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A Study into the Influence of Visual Prototyping Methods and Immersive Technologies on the Perception of Abstract Product Properties

Tegan Forbes, Hannah Barnes, Peter Kinnell, Mey Goh

Wolfson School of Mechanical, Electrical and Manufacturing Engineering
Loughborough University, Loughborough, United Kingdom
t.forbes-16@student.lboro.ac.uk, hannahkathrynbarnes@gmail.com,
p.kinnell@lboro.ac.uk, y.goh@lboro.ac.uk

Abstract (300-500 words)

Virtual Reality (VR) and Augmented Reality (AR) software are becoming increasingly sophisticated, and they are finding new uses in a wide range of applications. From a product design perspective, the ability to visualise computer generated 3D models, in natural and more intuitive ways may offer many benefits. However, as yet there have been limited studies that have systematically evaluated the benefits of these technologies for product design related applications. This study is focused on furniture design, and it looks at both technologies, to assess how their immersive qualities can affect human perception of what is being viewed. The purpose of the study is twofold; first it aims to find out how increasingly immersive technologies affect human perception of comfort, ergonomics and style, and second it investigates the differences in the experiences of design-trained and non-design-trained users. The study comprised each participant viewing three different armchairs in six different media, with each medium providing a different viewing experience. The media used were 3D isometric views of CAD images printed on paper, 3D interactive CAD models, AR, VR, viewing real armchairs with no tactile interaction and experiencing real armchairs with tactile interaction. After viewing the armchairs in each medium, a questionnaire rating the comfort, ergonomics and style for three different armchairs was filled out by participants. In addition, the participants were also asked to score their level of confidence in the provided ratings. The study shows that there are differences, between the media considered, in the level of confidence with which participants are able to rate products. In general, it shows that more immersive viewing experiences lead to increased levels of confidence. While no purely visual interaction can compete with real physical interaction, the study also demonstrates that for all participants AR and in particular VR can offer a viewing experience that is comparable with true reality.

Keywords: virtual reality, augmented reality, product properties, product design, visual prototyping, immersive technology, product assessment, furniture

1 Introduction

Morton Heilig's Sensorama machine is one of the earliest examples of VR technology. Invented in the 1950s, and first shown in 1962 (Virtual Reality Systems, 1993), the device was the first instrument to provide a multisensory theatre experience combining stereoscopic visuals with 4D effects. The system consisted of a pre-recorded film augmented with body tilting functionality, stereo sound, and even triggered aromas and wind during the film, to provide the illusion of reality (Peddie, 2013). Heilig realised the potential of head mounted televisions which lead to his next invention, the Telesphere mask, known as the first example of a Head-Mounted-Display (HMD) (Flores-Arredondo and Assad-Kottner, 2015).

In recent years there has been a surge of interest in, and an increase in the popularity of, Virtual Reality (VR) and the closely related Augmented Reality (AR) systems. Over the last 70 years VR has transitioned from one-off obscure inventions to a multi-billion-dollar industry and after multiple failures to satisfy in the past, the technology has finally become viable for adoption into many serious applications, with the potential to revolutionise processes within multiple industries. While many claims are made regarding the advantages of these technologies, as yet, there have been limited studies that have sought to systematically evaluate their use and understand the true potential benefits of these technologies for product design related applications. This paper looks at the potential for its use, alongside other immersive technologies such as Augmented Reality (AR), within the product design and development process, to enable the creation of more realistic virtual prototypes (VP).

In 2005, Söderman conducted an early exploratory study that compared VR with conventional product representations. In this study VR representations of a car were compared with both concept sketches, and a real car as a means for customer evaluations. The results suggest that a higher degree of realism in the product representations does not necessarily give better understanding of the car than the participants already have from their own product knowledge. When comparing the sketches and the VR, there was only a small difference in the participants' understanding of the car, despite a higher degree of realism in the VR (Söderman, 2005). In a more recent study, completed in 2014 by Kaapu et. al., the ways that consumers describe and evaluate virtual and physical prototypes was investigated. The study saw a group of 28 consumers evaluate both virtual and physical prototypes of furniture products; it concluded that virtual prototypes are useful when there is a desire to involve consumers in the product development process (Kaapu, Ellman and Tiainen, 2014).

