Geometry vs Realism: an exploration of visual immersion in a synthetic reality space

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With the broader aim of using a synthetic reality environment to improve and develop packaging designs for Welsh food Small-Medium Enterprises (SME), two studies were undertaken in a simulated environment to explore the geometry and realism of visual content of supermarket shelves, in relation to psychological variables that correlate with sense of presence. The first experiment compared two types of visual geometry: Linear perspective and 'Natural' perspective (using non-linear projection techniques) as well as the realism of the depicted supermarket scene (by comparing a Computer Aided Design (CAD) image versus a photograph). Results from the first experiment showed that the type of image geometry had more of an impact on the sense of presence than the realism of the depicted supermarket scene. A second study was then conducted to test whether a hybrid image of CAD components and a photograph could create a similar sense of presence compared with a photograph alone (because the use of a hybrid image can reduce costs). The results showed that there were no significant differences between the hybrid image and the photograph in terms of creating a sense of presence.

Keywords: Immersion, food packaging, design, user testing, presence, simulated environment

1. Introduction

Large food companies such as Coca Cola and Unilever regularly utilise user testing facilities and systems that allow for products to be tested before release. This iterative design process is hugely advantageous; however, the costs are prohibitive for Small-Medium Enterprises (SME), and the methods are not available to the public.
The wider aim of this research is to develop a cost effective, and customisable user testing space to validate and improve packaging design for Welsh food SMEs. Testing in context is ideal but logistically difficult; testing in a laboratory setting offers high levels of control, however lack environmental cues. Thus, the Perceptual Experience Lab (PEL), consisting of a 200° wrap-around screen, was developed to accommodate for immersion, whilst maintaining a high level of control of sensory cues and monitoring technologies. The following studies explore visual geometries and content realism to create the highest possible sense of immersion in a simulated environment.

The first part of this study looks at what visual geometry is best suited for projecting onto a 200° wrap-around screen. Research has found that peripheral vision has a big impact on spatial awareness and can increase the sense of presence (Strasburger, et al., 2011; Pepperell, 2015). Testing the geometry of the images will help determine whether linear

perspective or natural perspective will create the most immersive content to use in future studies in PEL. The second part of this study is to determine whether Computer Aided Design (CAD) can be used as an alternative to real photographs as photographing a real space is logistically problematic in the long term. The purpose of PEL is to provide a flexible testing space that can achieve cost-effective and quick turnarounds for validation studies; using CAD shelves would allow for rapid set up and high levels of customisation.

1.1 Food Industry

The competition between packaged food products is growing ever more intense as they increase rapidly in choice. A review by Simmonds and Spence (2016) reveals that more than 70% of consumers make purchase decisions on daily necessities in store, 85% of goods are purchased without picking up an alternate option, and 90% are purchased after examining only the front packaging design of a product without holding it in their hands. Corporations that dominate the industry, have a distinct advantage in the food market as they have the capital for developing leading facilities that test branding and packaging design before a product is released (Wedel and Pieters, 2008; Tonkin, et al., 2011).

Incorporating iterative feedback into the packaging design process, may prove to be a challenge for SMEs as the cost of technology and testing space is a significant limitation. Thus, Tonkin et al. (2011) conceptualised The CUshop, a facility that functioned as an alternative to real supermarkets. Tonkin et al.'s study (2011) focused exclusively on the immediate visual cues of a shopping context (shelving) and suggested that further studies incorporate other environmental factors that can make the simulated shopping experience more realistic, and if possible, suggests higher fidelity projectors, but stresses the point of keeping the testing facility costs low.

1.2 Context in User-testing

The importance of keeping participants in a shopping context is emphasised by Young (2002) to attain the most relevant results in product testing. Research suggests that when a participant does not associate their surroundings with a shopping context, they will often disconnect themselves from a shopping mind-set, and instead assume a more aesthetically critical mentality, transforming the experiment into a 'beauty contest' where the most visually appealing design will rate higher; a behaviour that is inconsistent with purchase decisions made at the shelf in real life (Young, 2002).

If possible, user-testing conducted in-context is best as it yields the most true-to-life results, however a simulated environment is a good alternative as it accommodates for important testing considerations that traditional laboratory settings cannot achieve (Gordon, 2010). It is able to recreate social and physical variables (to some extent) and can induce mental states similar to that of the real context, with the advantage of confidentiality and ease of data recording, inherent to user-testing in traditional laboratories. Additionally, a simulated environment space is quick and easy to set up, providing flexibility for studies across a range of different fields, resulting in a comparatively more cost-effective alternative to testing in-context.

