Experience of 3D printed textures

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ABSTRACT
3D printing techniques are upcoming and bring new opportunities. One of those opportunities is printing textures on textile. 3d printing can be a way of changing the hand of textile and thereby changing experiences. This study aims to describe the perception of the users' point of view of those new textures and if they recall memories when experiencing those textures. This study is a collaboration with Rafaëla Pires, and aims to provide information that she will use within her PhD project. The repertory grid technique was used, a structured interview technique based on the personal constructs theory of George Kelly. The results of the interviews held with 8 participants were analyzed with the principal component analysis, cluster analysis and qualitative analysis. From these analysis we can conclude that every sample is experienced differently by all participants.

Author Keywords
3d printing; hand of textile; textures; repertory grid; principal component analysis; cluster analysis

INTRODUCTION
Visual communication is an important medium in our society. Due to the digital revolution, the way we perceive the world around us has shifted more to the sense of vision than to any other sense. The nature of visually perceived experiences is analysing and detached from the world that is observed. In contrast to this detached way of perceiving the world, stands the connected way of perceiving, using the sense of touch. Touching an object makes the experience much more rich, and therefore more present in that particular moment. [Pallasmaa, 2005] To make people aware of this, PhD student Rafaela Pires aims to create a critical design piece. This will be a garment that will make the wearer aware of the present while wearing it. By textures on the inside of the garment, the skin of the person wearing it will continuously be stimulated, making the person constantly aware of his or her own body. To understand the experience of textures, a research collaboration was initiated. This need for information on textures is combined with the exploration of the fabrication technique of 3D printing on textile, and resulted in this study.

3D printing, and especially 3D printing on fabric is a rather unexplored technique within the area of digital fabrication. This technique empowers changes in the hand of textile, manipulating the textile by printing different textures upon it. In this way the fabric and the additive manufactured texture merge together into one new material, with its own hand of textile, thereby creating a unique user experience. This study aims to explore and describe this user experience.

HAND OF TEXTILE
The exploration of the perception of textures leads to the hand of textile. There are many definitions of the hand of textile which have changed much over time [Ciesielska-Wróbel and Langenhove, 2012] The definition we allocated to the hand of textile is as followed: The hand of textile is all the feelings experienced when touching a fabric. Ciesielska-Wróbel and Langenhove mentions three main techniques to quantify the hand of textile. The first technique is an objective technique in which physical tests are performed and analyze the characteristics of the textile to assign values to the measurements. Many studies were performed and different systems are used to measure mechanical properties of the materials. [Park, Hwang, Kang, Yeo, 2001], [Stylios, 2000]. Subjective technique is another technique and is about individual perception and assessment of the hand of textile as can be read in the work of Ciesielska-Wróbel and Langenhove. The assessment process of textiles is a result of the psychological reaction through the sense of touch so they differ for each individual. A combination of objective and subjective techniques are held to take the qualities out of both approaches. [Cardello, Winterhalter, Schutz, 2003] Where the objective approach lacks the human element, the subjective approach can depend on the moods of the person.

USER EXPERIENCE

In order to explore and describe the user experience, this experience first needs to be defined. It is a dynamic, complex and subjective phenomenon based on appreciation and the resulting relationship following from any interaction between the object and the person. [Tomico, 2007] The domain of this user experience is built from past, present and future times. Past experiences are memories, future experiences are imagined or expected situations. These memories and dreams create a reference frame where all present experiences are placed in. People interpret the world around them by referencing to past experiences, and at the same time anticipating on their hopes, dreams or fears for the future. [Tomico, 2007] To understand the perception of the textures, we thus should focus on a person's memories and dreams that specifically create the experience. As these experiences are highly subjective, these only can be obtained using an subjective user experience gathering technique. Therefore the repertory grid study was chosen.

METHODS AND MATERIALS

The repertory grid technique

The repertory grid is based on the Personal Constructs Theory of George Kelly. [Kelly, 1955] Generating constructs out of triads (a group of three) is the classical approach brought and was originally used in the field of psychology [Fransella, Bell, Banister, 2004] but over time studies of human-computer interaction adopted the repertory grid. [Hassenzahl, Wessler, 2000] Nowadays the repertory grid is also used in the field of design. [Tomico, 2007] [Kwak, Hornbaek, Markopoulus, Bruns Alonso, 2014]

Practically, three samples are showed to a participant. The participant has to answer the following question: what makes two of the samples alike but different from the third? By answering this question the participant indicates a construct as well as the opposite construct, which can be inserted in the grid. Obtaining those constructs is not as easy as it sounds because the interviewer needs to understand as good as possible what the respondent means with their choice of the construct. Therefore laddering techniques are used. Laddering is a technique used in one-to-one interview and tries to find out the how the participants translates the samples to associations they have to this specific sample [Reynolds and Gutman, 1988] According to Kelly, personal constructs helps participants understanding and interpreting the world around them with their experiences.