In Söderman's automotive study three media (sketches, VP, and the real products) were considered, while the work by Kaapu et. al., only VPs were compared with physical models. The study presented in this paper describes a continuation of a study initiated as part of a undergraduate dissertation (Barnes, 2017), it sets out to investigate the appropriateness of utilising both AR and VR technology for creating virtual prototypes for assessing comfort, ergonomics and style, which are important properties for both designers and consumers. Rather than compare just two or three prototyping methods, this study presents products using several media, with each of the media offering increased levels of immersion and interaction. The aim is to determine the effect of AR and VR on the ability of study participants to accurately perceive armchair properties. The products being assessed were three armchairs supplied by The Quality Furniture Company Ltd (QFC, 2018). The study addresses three properties: comfort, ergonomics, and style; they are considered abstract due to their subjective nature and varying human judgement being difficult to describe and assess accurately in a purely quantitative format. In this paper first, the study format is described, with details given of the key parameters and the procedure followed. The collected data is then presented and summarised before a discussion of the key results is given.

2 The study format

The study presented in this paper is based on a practical experiment whereby participants view the same three armchairs in six increasingly immersive media, culminating in visual and tactile interaction with the real armchairs, where a true value can be given for each of the assessed product properties. The three product properties considered were comfort, ergonomics and style. Participants were broadly selected from a diverse range of backgrounds; however, they were specifically divided into two groups: design-trained and non-design-trained. This was done in order to draw conclusions on how design background can affect judgement of properties while using the different media, as well as affecting the resulting confidence in scoring each of the properties. Therefore, before commencing the study the properties of interest were careful described to all study participants, so as not to discriminate based on design background. In the initial study (Barnes, 2017) the overall methodology followed and data collection strategy used was defined, the CAD definitions of the armchairs were created, and initial experimental results were collected. This was extended further for this work, and in the following sections the full study procedure is detailed with a description of the key materials and methods employed.

2.1 Participants

The study comprised 51 participants, and the age of participants ranged from 19 to 57. Occupations of the participants included bar staff, administrative assistants, financial consultants, students, product designers, showing a diverse range of backgrounds. However, the participants were subdivided into two categories; these were design-trained and non-design-trained. The design-trained group was identified by participants having at least 12 months experience working or studying in the design or design engineering sector. This created two sub-groups with the design-trained group comprising 19 of the 51 participants, the remaining 32 in the non-design-trained group. Each participant was required to complete a Health and Safety form to ensure they were fit to complete the study, key areas of concern were balance disorders and epileptic conditions.

2.2 Procedure

Each participant (or participant group) was given the same information prior to starting the study. The order in which they would view the armchairs was explained and an outline of this is given in Figure 1.