The capabilities of PEL as a low-cost simulated supermarket environment is developed by increasing the fidelity of projected images with the addition of exploring different visual geometries to further increase the sense of immersion while keeping costs low and provide high levels of customisation. The synthetic reality space can replicate external variables (to some extent) to simulate a real-life context in a laboratory setting; it is also customisable, it ensures confidentiality, and enables the easy set-up of an array of data recording devices.

1.3 Perceptual Experience Lab

A new synthetic reality space, PEL was developed by FOVOLAB© and the User Centred Design Research Group (UCD-R) at Cardiff Metropolitan University. The function of PEL is to serve as a low-cost, customisable, synthetic reality backdrop, providing context for product testing. A realistic context is crucial to this research as the most true-to-life results are yielded when product testing is conducted with participants in a shopping mind-set (Young, 2002).

The laboratory replicates real environments with controlled and monitored conditions. An idea initially conceived as the Augmented Virtual Environment (AVE) by Gordon (2010), the PEL space allows for customisable low-cost immersive synthetic environments. Expanding on Gordon (2010) and Tonkin's (2011) recommendations for further research, PEL has achieved higher image quality, and expanded on the field of view. High resolution images are back-projected by six 4K projectors, on to a custom built 5280px by 1980px, 200º wrap around screen.

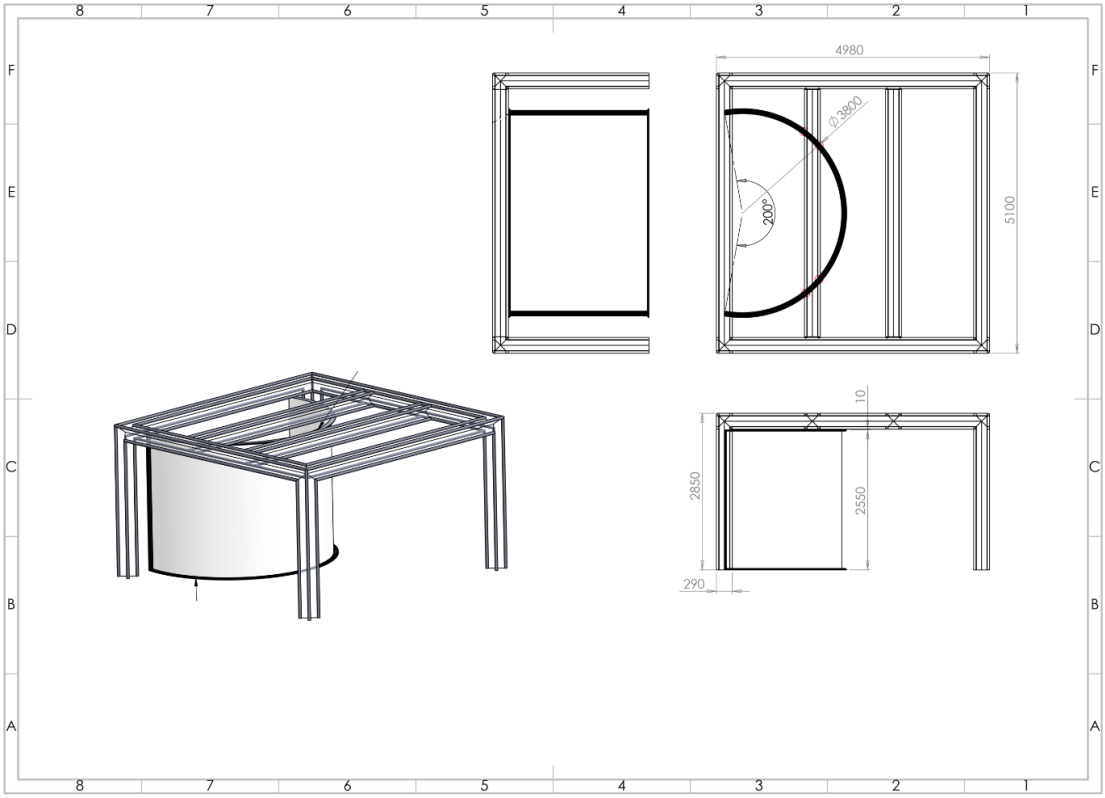

Figure 1. Perceptual Experience Laboratory Screen Dimensions

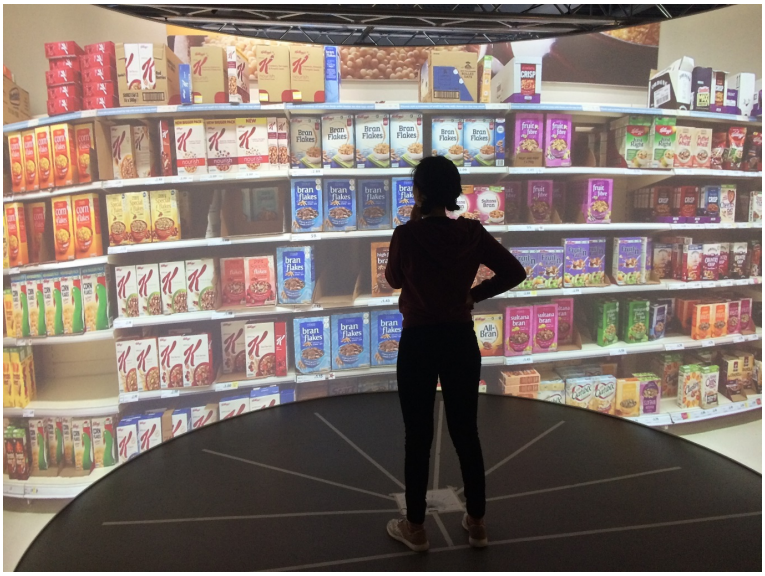

Figure 2. High resolution photograph of supermarket shelves projected on 200°-degree wrap-around screen

PEL offers a high level of customisation, flexibility, and a broad spectrum of data collection methods. Surround sound, light and temperature control, air flow, smell diffusion, and the capacity for physical props can be adjustment and manipulated to control the sense of immersion. State-of-the-art observation software, eye-trackers, microphones, and heart rate variability monitoring equipment allow detailed monitoring and recording of studies.

1.4 Linear vs Natural perspective

The process of vision is composed of both foveal and peripheral modes of seeing (Danahy, 2001). Foveal vision is a rapid, dynamic scanning and sampling of objects, whilst the peripheral vision works in tandem to judge where the body is in space. Research conducted by Watanabe and Matsuoka (1999) suggests that peripheral vision improves our ability to make depth judgements in the fovea and plays a significant role in our awareness of space. This is important because we want the participants to make true to life purchasing decisions.