Showing different triads will lead to more constructs and fills in the matrix of the grid. To complete the grid, the participant is asked to rate, dichotomize or rank the samples according to their perception. (the design, analysis and interpretation of repertory grids – Mark Easterby-smith) each of the objects, shown between the contrary constructs, which were obtained during the first part of the interview. [Easterby-Smith, 1980]. There are different ways of analyzing the repertory grid. F.B. Tan and G. Hunter (2002) sums up some of the techniques for individual grids and composed grids. [Tan, Hunter, 2002] Examples are the content analysis or cluster analysis.

The potential of the repertory grid technique as method for the study of different textures lies within the fact that the participants can use personal constructs to explain their perceptions of the 3d printed textures. This makes the study more reliable and specific but difficult to compare with other participants.

The interview

The interview was performed on eight participants, their ages vary from 19 to 24 years. The group existed of four men and four women. The participants were shown 7 different triads of each time three samples. The triads were chosen in a way that all samples were shown 3 times, each time in a different combination of three, with a maximum of two times the same pairs in the triads. In this way, all samples were combined in all possibilities, without repeating the same combinations of three. Hereby the triads imposed different constructs every time. The order of the triads was every time the same, the order of the samples within the triads was randomized every time.

During the interview, the participants were asked to interact with the samples with closed eyes. The sense of touch is more sensitive when not looking at the world. [Pallasmaa, 2005] Thereby, the expectation of the feel of a sample is different when the participants would firstly judge by the visual appearance of the samples. The participants were asked to feel the samples with the palms of the hands, their fingertips as well as the back of their hands. As this research focuses on the experience of 3D printed textures on the skin, to use the textures on the inside of a garment, the participants were asked to pick the sample up, bend them around their hands and arms and press. In this way the experience of wearing a garment with a texture inside was mimicked.

To obtain the constructs, the question of which sample is alike another and which is not, is asked, as explained above. Laddering techniques up and down were used to specify this information and understand the perception of the samples. To understand higher or deeper reasons questions as 'why' were asked. To gain more detailed information questions as 'what or how' were asked. [Tomico, 2007]

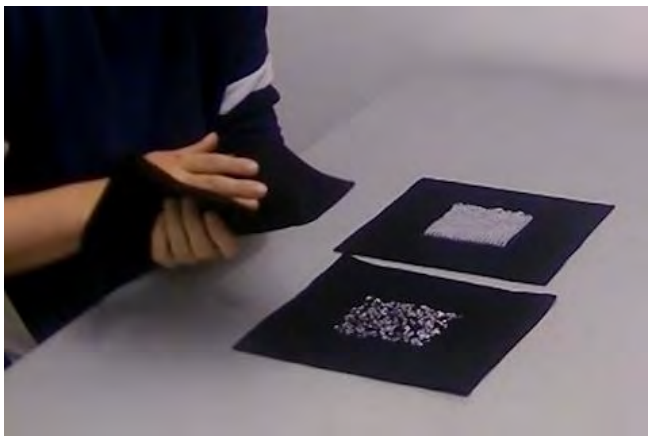

Figure 1. Showing the participant experiencing the sample

The samples

The 7 samples which are used all exist out of spacer fabric, which is a textile made out of polyester and has an airy knit, as recommended by Sabanita, in "Combining 3D printed forms with textile structures-mechanical and geometrical properties of multi-material systems" for a good binding between textile and filament. There was chosen to print on fabric to preserve the feeling of a garment. The filament which was used is Filaflex. This filament has the property that is stays flexible when printed, yet the setting of the printed file and the machine can influence this. These qualities are desired, because the printed item has to be flexible to stay attached to the garment, yet has to be able to be hard and give a structure to the fabric.

Each sample had a printed surface of 10 cm by 10 cm on a piece of fabric which was about 23 cm by 23 cm. The files which were printed are chosen in such a way that they contain a variation in heights (2mm-15mm), textures, and shapes (organic - geometric). Each file is inspirited by other shapes, such as lemongrass, wrap plastic, the facade of a building, corduroy fabric, or the structure on an ice cone. These shapes were chosen to create as much variation as possible, in order to get a wide variance of experiences.

