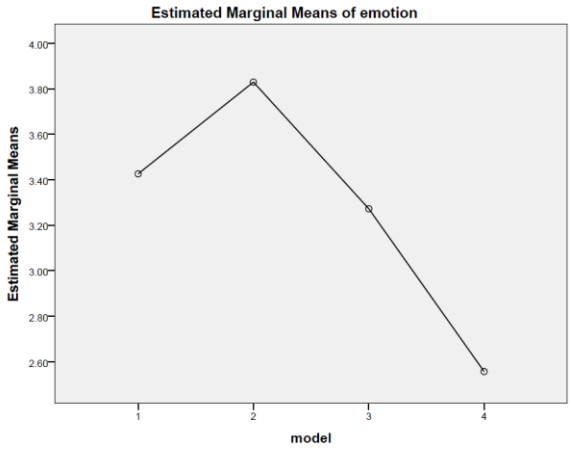


Figure 1: Emotional score of system A (1), B (2), C (3) and D (4).

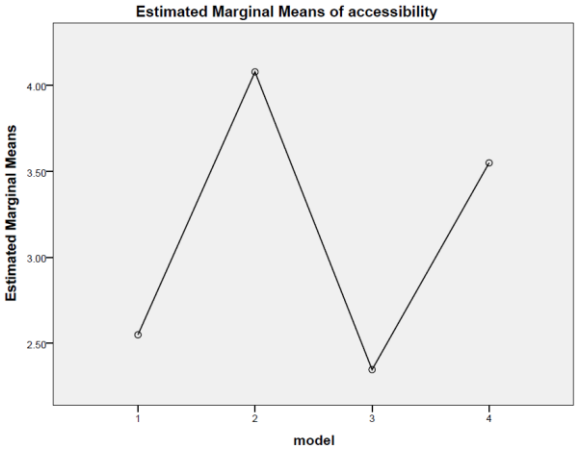


Figure 2: Accessibility score of system A (1), B (2), C (3) and D (4).

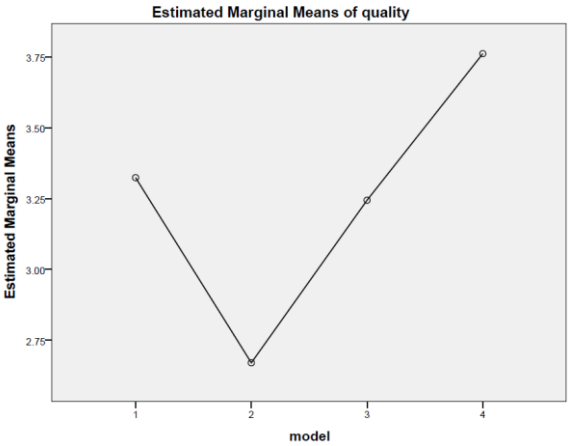


Figure 3: Qualitative score of system A (1), B (2), C (3) and D (4).

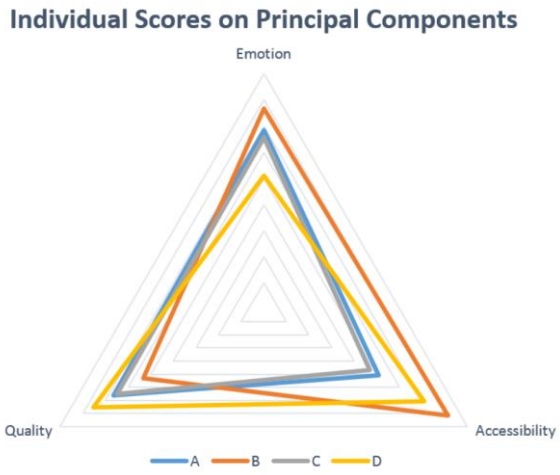
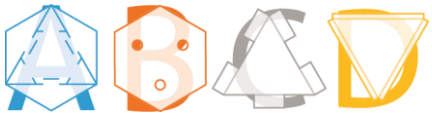


Figure 4: Visual overview of all individual scores of system A, B, C and D.



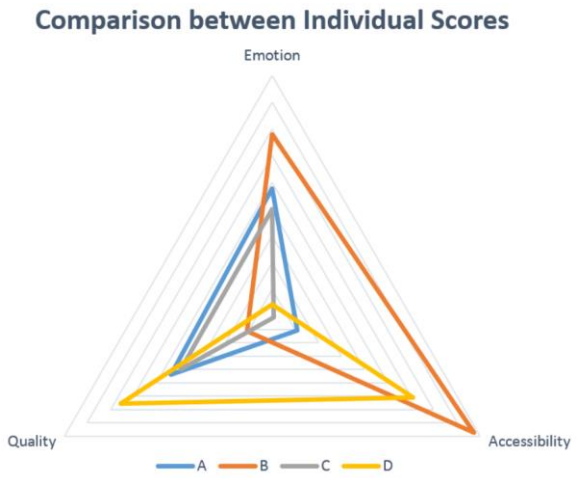


Figure 5: Visual overview of comparison between individual scores of system A, B, C and D.

There was only a small correlation between the components of Emotion and Accessibility [Appendix G]. Other than that, the three groups have no significant correlations between them.

All differences shown in the graphs were significant according to the t-tests, except for the difference in emotion between A and B; and system A and C which got similar scores on all three components [Appendix F]. The largest differences (largest t-values) were found on the accessibility component, where system B was far more accessible than system C.

In emotion the largest difference was between the most cheerful system B and most depressing system D.

On the qualitative component, system B scored the lowest and system D the highest.