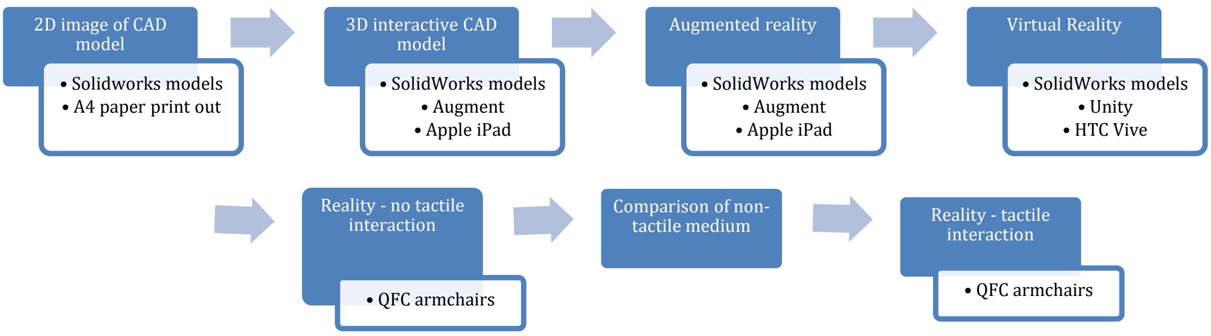

Figure 1. Study Procedure Outline

The flow chart indicates the order of the viewing media, and in each instance and relevant software, user interface, and hardware are noted. Before beginning the study (viewing media and completing questionnaire), participants were given an overview of how to fill out the questions and what certain key words meant. This ensured all participants irrespective of design background were given the same definitions to work with. This was important as there are a variety of widely used definitions of ergonomics (P. G. Dempsey, M. S. Wogalter and P. A. Hancock, 2011) and so rather than defining it, participants were given ergonomic considerations to evaluate during the study. This allowed each participant to outline what was most prominent to them in the qualitative data, which could indicate the focus for their quantitative scores. For example, when asked about Ergonomics the question was phrased as such: *considering the seat height, arm height, back height, inclination of the back rest, depth of seat and seat rake angle; think about how well the chair fits your body, encouraging good posture and ease of use*. Style was also mentioned in this capacity, and participants were informed of the focus of the style evaluations as follows: *Consider the overall shape and size of the chair, the features and geometry of it, rather than specific colour or pattern of the fabric.* For comfort, no additional description was deemed necessary. The questionnaire was the same for each viewing medium. The armchairs were always presented in the same order, type a, then b, then c, and the product properties were always assessed in the order of comfort, then ergonomics, then style. These were each rated on a 5-point scale. For comfort, 1 was “not at all comfortable” and 5 was “very comfortable”; for ergonomics, 1 was “poor” and 5 was “good”; for style, 1 was “strongly dislike” and 5 was “strongly like”. After assessment of product properties, the questionnaire concerned participants’ confidence in their assessments. For each product property participants then scored their confidence in each viewing medium out of 5, with 5 being the highest confidence score.

2.3 Products and Representations

The three sofa armchairs used for this study are shown in the top row of Figure 3. The armchairs were selected based on their obvious visual differences. Photographs of existing armchair designs with key dimensions were used as a reference to generate the 3D CAD representations of the three chosen armchairs. The 3D CAD representations of the armchair designs were as close to the physical armchairs as achievable with the data available at the time of their construction.

Figure 2. CAD models compared with physical armchairs – left to right: type a, type b, type c

The six different media used to display the product were as follows:

1. Printed 2D image of a rendered CAD model
2. 3D interactive CAD model
3. Augmented reality (AR)
4. Virtual reality (VR)

5. Reality - no tactile interaction
6. Reality - tactile interaction

Media type one was a coloured 2D image of the CAD model, printed on A4 paper. Media type two was a fully rendered 3D interactive CAD model, displayed on a tablet computer, using software called Augment; this allowed adjustment of the displayed armchair model using zoom, rotation and pan functions. Media type three was Augmented reality (AR), using a tablet computer, the participants are able to walk around a target marker placed on the floor, viewing overlaid images of each armchair at different angles, in a close-to-reality fashion, with the only constraint that the tablet must be facing the target marker. Media type four was Virtual reality (VR) using an HTC Vive system, with participants wearing the VR headset and walking around a Virtual environment scene to view different angles of the armchair CAD models. Media type five was viewing real versions of each armchair, but with no physical interaction, and media type six was a full viewing experience complete with tactile interaction.

3 Data Collection

The main resource used by participants to record results was hardcopy questionnaires that comprised two main elements. The first section was a single page questionnaire for each specified visual medium on which participants were asked to score each product on a 5-point scale (e.g. not at all comfortable = 1, very comfortable = 5) against the product properties: comfort, ergonomics and style, and rate their confidence in the accuracy of these scores on a 5-point scale (5 being complete confidence that the value given here for each property would match the value given when sitting on the armchair in reality). The second section was a final single page questionnaire for Medium 6 where the participant has physically interacted with the product and given a 'true value' for the product properties.