The human binocular visual field is 180° horizontal and 130° vertical, however common methods of capturing what the eye perceives is usually cropped by the window format of linear perspective, consequently excluding much of the peripheral field, including our own bodies (Strasburger, et al., 2011; Pepperell, 2015). Artists have long been aware of linear perspective's limitations as it cannot effectively capture wide angles of view because objects in the periphery become increasingly stretched or distorted (Tyler, 2015).

The term "Natural Perspective" became popular amongst artists in the 19th century as an alternate method of depicting reality as it appears to the eye, rather than a mathematical equation (Herdman, 1853; Raynaud, 2016). Natural perspective accommodates for features of perception that linear perspective is unable to do, for example, the perceptible fading of objects as they recede from the viewer's frontal plane, or the distinct curvature of straight lines in the peripheral visual field (Macnair, 1957). Burleigh et al's (2018) research found that people prefer photographs of wide scenes in natural perspective as it has more curvature in the periphery and tends to enlarge areas of the scene under central fixation. Participants reported that they preferred natural perspective over linear perspective as they found that it has more spatial presence and is more comfortable to look at. Burleigh et al's research concluded that in comfortable viewing condition, natural perspective is more effective at depicting wide angle scenes than more common perspective alternatives.

Most image capturing devices are based on linear perspective, and generally capture only a single eye point of view. FOVOGRAPHY© overcomes these limitations by capturing the full

field of vision, resulting in more images that appear to have much more breadth and depth than conventional images (Smith, et al., 2017). Fovography is a non-linear projection framework that reproduces the subjective appearance of what the eye sees as perceived via the human visual system. Burleigh, et al. (2017) have found that Fovogaphised images have shown higher ratings in psychological factors such as sense of presence, comfort, and ecological validity compared to standard visual projections. Furthermore, Fovograph images rated on par with a virtual reality system without glasses, headsets or specialist display hardware and rated as equally immersive on large format 180° cylindrical projection screen.

1.5 How to measure sense of presence?

Presence is generally defined as a participant's subjective sensation of "being there" in a scene depicted by a medium, additionally described as a "cognitive state" consistent with a sense of "being there" in an environment, a state that results from attending to and evaluating in coming sensory information (Barfield, et al., 1995).