ANALYSIS

The constructs of the repertory grid are elicited by the participants, and each sample was rated by the participants on the obtained constructs. A rating method on a 5-point scale was chosen as it discriminates more than a dichotomous scale but not too great as a ranking scale would, so a good difference can be seen. [Easterby-Smith, 1980]

Principal Component Analysis

The individual grids are analyzed with the principal component analysis (PCA), cluster analysis and semantic analysis. The PCA is closely related to factor analysis and breaks an individual repertory grid down to important factors and can be plotted in a 2D space. According to Bell (1990) most of the grids can be broken down to two or three factors, which means that there is more than 80% of the variance explained. The two principal components of each individual grid are interpreted by looking at the constructs on the extreme values of those components. In this way the representations of the components can be named. When all the individual grids are analyzed, there can be searched for similarities between the components of the participants. These components carry the most information and can therefore be interpreted as the most important aspects of the experience of the participants.

Cluster analysis

Cluster analysis is an analysis method in which groups are made out of objects in such a way that the objects that are more similar are in the same group. The similarity is measured is by the distance between the objects when plotted in a graph. [Rokach, Lior, Oded Maimon, 2005]. In this study agglomerative hierarchical clustering is used to build a hierarchy of clusters. This means that each sample is a cluster of its own and starts merging with other clusters instead of starting with one big cluster and divide into multiple smaller clusters. The samples were clustered and presented in a dendrogram. The cluster analysis has been done with the web based software OpenRepGrid onair in which we used the Euclidean distance method and Ward's correlation method [Ward, 1963]. Ward's method uses clustering algorithms called average-link clustering and measures all the distances from any sample of one cluster to any sample of the other cluster. The average of those distances is considered to be equal to the distance between the two clusters. The clusters are obtained and the constructs with the same rating for the samples in the clusters are traced back from the grids.

Qualitative analysis

To link the characteristics of the samples with feelings and the memories of the participants a qualitative analyses was undertaken. Each interview was analyzed. All mentioned reasons behind the memories and feelings of participants were collected. Only the memories and feelings where a clear reason was given for, were then listed in an overview (appendix 1). In this overview can be seen per sample which feelings and memories are linked and the reason for this behind it. Per sample is then looked for corresponds between reasons, feelings and emotions between different participants.

RESULTS

There are 8 repertory grids obtained, one for each of the participants.

Principal Component Analysis

A Principal Component Analysis was performed on each of the grids. One of those plots can be found in figure 2 and all can be found in the appendix 2. The personal constructs were used as variables. A two dimensional solution was chosen as there were only seven samples tested and it is much easier to read.

Participant	Explained variance component 1	Explained variance componen t 2	Explained variance component 1+2
1	69,531	16,565	86,096
2	49,485	27,48	76,965
3	60,941	25,397	86,338
4	52,066	21,103	73,169
5	58,088	30,486	88,574
6	50,492	26,069	76,561
7	49,615	21,486	71,101
8	49,083	22,561	71,644

table 1. Explained variance per participant, for component 1 and 2 separately and together.

Table 1 shows that the first 2 components of three of the participants got 80% or more of the explained variance. This means that 5 of the repertory grids did not have enough information on the two dimensional plot.

Three of the participants had some specific aspects in which they could rate the samples as only two dimensions where needed to gain most of the information of the grid. Unfortunately those aspects or components could not been interpreted as the range of elicited constructs was too large and the fact that no characteristics could be assigned by the researches to the samples on forehand. The conclusion that can be drawn is that most participants rate the samples from different aspects as more than two dimensions were needed to gain more than 80% of the explained variance.

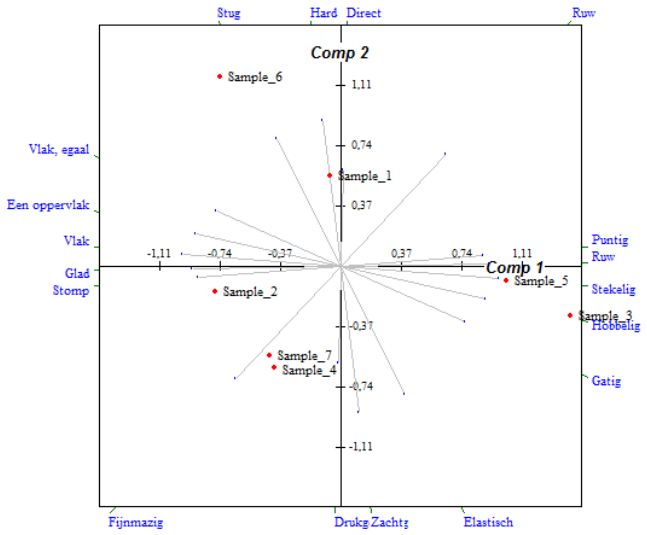

Figure 2. Example of an principal component analyses.

Cluster analysis

The dendrograms of the samples were plotted and then cut at a height of 8. In table 2 the clusters of samples for each participant can be found. Next to the clusters there is a column called 'shared constructs'. 'Shared constructs' are the constructs on which the samples of the particular cluster rated around the same. The clusters of the participants were compared with each other but there were no exact same clusters for two participants. There are some clusters that appear at different participant (like 1, 2) but there is no pattern that can be traced.