The questionnaire for Medium 4 and Medium 3 was narrated to the participant and responses recorded in real time as the participant was immersed within the viewing experience or virtual environment. This was done to minimise time between experiencing the medium and recalling the experience in order to complete the questionnaire as accurately as possible.

4 Results

The collected results were first analysed by considering the results of all the participants as a single group. Mean scores were calculated for each of the assessed product properties (comfort, ergonomics and style), and this was done for each of the armchair types. The mean confidence scores for each of these property scores were also calculated. These results are shown in Table 1. To aid viewing of the results, the scores were normalised by dividing mean scores for each media type by the mean scores assigned for media type five. Media type five was chosen as it was visualisation of the real armchairs with no tactile interaction. This scenario represents the ultimate goal of virtual prototyping technologies that only allow visual interaction. For the confidence scores, the normalisation was done using media type six, as this scenario allows for tactile interaction and reasonably represents the highest possible level of confidence. Three bar charts illustrating the normalised results for comfort, ergonomics and style can be seen in Figure 2, Figure 3 and Figure 4 respectively. In these graphs, for each viewing media there is a group of four bars, these are used to represent the normalised property scores awarded to each of the three product types, followed by the normalised confidence score; the order of bars from left to right: chair type a, chair type b and chair type c, confidence score in given medium.

Table 1. Average scores across all participants

Chair name	Product property	Viewing media type					
		1	2	3	4	5	6
Chair type a	Comfort	3.04	3.02	3.17	3.29	3.57	4.12
	Ergonomics	2.67	2.92	2.96	2.96	3.20	3.57
	Style	3.55	3.52	3.45	3.65	3.53	3.84
Chair type b	Comfort	3.67	3.76	3.70	3.65	3.61	2.78
	Ergonomics	3.65	3.52	3.49	3.41	3.47	3.12
	Style	3.39	3.16	3.28	3.29	3.24	3.27
Chair type c	Comfort	3.33	2.72	2.87	3.27	3.53	4.10
	Ergonomics	3.14	2.68	2.68	3.25	3.49	3.65
	Style	3.06	2.76	2.72	2.76	3.04	3.04
Confidence	Comfort	3.06	3.34	3.55	3.94	4.04	4.94
	Ergonomics	3.12	3.64	3.85	4.22	4.27	4.88
	Style	4.12	4.04	4.13	4.65	4.69	4.82

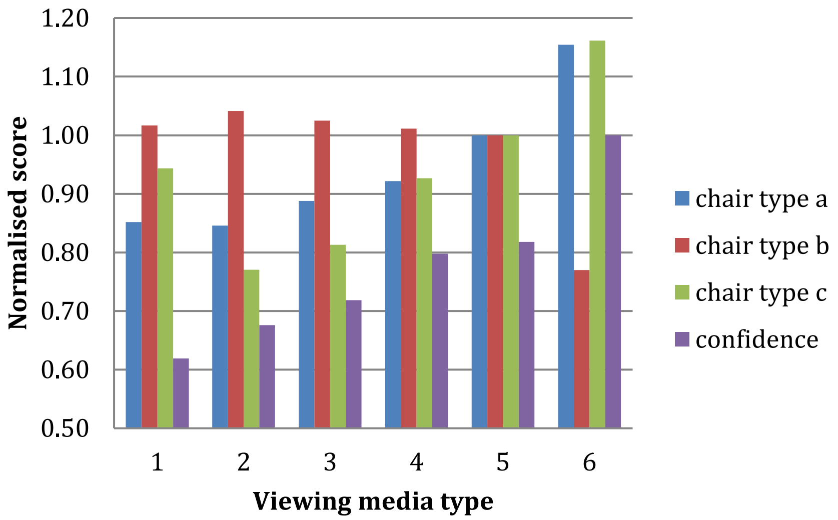

Figure 3. Comfort assessment scores normalised to the real visual assessment (media type 5).