The ITC-Sense of Presence Inventory (ITC-SOPI) is a questionnaire measure developed by previous research on determinants of presence and current self-report measures (Lessiter, Freeman, Davidoff, & Keogh, 2001). It uses a 5-point Likert scale (1=strongly disagree, 5 = strongly agree) for consistency and makes it easier for participants to complete the questionnaire and for responses to be scored. Questions are phrased carefully, simply, and unambiguously, and numbered. It focuses on users' experience of media, with no reference to objective system parameters.

2. Experiment 1: Geometry vs Realism

2.1 Aim

It is necessary that participants feel immersed in a shopping environment to obtain the most true-to-life purchasing decisions when user-testing. The aim of this experiment was to determine if image geometry (Linear vs Natural perspective) and content realism (Photograph vs Computer Aided Design (CAD)) have an impact on the sense of presence, and whether these two variables are dependent on one another.

2.2 Conditions

As found in a previous Environmental Validation experiment (Lawrence, 2019), the set up engaged the visual, olfactory, haptic and auditory senses.

Figure 3. Additional environmental stimuli (Visual, Auditory, Haptic, Olfactory)

To further augment the sense of presence, participants were given a filled shopping basket to hold, a specialist bread smell was sprayed around the screen, and a 24-point surround

sound system created a full 360° soundscape (Darken et al., 1999) to serve as sensory cues to create a supermarket context.

Figure 4. Conditions from A-D; A – linear perspective photograph; B – Fovographised (natural perspective) photograph; C – linear perspective CAD model shelf; D – Fovographised (natural perspective) CAD generated scene.

Condition A is a linear perspective photograph of supermarket shelves taken at Tesco. Condition B is the same image, “Fovographised”, and remapped into natural perspective. The Fovographised photo is more curved at the periphery and offers a wider field of view. Condition C is a CAD rendering of a supermarket shelf with the same cereal options as the photograph. Condition D is a “Fovographised” CAD scene, custom made to imitate the photograph in conditions A and B. It is important to note that although images for conditions A, B and D look distorted in Figure 4 above, when viewed while standing in front of the curved PEL screen the perceived distortion disappears and the aisle looks straight.

2.3 Methodology

1. 32 participants, varying in occupation, gender, and age, took part; the broad spectrum of demographics represents a diversified sample of supermarket frequenters. Participants and conditions were counterbalanced, so the cumulative increase of stimuli did not yield bias results.

Counterbalancing is a method of experiment design in which, when applied, the researcher can control order effects when using repeated measures (Field, 2013). Independent variables (usually two or more) occur equally in each test group and balance each other out in the results (Alferes, 2012). The 32 participants were split into 4 groups of 8, with each group experiencing a different order of conditions (ABCD, BCDA, CDAB, DABC).

2. Participants were taken to the test condition, asked to perform a search task in PEL and wait 30 seconds before being removed from the environment.

The search task given to participants to perform in each condition was to identify a brand of cereal in the projected image. The order of cereal brands was also counterbalanced against the order of conditions. The search task was a method of priming, and to further enhance the authenticity of the simulated shopping experience; the function was to maintain a sense of purpose and mitigate against the unfamiliarity of the PEL space.

Participants were asked to stand in each condition for 30 seconds to ensure consistency of time immersed in each simulated environment. 30 seconds proved long enough to complete the search tasks given in every condition test, but not so long that participants lost interest and/or become disconnected from the shopping context.

3. Each participant was asked to fill in a questionnaire form after each condition to capture their experience while it was fresh in their minds.

The questionnaire was informed by the Cross-Media Presence: ITC-Sense of Presence study (ITC-SOPI) (Lessiter, Freeman, Davidoff, & Keogh, 2001). It is an inventory of questions that measures the sense of presence with a focus on users’ experiences of media. There are three facets of media experience that are believed to be related to presence: Spatial presence, ecological validity, and negative effects. Questions relating to participants’ sense of immersion and believability were selected from this inventory for this experiment. Following the ITC-SOPI questionnaire guidelines, additional questions were added where deemed appropriate to get a better sense of how participants’ feelings of enjoyability, likability, and believability of the simulated space.

Table 1. This table lists all items used for the questionnaire in Experiment 1 and 2. The first, second, and third rows are items selected from the ITC-SOPI inventory; the fourth through sixth rows are customised questions.

