

A comparison of the effect that the visual and haptic problems associated with touching a Projection Augmented model have on object-presence

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Abstract

A Projection Augmented Model (PA model) is a type of haptic Augmented Reality display. It consists of a real physical model, onto which a computer image is projected to create a realistic looking object. Users can physically touch the surface of a PA model with their bare hands, which has experiential value for the types of applications for which they are being developed. However, the majority of PA models do not provide haptic feedback for material properties such as texture, and hence feel incorrect when they are touched. In addition, most PA models are front-projected which means the projected image appears on the back of the user's hand, and their hand casts a shadow on the display. Previous research has found that touching this type of PA model reduces a user's sense of object-presence. The empirical study reported in this paper investigated which of the problems had a greater effect on object-presence. It was found that object-presence was significantly higher when correct haptic feedback for material properties was provided; however eliminating the visual projection problems often did not effect object-presence. These results have implications for the direction in which PA model technology should be developed. They also have implications for theory on how the haptic and visual senses contribute to a person's sense of object-presence, and indeed presence.

1. Background



Figure 1. PA model with projection on and off.

A Projection Augmented model (PA model) is a type of projection based haptic Augmented Reality display. It consists of a physical three-dimensional model, onto which a computer image is projected to create a realistic looking object [1]. For example, the PA model in figure 1 consists

of smooth white plaster models of various objects that are commonly found in a garden shed [2]. The image projected onto these objects provides color and visual texture, which makes them appear to be made from different materials. PA models can either be front-projected (e.g. figure 1), or if a semi-transparent physical model is used, they can be back-projected (e.g. [3]).

PA models can create very realistic looking objects, which multiple people can view and interact with in a natural and intuitive way, for example using a touch or gesture based interface. These properties have lead to PA models being developed for applications such as museum displays [4][5], and for product design applications such as cars [6] and mobile telephones [7]. The latter application highlights the importance of the fact people can touch a PA model with their bare hands, and feel its physical shape. PA models can also provide some haptic feedback for the material properties of the object that it is representing. For example, a PA model of a fossil which was created using a cast from a real fossil, provides haptic feedback for texture [4]. This accurate haptic feedback for material properties makes the PA model feel more realistic to touch.

Thus, considering the examples outlined above, there are four types of PA model: front-projected with haptic feedback for material properties; front-projected without haptic feedback for material properties; back-projected with haptic feedback for material properties; and back-projected without haptic feedback for material properties.

The majority of the technology that enables PA models to be a viable display option has been developed for front-projected PA models that do not provide haptic feedback for material properties (*simple PA models*). Technology has been developed that semi-automates the setup procedure of a simple PA model, for example software that correctly registers the projected image onto the physical model [8][9]. This technology can be combined with rapid prototyping and 3D scanning techniques to semi-automate the whole construction process [6][9]. Additionally, it is possible for a simple PA model to be created that changes its physical shape within a limited range [10][11]. Technology has also been developed which enables dynamic visual effects to be simulated using the projected image; examples include animated specula highlights, apparent motion and different lighting conditions (see [12] for a review). It is also possible for the projected image to remain registered on the surface of a moving object [5][8].

Given that PA models aim to create realistic objects, an important issue is the user's sense of object-presence. Object-presence is the subjective feeling a particular object

exists in a person's environment, when that object does not [1]. PA models use real physical objects; therefore it could be argued that PA models do actually exist in a person's environment. However, object-presence is the sense that the specific object the PA model is representing exists, as opposed to a white physical model and a projected computer image. Thus, a PA model is an essentially computer generated display because it is the projected image that gives the dummy physical objects meaning. Previous work has found that when a simple PA model is touched, a user's sense of object-presence is reduced [13].

Touching a simple PA model may reduce object-presence for two reasons. Firstly, when a person touches the surface of a simple PA model, the projected image appears on the back of their hand, and their hand casts a shadow onto the display. This draws attention to the fact the PA model is not a coherent object, and thus may reduce object-presence. Indeed, it has been found that the use of shadows on virtual objects viewed using an optical see-through augmented reality display can affect object-presence [14]. Additionally, a study that directly compared front and back projected flat-screen displays, reported that people found the shadows on the front-projected display very distracting [15]. The second possible reason why object-presence is reduced, is the mismatch between the visual and haptic feedback for material properties, such as texture, becomes apparent when a simple PA model is touched. This suggestion is supported by previous work which has shown that touch is very sensitive for perceiving material properties, such as texture [16].