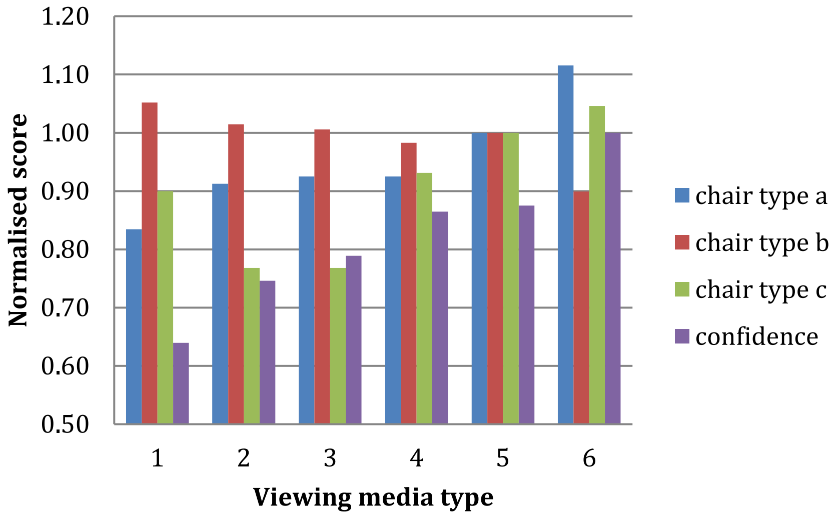

Figure 4. Ergonomic assessment scores normalised to the real visual assessment (media type 5)

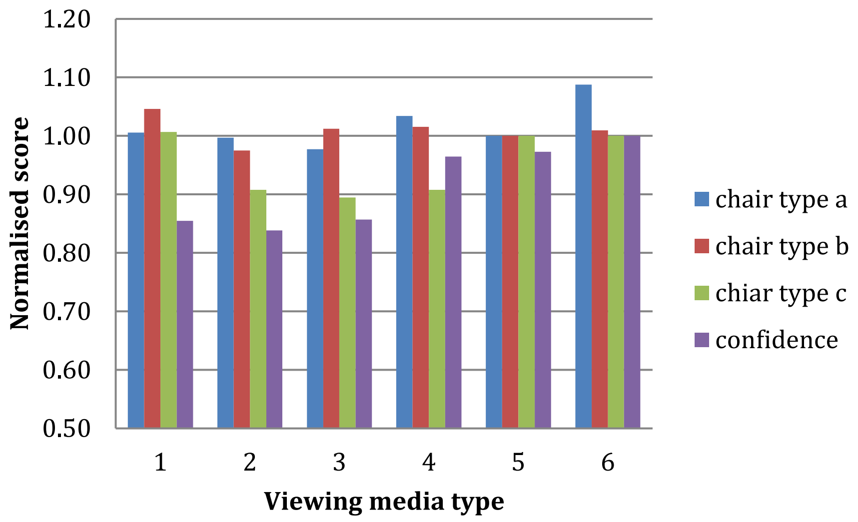

Figure 5. Style assessment normalised to the real tactile assessment (media type 6)

The following three graphs show the total group of participants subdivided into those who were design-trained and those who were not. Figure 6 shows the difference in mean scores given in each medium with those given in media type 6 – the true value. The graph shows the difference in deviation between the two groups as well as the general increase in accuracy of scores as the media become more immersive. Figures 7 and 8 show the participants' mean confidence through each medium, normalised to the scores given in media type six which represents the highest possible level of confidence. Figure 7 shows the participant group as a whole, whereas Figure 8 shows the subgroups of design-trained and non-design-trained participants comparatively.