Psychological Variables	Items used in Experiment 1 and 2
Spatial Presence	*"I felt I could interact with the displayed environment."* *"I felt I was visiting the places in the displayed environment."* *"I had a sense of being in the scenes displayed."* *"I felt that I could move objects (in the displayed environment.)"*
Ecological Validity/Naturalness	"The displayed environment seemed natural." "The content seemed believable to me." "I felt that the displayed environment was part of the real world."
Negative Effects	"I felt disoriented."
Enjoyability	"I enjoyed the experience."
Likeability	"I liked the image."
Believability	"The simulation is a realistic representation of a supermarket." "I felt I could interact with the displayed environment."

The Cardiff School of Art and Design's Research Ethics Committee gave ethics approval for the study. All participants gave their informed consent prior to their inclusion in the study.

2.4 Results

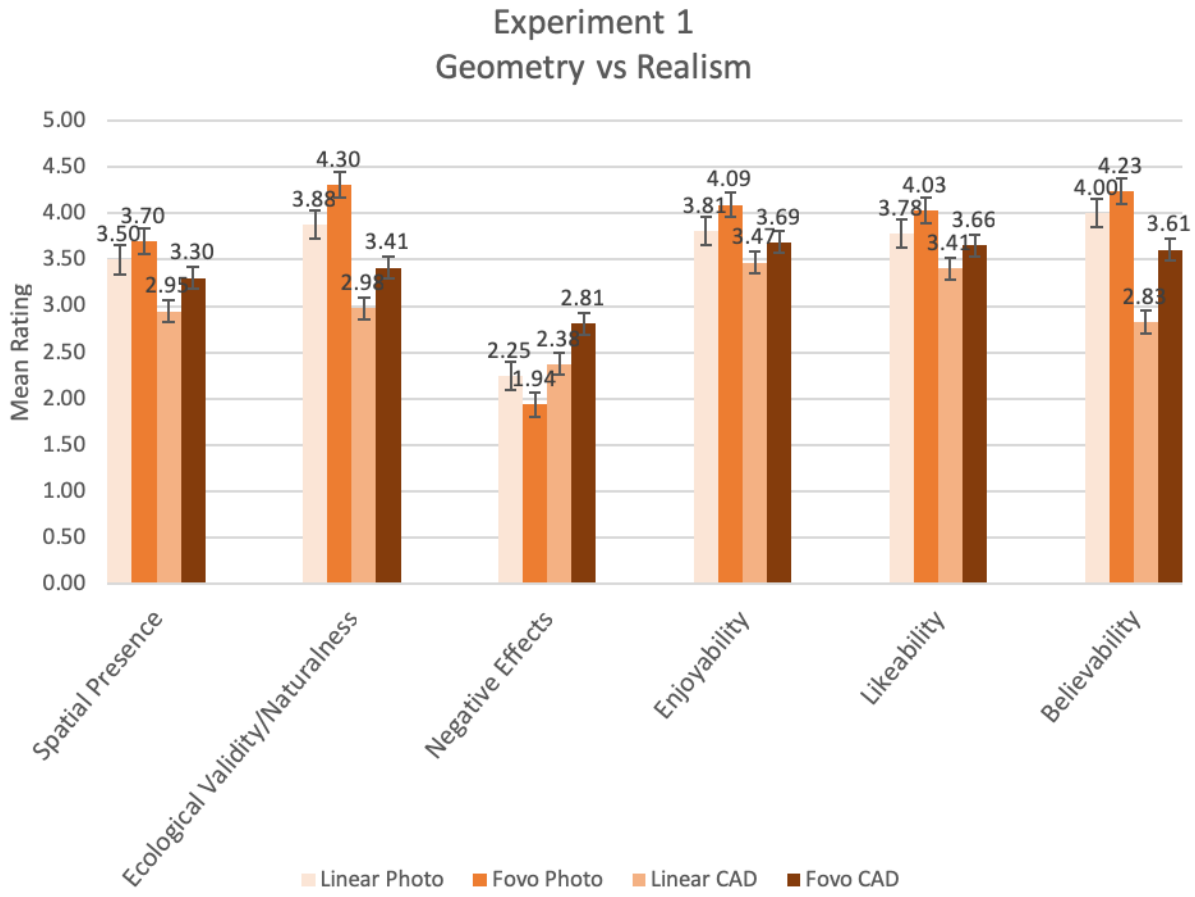

Figure 5 This graph reports the mean ratings (N= 32) of psychological variables on a 5-point Likert scale for each visual content: Linear Photo, Fovo Photo, Linear CAD, and Fovo Photo. Standard error is represented by the error bars attached to each column.