Participant	Cluster	Shared constructs
1	samples 2 , 4 , 5	Much, present; Hard edges; Sharp; Aloof
	samples 6 , 7 , 1 , 3	Flexible; Restful; Dynamic;
2	sample 6	Closed;
	samples 4 , 7	Chaotic; Open;
	samples 3 , 5	One piece; firm; static;
	samples 1 , 2	Hard;
3	samples 1 , 2	Thick; Relief; Bumpiness; Loose pieces
	samples 4 , 7	Irregular; Unique, handmade; Open-ended
	samples 5 , 6 , 3	Smooth; Deep structure;
4	samples 2 , 1 , 5	Static; Regular pattern; Hard;
	samples 4, 3, 6, 7	Intriguing; Naturally; Interesting
5	samples 3, 5	Unresisting; Flat; Plain; Squared
	samples 1, 2	Resisting; Space in between; Bumpiness; Uneven; Spatially; Playful;
	samples 7, 4, 6	Womanly;
6	samples 3, 5	One piece; Fine-grained; Flat
	samples 2, 4, 7	Hard; Rough; Pointed; Prickly
	samples 1, 6	One piece; Soft; Elastic; With holes;
7	samples 1, 3, 5	Simplistic, boring; Structured; Far-fetched;
	samples 2, 4, 6, 7	Variously; Disjointed;
8	samples 1, 2	Flat; Piles;
	samples 3, 7, 5, 4, 6	no shared constructs

Table 2. Outcome clusters analysis

Qualitative analysis

In table 3 some results from the qualitative analysis can be found. All the tables can be seen in appendix 1. Per sample the amount of memories and feelings with belonging reasons is between 5 and 12. Only for the samples 2 and 3 there is some correspondences between the memories feelings and reasons between the different participants.

participant		Because
4	Painfully	Of the cones
4	To walk with through the snow	It already holds your hand
1	Less pleasant	It has points and tickles
1	Feel uncomfortable	You are constantly aware that you are wearing something
8	Unfinished wall	Despite it is not that hard, it also has also pieces which stick out
8	Not nice	Not moveable at all
6	Like an Indian bed of nails	It is pointy
2	Less pleasant	I imagine wearing it as clothing and when you are wearing it my skin would come in contact with it. And that would stick out and attract attention.

Table 3. Overview of feelings and memories with reasons for sample 2.

CONCLUSION

The three different analysis techniques used all address a slightly different aspect of the research question. Where the PCA gives the most important components of which the experienced are based, the cluster analysis tells the specific clusters of which these experiences are built from. The qualitative analysis gives insight in the memories and describe the specific experiences of the participants. Therefore the conclusions of the separate analyses are discussed.

PCA and cluster analysis

The conclusion that can be drawn is that most participants rate the samples from different aspects as more than two dimensions were needed to gain more than 80% of the explained variance. This conclude that the participants rate each sample based on other reasoning or experience. This can be seen as well from the 'shared constructs' which differ for each of the participants.

Qualitative analysis

Out of the qualitative analyses can be concluded that not all the samples recall the same feeling by all the participants. In fact only for sample 2 and 3 the memories given by the participants were somewhat alike. The out of quotations such as painfully, less pleasant, feels uncomfortable and not nice the conclusion can be drawn that wearing a structure as sample 2 would not be comfortable. The reasons the participants gave for this was that sample two was hard and pointy. Out of quotations such as feels happy, funny, nice to wear at the outside of your clothes can be concluded that the structure of sample 3 is experienced as a very nice one. The reasons the participants gave for this was that it partly moves.

About the other samples not much conclusions can be drawn, the reason behind this is that participants did not gave many reasons for the memories and the feelings of some participants contradicts with the other ones.

DISCUSSION

Although the research does give a clear idea about the experiences participants have with the different samples, some improvements can be made to give a higher quality to the research. The qualitative analysis is due to time issues not based on an academic research technique. If we would have had more time a semantic analysis would be a good substitute for the current qualitative analysis technique used for this research. Further it might be that more relevant information could come out of the interviews if these would be more consistent, not all the participants felt all the samples in in the same way. Blindfolding the participants would have helped to bring more consistency to the way the participants experienced the samples. Another improvement that should be made is to iterate more on the research process. We should have executed a pilot test with more than one participant and run the whole cycle of performing the research on forehand. From obtaining the data to the analysis and conclusion, to make sure we all exactly understand the methodology and analysis techniques. This would have provided us with a concrete plan, instead of breaking the research down in separate activities that all had to be learned at that moment.

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