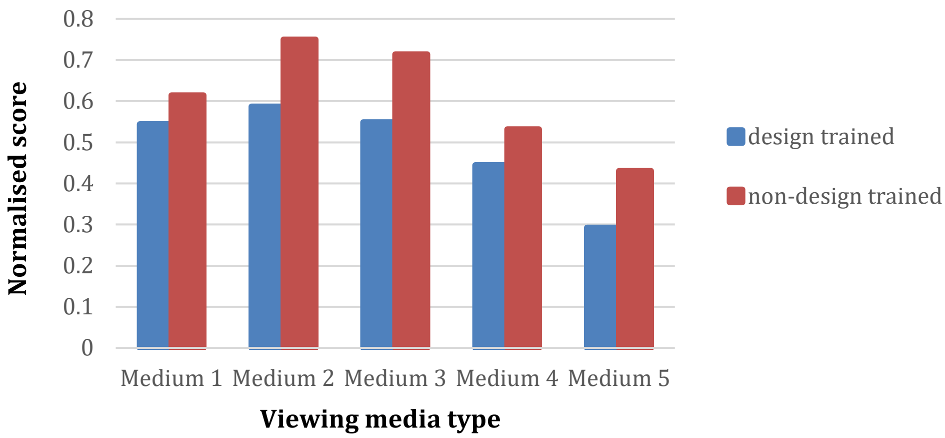

Figure 6. Deviation of average design-trained and non-design-trained scores from respective true values

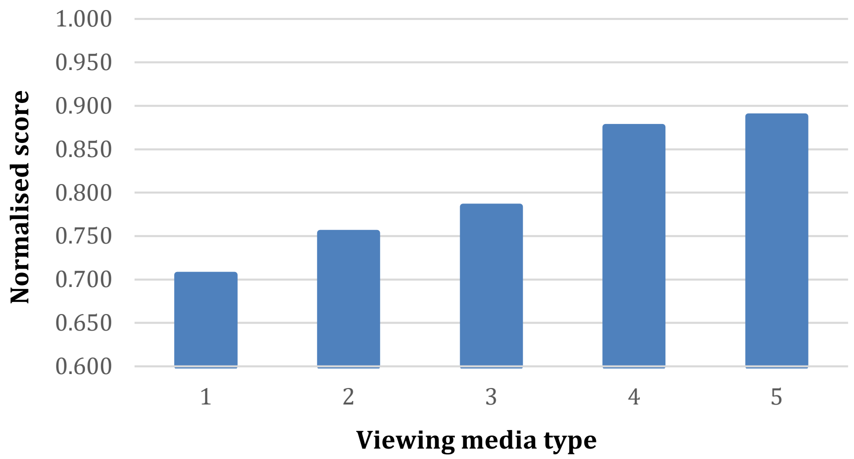

Figure 7. Confidence scores of all participants normalised to the score given in media type 6

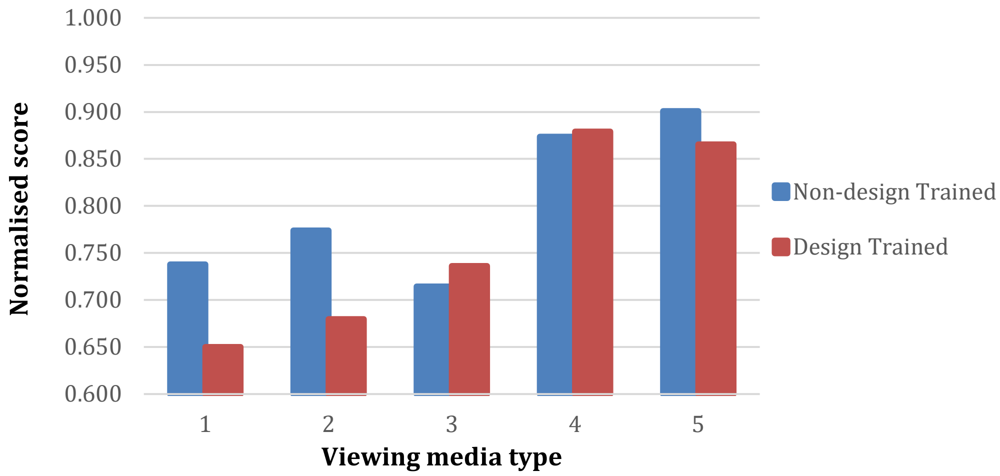

Figure 8. Comparison of confidence scores between design-trained and non-design-trained groups when normalised to the score given in media type 6