Interpretation of Quantitative Findings

From the results it can clearly be seen why modular clothing has not made its way into our daily lives yet, since the most disliked module was by far system D, which happens to be the most similar to the most common form of modular clothing currently on the market: the zip-off trousers.

From the PCA, system B was clearly deemed too fragile and loose. The application of the buttons in this way was novel to the users, which is what caused the perceived quality of the system to be lower than the actual quality. Most users were unnecessarily careful when handling this system. This was also the case with system A, and maybe even more so, because system A was a completely new experience for the users.

System B was the easiest to use and most intuitive, followed by system D. Both systems use conventional connection methods that are currently present in our clothes. Therefore, it should come as no surprise that B and D scored the highest on the accessibility component, because this component factors in the users familiarity with the connection methods.

Below is a comparison table with grades for each modular system, based on their PCA scores.

	Emotion	Quality	Accessibility	**Overall**	**Familiarity Assumed**
System A	6.9	6.6	5.1	**6.2**	**6.8**
System B	7.7	5.3	8.2	**7.1**	**6.5**
System C	6.5	6.5	4.7	**5.9**	**6.5**
System D	5.1	7.5	7.1	**6.6**	**6.3**

Table 1: Grades based on PCA scores for system A. B, C and D.

As mentioned before, the familiarity with conventional connection methods such as buttons and zippers, causes these systems (B and D) to score very high on accessibility. Since all systems would eventually be equally as familiar to the users, we also calculated the grades for this scenario.

Qualitative Findings and Interpretation

During the exploration of the connection methods, participants were observed and were allowed to give comments on their experience.

The duration to connect the modules to each other was timed during the pilot tests. It turned out that the two systems which took the most time, system C and D, were perceived as difficult, whereas system A and B, which were the fastest methods, were perceived as easy.

Some of the connection methods were directly clear towards the participants, this were the modules inspired by existing methods, connection method B and D. For the other methods, it took some longer before the participants understood the method, the participants first had to analyse the methods themselves or they needed some explanation from the researchers. After this, system A was quite easy for most of the participants, whereas system C was still a bit puzzling to place the modules in the right order. Above that it was fascinating that some of the participants preferred the side with overlaps as the outskirt, whereas others preferred the other side.

In the first and last part of the survey, the participants had to fill in open questions. The questions which were most relevant for this research were used for the qualitative analysis: Which modular system appeals the least to you for creating and wearing your own garments, and why?; Which

modular system appeals the most to you for creating and wearing your own garments, and why?; What is the most important requirement you need in order to create your own clothes?

It turned out that system A and B appealed most for creating and wearing a garment. System A was preferred for the reasons that the system is easy, enjoyable, has an interesting result and does not require an additional tool. System B was mainly preferred for the reason that the system is easy and quick. System C and D appealed least for creating and wearing a garment. They were difficult to connect and took a lot of time, were less enjoyable, and people were not very enthusiastic about the result.

Furthermore participants mentioned as requirement that they would like to make something personal and unique.

Interpretation of Combined Results

After combining the quantitative and qualitative analysis, we can assume that connection method A had the highest potential to be adopted for creating modular clothes. System A was the best overall performer on the combined components of quality and emotion, is easy to connect and enjoyable, next to that it has an interesting look once assembled and does not need any additional tools or resources.

Limitations of the Research

Several limitations of the research need to be discussed, which could be improvements of the quality of the research.

Firstly, a larger sample group would make the analysis more reliable and less susceptible to chance.

Secondly, the pilot test with Dutch speaking people has been done in Dutch, due to this, their opinions had to be translated in English. The English translation could be a nuance of the Dutch word, by doing the pilot directly in English, the results could have represented the opinion of the users more accurately.

Thirdly, since obtaining the constructs was done with a small pilot group instead of during the user test, the constructs were not exactly in the own words of the participants. This sometimes lead to misunderstanding of a couple of the constructs by some participants.

Finally, another improvement is that more different connection methods could have been developed as test-systems. Different connection methods without an additional tool would be an option, this way the shape of the connection could be compared better. Now we made an iteration on the shape of this connection method, which is described in future work.

FUTURE WORK

As our research was focused on finding the best connection method for use in a modular system, we neglected to improve the material of the modules themselves. In order to improve the wearability of the modular system as a whole, different modules could have different functions and materials. For example, think of modules with the sole purpose of stretching, ventilating or reinforcing certain areas in your modular garment. With these options available, you would get even more depth in customisation and adaptability within your self-made modular piece of clothing.

Since modular system A resulted as the most promising modular system for use in everyday garments, we decided to carry forward the design of this particular module. As every module in this system is identical, it was able to directly improve the flaws the previous design faced. With the initial module, holes would appear in the locations where only corners met. Plugging these holes with another module created a clutter which in turn deformed the fabric.

The redesign removes the overlaps by reducing the size of the triangular flaps, creating a hexagon. This shape allows for the module to be connected to even more modules than the previous design, resulting in an almost woven structure once connected.

CONCLUSION

From this research, we find that modular system A has the highest potential to be adopted by the consumer. It enables them to easily create, repair and modify their own clothes without the help of any additional materials or tools. When referring to our hypothesis, this is indeed the connection method with the least limitations. The only problem with this module is that it is not very similar to existing connection methods and therefore it requires some instruction on how to use. During testing however, we found that once participants were told how to use the module, they got the hang of it very quickly.

This research also confirms that common approaches to modular clothes, such as zip-off trousers, do not appeal to the general public all that well. System D was perceived to have a negative impact on the emotions of the participants, whereas all the other systems (and in particular system B) had a positive emotional influence.

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