A repeated measures ANOVA was conducted for all the psychological variables. For the Spatial Presence variable, the Mauchly's Test indicated that the assumption of spherity had not been violated, $\chi^2(2) = 6.50$, $p = 0.26$. The pairwise comparison showed that there was a significant difference ($p < .05$) between the Spatial Presence rating of Fovo Photo (3.70) and Linear CAD (2.95). No other comparisons were significant (all $p > .05$).

For the Ecological Validity variable, with a Greenhouse-Geisser correction, the results showed that mean Ecological Validity differed significantly between images [$F(2.10, 65.10) = 18.74$, $p < 0.001$]. Post hoc tests, using the Bonferroni correction, revealed that there were significant differences ($p < .05$) between Linear Photo (3.88) and Fovo Photo (4.28), Linear Photo (3.88) and Linear CAD (2.98), Fovo Photo (4.28) and Fovo CAD (3.41), Linear CAD (2.98) and Fovo Photo (4.28). The highest average rating of Ecological Validity was Fovo Photo (4.28), and the low average rating of Ecological Validity was Linear CAD (2.98).

For the Negative Effects variable, the Mauchly's Test indicated that the assumption of spherity had not been violated, $\chi^2(2) = 10.56$, $p = 0.06$. The pairwise comparison showed that there was a significant difference ($p < .05$) between the Negative Effects rating of the Fovo Photo (1.94) and Fovo CAD (2.81). No other comparisons were significant (all $p > .05$).

For the Enjoyability variable, the Mauchly's Test indicated that the assumption of spherity had not been violated, $\chi^2(2) = 11.04$, $p = 0.05$. The pairwise comparison showed that there was a significant difference ($p < .05$) between the Enjoyability rating of the Fovo Photo (4.09) and Linear CAD (3.47). No other comparisons were significant (all $p > .05$).

For the Likabilty variable, the Mauchly's Test indicated that the assumption of spherity had not been violated, $\chi^2(2) = 6.25$, $p = 0.28$. The Post hoc test showed no significant interaction between the Likability rating of the four images.

For the Believability variable, with a Huynh-Feldt correction, the results showed that mean Believability differed significantly between images [$F(2.53, 78.43) = 17.89$, $p < 0.001$]. Post hoc tests using the Bonferroni correction revealed that there were significant differences ($p < .05$) between Linear Photo (4.00) and Linear CAD (2.83), Fovo Photo (4.23) and Linear CAD (2.83), Fovo Photo (4.23) and Fovo CAD (3.61), Fovo Photo (3.61) and Linear CAD (2.83). The highest average rating of Believability was Fovo Photo (4.23), and the low average rating of Believability was Linear CAD (2.83).

2.5 Discussion

The repeated measures ANOVA revealed that there was no significant interaction between geometry and realism. Meaning the Fovographised images were significantly impactful on the participant's sense of presence, irrespective of whether it was a photograph or CAD rendering.

The Fovo photo was consistently the highest rated in the psychological variables (except Negative effects, where it is rated the lowest), rating significantly higher than Linear CAD in all categories expect likeability. The Linear Photo ranked consistently in second place, however it did not rate significantly higher than the Fovo CAD in any category. The Fovo CAD ranked third with the Linear CAD rated the lowest throughout. This result reveals that geometry is a significant factor in affecting the participants' response with regard to sense of presence and that does not correlate with realism. However, realism is still important. This is demonstrated by the mean believability ratings that showed that the Linear Photo was rated significantly higher than the Linear CAD, however not significantly higher than the Fovo CAD, meaning realism is important, but second to geometry.

The photograph used in this experiment was taken in Tesco, however, photographing permissions are difficult to acquire, and consent to photograph at the same store was later

denied due to a rotation in store management. Moreover, external variables are hard to control in the real supermarket environment and may cause ethical concerns of unintentionally photographing real shoppers. Thus, the second part of this study studies whether a CAD-Photo hybrid can be used as an alternative to photographing real supermarket shelves for each new study. A hybrid will increase flexibility, allowing for quick turnovers of studies thus keep costs low for SMEs.

3. Experiment 2: Hybrid

To further investigate the possibilities and push the boundaries of conventional visual stimulus, a hybrid image between CAD shelving and the preferred Fovographised photograph was created. If successful, this hybrid scene will allow for high levels of customisation, and rapid content alteration for faster, more cost-effective testing; keeping costs low for Welsh SMEs.