5 Discussion

It would be expected that the more immersive the technology, and therefore the more information you can gain through the visual prototype about a product, the more accurate product property ratings in these immersive media would be as compared to the true values. It might be considered that viewers can gain more insight to a product's properties in more immersive media such as an interactive CAD model or within a Virtual Environment, but they are in general much more familiar with judging a 3D object from a piece of paper than through any other medium. In this study, whilst design-trained participants may be more used to making judgements of products through CAD models for example, this doesn't necessarily translate to a higher confidence compared with non-design-trained participants when scoring in this media (type two). When scoring their confidence in media type one and two, both times the non-design-trained group had a higher confidence than the design-trained group with a score 10% higher for viewing on paper (media type one) and 4% higher for the interactive CAD model (media type two). This is complemented by a comment made by a non-design-trained participant after viewing the armchairs in the first five media: "[one is] used to seeing things on paper so naturally you feel confident even though you realise how unconfident you should be once seeing the later ones".

The confidence scores of the design-trained group peaked for both comfort and ergonomics, in VR. However, the lack of significant similarity between the same design-trained participants' VR scores and those in media type 6 shows that the confidence was misplaced and there is no evidence that either sub-group can more accurately identify product properties in VR than they can in real life. Figure 4 shows this clearly, as while the design-trained group is better at judging product properties than the non-design-trained group, the scores in VR were still less accurate than those when looking at the armchairs in real life. This graph also shows that whilst the accuracy of judgements made in VR did not surpass those in reality, there is a clear benefit and accuracy improvement when judging the product properties in VR, compared with all the other virtual prototyping media.

A limitation of the study is that it was conducted solely with furniture. It is not yet determined which product categories, or features are most suited to virtual prototyping methods and screening such as VR. It is clear, from the results in this work, that when assessing some aspects of a products performance (e.g. comfort in the assessment of an armchair) there is a strong reliance on tactile interaction. Taking the example of chairs as a category in general, then within this, it is likely that some chairs are more easily assessed than others. This could depend on whether the geometry of a chair projects the perception of actual comfort. Chair type B for example is quite rounded and curved, visually implying softness and comfort, however, not being able to visually assess the material properties of the chair means that the firm cushion – not synonymous with comfort – comes as a shock to participants and the comfort scores from all the visual media, which have been only steadily declining through media two to five as shown in Table 1, suddenly drop when tactile interaction is allowed.

In general, the results suggest that virtual prototyping could be used as a powerful tool in concept development and stages of product development and the design process where decisions are required before physical prototyping is feasible; as during these stages of the process, while popular selection matrices (e.g. those found in 'Total Design' (Pugh, 1991)) may form a foundation for judgement and elimination of concepts, it is vital that individuals or groups are confident in the concepts they are taking forward. This study has shown that design-trained individuals are most confident in their perception of abstract product properties when viewing designs in a Virtual Environment, and so this technique of virtual prototyping or viewing concept designs could provide the confidence a designer or design group needs to go forward with a concept.

In other literature, the use of immersive technologies has been addressed mainly as a design tool, not an evaluative one. Designing within a Virtual or Augmented environment is a different use to that proposed using evidence from this study. Evaluating and assessing concepts and designs with visual prototyping methods and immersive technologies is different from using these tools as the design method and could have wider applications. The furniture industry seems a useful place to implement the use of immersive technologies during design and development due to the large costs involved with physical prototyping, but this could also be applied in other industries such as motorbike design. The nature of the design of an armchair or motorbike has similarities in the ability to be assessed holistically from one view-point (outside the object) as unlike with a car, you can see all the key features without needing to go 'inside' of it. The seat and dimensions for ergonomic analysis and the overall geometry and colour choice for assessment of style are all visible at once without the need for multiple different CAD models displaying the inside or outside exclusively.