Although using a back-projected display and providing haptic feedback for material properties could overcome these problems, technology is currently not sufficiently developed for these to be viable options (e.g. no automated setup procedures exist for back-projected PA models). These two areas are separate and distinct from each other, which suggests that research is needed to determine which is the most effective way of increasing object-presence, and hence the most effective area in which technological efforts need to be focused.

2. Research questions

This paper focuses on a user's sense of object-presence when touching a PA model. It investigates whether object-presence is increased by eliminating the visual projection problems, or by providing haptic feedback for material properties and hence making the PA model feel correct to touch. The results will indicate the most effective direction in which technology should be developed.

It is possible that the effect of eliminating the projection problems and providing haptic feedback for material properties will differ depending on the object that the PA model is representing. Different objects have different 'key' properties, which are most suited to being perceived by either the visual or the haptic sense [17]. The properties that are most suited to being perceived through the haptic sense are material properties (e.g. temperature and texture), whilst geometric properties (e.g. size and shape) are most suited to being perceived through the visual

sense [17]. Clearly all objects have both 'haptic' and 'visual' properties; however their relative importance may be biased towards one or the other depending on the task being completed with the object. When considering where an object is on a 'visual' to 'haptic' scale, it is useful to think in terms of general activities, as opposed to specific tasks. By considering general activities in combination with an object's most prominent features, a rough position on the scale can be identified. For example, when choosing a box of breakfast cereal, the salient property is the visual design on the package, and hence the object can be classed as a 'visual' object. Whereas, the salient property when choosing high quality printing paper is how the paper feels to touch, and hence the object is classed as a 'haptic' object.

It is possible that if a PA model is touched that represents a 'haptic' object, object-presence will be reduced more by the lack of haptic feedback for material properties than the visual problems associated with the projected image. Conversely, if a PA model is touched that represents a 'visual' object, object-presence may be reduced more by the visual problems associated with the projected image.

However, it has been argued that touch is a human's reality sense [18], which suggests that the lack of correct haptic feedback for material properties will always reduce object-presence more than the problems associated with the projection. Conversely, the theory of Visual Capture, which argues that vision is the primary sense that dominates over the others [17], suggests that the visual projection problems will always reduce object-presence more than the lack of haptic feedback for material properties. In fact, it has been shown that visual feedback can be used to 'fool' the haptic sense, and make a person believe that they have felt something when they have not [19]. For example, a person can be made to believe that they have felt a specific texture by manipulating the visual feedback [20].

Thus, it is possible that the type of object a PA model represents does not matter; either eliminating the projection problems, or providing accurate haptic feedback for material properties, will always be the most effective solution. However, whilst one solution may always be more effective, the amount by which it is more effective may vary depending on the type of object that the PA model represents. Given that previous research does not provide a clear indication as to which of the two solutions is the most effective, this study investigates the following questions:-

- 1) *When touching a PA model that represents a 'visual' object, to what extent is a person's sense of object-presence affected by the visual problems associated with the projection, and to what extent is it affected by the incorrect haptic feedback for material properties?*
- 2) *When touching a PA model that represents a 'haptic' object, to what extent is a person's sense of object-presence affected by the visual problems associated with the projection, and to what extent is it affected by the incorrect haptic feedback for material properties?*
- 3) *Does the extent to which object-presence is affected by the projection problems and by the haptic feedback for material properties differ depending on the type of object (visual/haptic) that a PA model is representing?*

3. Experiment 1: Investigating question 1

3.1 Design and procedure

This experiment investigated the first research question (section 2). A 2x2 factorial design was used; the independent variables (IV) were *ProjectionDirection* (*Front-Projected* and *Back-Projected*), and *FeelsToTouch* (*FeelsCorrect* and *FeelsIncorrect*). Therefore 4 PA models were constructed, and were arranged so that the participant could use them singularly or simultaneously (figure 2).