3.1 Conditions

In this experiment, PEL was set up in the same way as the previous study. The visual (sight), auditory (sound), olfactory (smell), and haptic (touch) senses were added.

Figure 6 Condition A Fovographised© Photograph (Fovo photo); Condition B Fovographised© CAD-Photograph Hybrid (Hybrid)

Condition A is the same Fovo photo that resulted in the highest ratings in experiment 1. Condition B is a hybrid of the Fovo photo and CAD rendered shelving.

3.2 Methodology

1. 16 participants from Cardiff Metropolitan University varying in occupation, gender, and age, took part; the broad spectrum of demographics represented a diversified sample of supermarket frequenters. Again, participants and conditions were counterbalanced, so the cumulative increase of stimuli did not yield bias results.

The 16 participants were split into two groups. Group 1 experienced the viewing order AB, whereas Group 2 experienced the viewing order BA.

2. Participants were taken to the test condition, asked to perform a visual search task on the PEL screen and wait 30 seconds before being removed from the environment.

As before, the search task given to participants to perform in each condition was to identify a brand of cereal in the projected image. The order of cereal brands was also counterbalanced against the order of conditions. Participants were asked to stand in each condition for 30 seconds to ensure consistency of time immersed in each simulated environment.

3. Each participant was asked to fill in the questionnaire form after each task and condition to capture their experience while it was fresh in their minds.

The Cardiff School of Art and Design's Research Ethics Committee gave ethics approval for the study. All participants gave their informed consent prior to their inclusion in the study.

3.3 Results

A paired sample t-test was conducted to compare dependent variable groups between condition A (Fovo photo) and condition B (Hybrid)

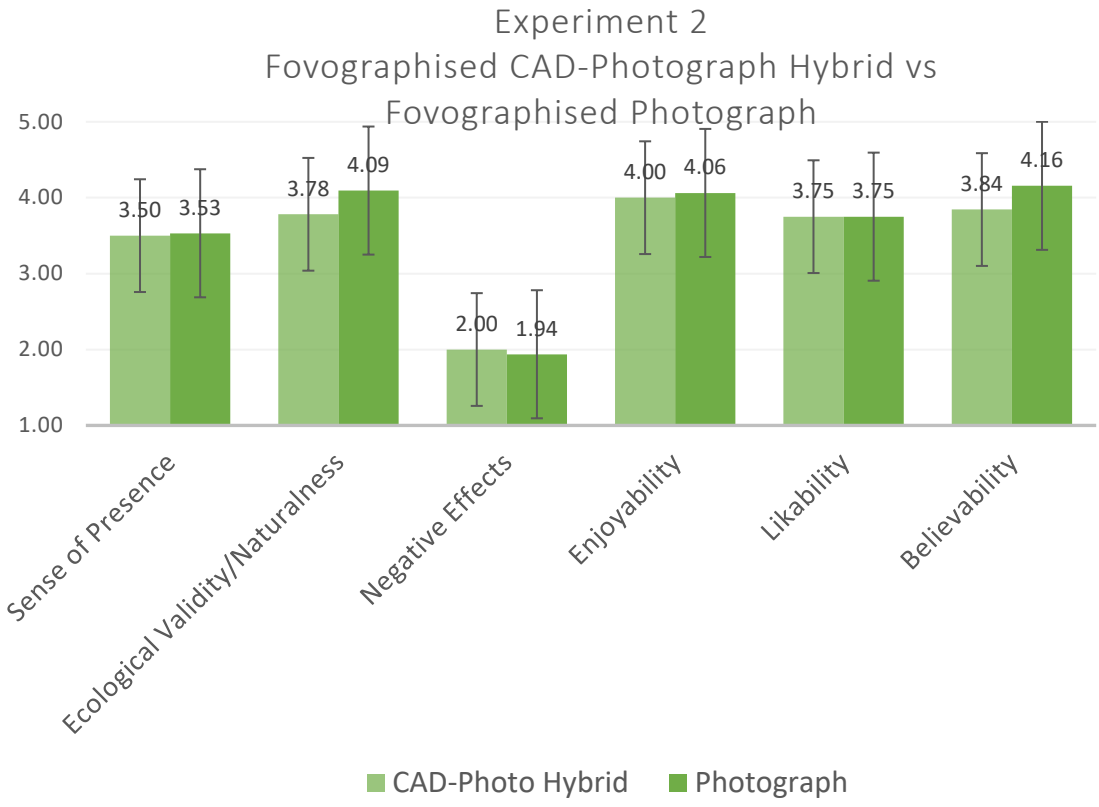

Figure 7. This graph reports the mean ratings (N= 16) of psychological variables on a 5-point Likert scale for each Fovo Photo and Hyrbid. Standard error is represented by the error bars attached to each column.