6 Conclusion

In conclusion, although it is not possible to determine exactly how a product performs in real life purely from virtual prototypes, they still hold valuable information which can benefit a designer, customer, or product development team, without having to invest in constructing a physical prototype. Whilst virtual prototyping methods cannot entirely replace physical prototypes, for abstract product properties like comfort, VR can provide enough information to filter out poorer designs or concepts before physical prototypes are made. Assessing a product in a virtual environment can even highlight details that may otherwise have been overlooked in a more traditional non-immersive prototyping scenario. One of the non-design-trained participants made a comment about this during his assessment of the armchairs in media type four: "[I] picked up more information here than in real life, [my] vision is more conscious and aware, looking for details more because it is a different type of experience, you are more heightened to things you wouldn't look at in real life e.g. colours of chair legs". VR was the most powerful virtual prototyping tool in that it provided scores most accurate to the true values. Participants also had highest confidence in VR of all non-physical prototypes, and the design-trained group even having higher confidence in their comfort and ergonomics scores when viewing a product in VR, than they did interacting visually with the product in real life.

The nature of armchair fabric and cushioning means that the comfort factor cannot be entirely described visually, however for products where we have a more universal internal model of how the materials behave, even comfort may be accurately assessed in a visual prototype or virtual environment. A plain wooden chair for example could be visually described more completely than a sofa armchair, which may allow an accurate assessment from both design-trained and non-design-trained participants. Furthermore, with more studies carried out into a wider range of products, designers could discover which elements of a product's modelling, rendering or presentation are contributing toward the perception of certain product properties and then use this information to manipulate product visualisations to appeal to customers as having certain qualities. This may be useful as we begin to make increasing numbers of purely visual judgments of products to use or purchase, as more and more product sales (Office for National Statistics, 2018) and production decisions are being made remotely, without the ability to interact with a physical prototype. Being able to portray certain properties by using different modelling and rendering techniques could allow virtual showrooms and visual prototypes to provide customers and designers with a more accurate perception of abstract product properties.

References

Barnes, H. (2017) Can virtual reality/augmented reality be used to improve the design and development of furniture? (unpublished bachelor thesis, Loughborough University)

Dede, C., Salzman, M., Bowen Loftin, R. and Ash, K (1997) Using Virtual Reality Technology to Convery Abstract Scientific Concepts. Learning the Sciences of the 21st Century: Research, Design and Implementing Advanced Technology Learning Environment

Dempsey, P. G., Wogalter, M. S. and Hancock, P. A. (2011) Defining Ergonomics/Human Factors, pg. 3.

Flores-Arredondo, J. H. and Assad-Kottner, C. (2015) Virtual Reality: a look into the past to fuel the future. The Bulletin, The Royal College of Surgeons of England, 97(10) pp.424-426.

Kaapu, T., Ellman, A. and Tiainen, T. (2014). Virtual prototypes reveal more development ideas: Comparison between customers' evaluation of virtual and physical prototypes. Virtual and Physical Prototyping, 9(3), pp.169-180.

Lau, H. Y. K., Mak, K. L. and Lu, M. T. H. (2003) A virtual design platform for interactive product design and visualization. Journal of Materials Processing Technology 139(1-3), pp. 402-407.

Office for National Statistics (2018) Retail sales, Great Britain: March 2018.

Peddie, J. (2013). The History of Visual Magic in Computers. 1st ed. London: Springer London.

Pugh, S. (1991). Total design: Integrated methods for successful product engineering.

QFC. (2018). What Do We Do? - QFC. [online] Available at: http://www.qfc.co.uk/what-do-we-do/

Söderman, M. (2005). VR in product evaluations with potential customers: An exploratory study comparing VR with conventional product representations. Journal of Engineering Design, 16(3), pp.311-328.

Ye, J., Campbell, R. I., Page, T. and Badni, K. S. (2006) An investigation into the implementation of virtual reality technologies in support of conceptual design. Design Studies, 27(1), pp.77-97.