There was no significant difference between the ratings of the variables apart from the Believability variable: Sense of Presence between Fovo photo (M= 3.5, SD= 0.68) and Hybrid (M= 3.53, SD= 0.51) conditions; t(-0.26)= 15, p= 0.8; Ecological Validity between Fovo photo (M= 3.78, SD = 0.77) and Hybrid (M= 4.09, SD= 0.67) conditions; t(-1.72)= 15, p= 0.11; Negative Effects between Fovo photo (M= 2.0, SD= 0.89) and Hybrid (M= 1.94, SD= 0.68) conditions; t(0.44)= 15, p= 0.67; Enjoyability between for Fovo photo (M= 4, SD= 0.73) and Hybrid (M= 4.06, SD= 0.68) conditions; t(-0.57)= 15, p= 0.58; Likability between Fovo photo (M= 3.75, SD= 0.86) and Hybrid (M= 3.75, SD= 0.57) conditions; t(0.0)= 15, p= 1.0. There was a significant difference in ratings for Believability between Fovo photo (M= 3.84, SD= 0.72) and Hybrid (M= 4.16, SD= 0.65) conditions; t(-2.6)= 15, p= 0.02.

3.4 Discussion

The results from experiment 2 showed that although the hybrid rated slightly lower than the Fovo photo, there was no significant difference between Fovo Photo and hybrid images in any of the psychological variables except believability. This suggests that the sense of presence rating of the hybrid image is on par with the Fovo Photo, which rated the highest in experiment one.

4. Conclusion

Experiment one showed that regardless of the realism of the content, image geometry had more of an impact on participants' sense of presence, with participants preferring the Fovographised (natural perspective) version of content, which provided more depth and field of vision. However, realism was still an important factor, with the photograph being preferred over the CAD image, based on our psychological variables.

With geometry and realism both being important factors to consider, the use of a hybrid image is a way of retaining both factors in a cost effective and practical way. With results suggesting the hybrid is comparable to the Fovo Photo (the highest rated scene), it can be used as a versatile alternative that can be adapted for numerous studies. The hybrid offers high levels of customisation and flexibility, allowing for rapid experiment turnover times, which feeds into the broader aim of using PEL as a low-cost user-testing facility for SMEs.

5. Limitations

As only 32 participants were involved in the first study and 16 in the second, the results from this experiment cannot be used to represent the choices of the general population. Further larger scale studies are required to validate these results. This study focused exclusively on vertical shelving fixtures that featured flat surfaced packaged products. Manipulation of packaging designs on a flat surface is technically more straightforward than free form packaging or fixtures of different formats and features. Other products and fixtures may prove technically more difficult and require further investigation.

6. Future Implications

The overall aim of the research is to combine theoretical knowledge of marketing and design, with the practical implications of user testing, to investigate if packaging design can be improved through low-cost simulated environments and increase Welsh food SME sales in the supermarket. The next phase of this research is to employ the results of this study as a framework for creating future visual content as part of an iterative design process.

This experiment focuses on PEL solely as a user-testing space for food packaging, however the purpose of this space is to be flexible, and therefore has the has potential for a variety of uses in a wide range of fields.

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Professor Gareth Loudon: Active in academic and industrial research for over 25 years with several patents to his name and over 50 publications in total, Gareth's research interests focus on creativity and the innovation process, combining ideas from anthropology and psychology, engineering and design.

Professor Steve Gill: A product designer with 23 years of professional experience in industry and academia, Steve has designed, or product managed around 50 products to market and has published around 70 peer reviewed outputs.

Professor Robert Pepperell: The founder of FovoLab, Robert's current research combines methods from art and science to investigate the nature of visual experience and how it can be represented; to develop a new form of pictorial perspective based on the phenomenology of visual perception.

Dr Joe Baldwin: Joseph Baldwin is a Product Designer, Educator, and Research Scientist who works full time as a Research Officer within CSAD. The publication of both his Ph.D. research and further research as a Research Assistant helped support and promote the Fovography imaging method at CSAD.