The experiment was split into two parts; each participant completed part 1, and then part 2 directly afterwards. Part 1 had a between-participants design; each participant did a set of tasks which required them to touch just one of the 4 PA models (section 3.1.1). An additional condition was included in this part, in which participants used the *Front-Projected+FeelsIncorrect* (i.e. simple) PA model without touching it. This was to verify the reliability of a previous study, which concluded that touching a simple PA model decreases object-presence [13]. Therefore in part 1 there were actually 5 conditions with different participants in each; four ‘touch’ conditions and one *NoTouch* condition.

Part 2 of the experiment had a within-participants design; all participants completed the same tasks which required them to touch all four PA models simultaneously (section 3.1.2). A total of 50 participants were used, who were all students on computing related degree courses.

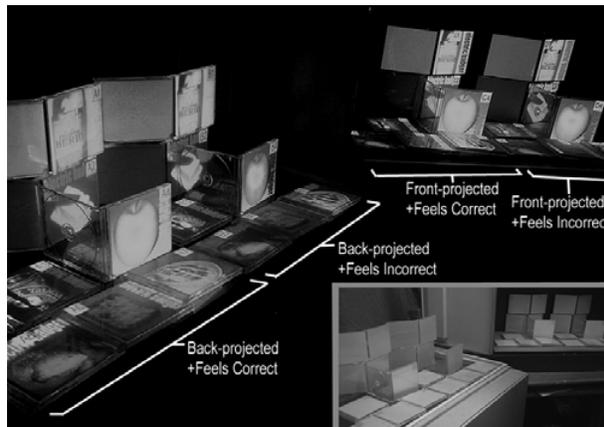


Figure 2. First experiment - ‘visual’ PA models.

The PA models represented CD cases and each of the four PA models consisted of a set of 7 cases (figure 2). CD cases were chosen because their most prominent feature is the visual design on the sleeve, and hence they can be classed as ‘visual’ objects. The CD cases were all firmly attached to the base and could not be moved. The image on the front-projected PA models was projected down from a 45 degree angle, which meant the projection problems only occurred when the participants touched the display. The projection equipment was equally visible for both the front and back-projected PA models.

The precise design of the PA models (CD cases) was directly related to the experimental tasks (sections 3.1.1 and 3.1.2). The sets of CD cases in the two *FeelsCorrect*

conditions felt like normal plastic cases. Whereas, in the two *FeelsIncorrect* conditions, 4 of the CD cases felt like paper to touch, and 3 cases felt like paper with a sticky area in the center. The images on the CD cases were of foods that could either be described as sticky (e.g. treacle) or smooth (e.g. butter). The same set of images was used on each of the 4 sets of CD cases. On each CD case the words ‘electric badger’ were written (as if it was the title of the album). The combination of the text colour and the image was different for every CD case. Importantly, all four sets of CD cases were the same in terms of image content (apart for the text colour) and image quality.

The experiment aimed to be ecologically valid, and hence a fair refection of a real life situation. This was achieved by designing tasks that appeared to be ‘natural’ and ‘sensible’ activities to do with a PA model. The participants were told that the PA models were a new type of design system which was being developed to assist in the design of products. They were lead to believe that they were doing the experiment to investigate how people evaluate products (i.e. CD cases) using the system. Throughout the experiment the participants had to touch the CD cases to ‘select’ them (section 3.1.1 and 3.1.2). This gave participants the opportunity to perceive both the haptic properties of the CD cases and the projection problems. To make the participants feel that this was a ‘sensible’ activity, they were told they had to do this because their hand was being tracked. This ‘story’ was made believable by placing a camera above the display.

To operationalise the definition of object-presence, high object-presence was defined as ‘*a strong sense that the paper sleeves are inside the CD cases, and the images are physically printed onto them*’. This was based on the notion that if participants found the projection problems very noticeable, they may have troubling imagining that the images are physically printed on the paper sleeves of the front-projected CD cases. And, if they found the haptic properties of the CD cases noticeable, they may have trouble imagining that the paper sleeve is on the *inside* of the cases that felt incorrect to touch.

Ten ‘measures’ were designed based on this definition (sections 3.1.1 and 3.1.2). Not all of the measures investigated object-presence directly. The measures initially explored the issues related to object-presence, and gradually asked increasingly more direct questions. Measures 5, 6 and 7 aim to measure object-presence directly. The principal behind these measures was to ask direct, but essentially subjective, questions relating to the visual and the haptic problems. If the participants indicate that they can suspend their disbelief when they notice a problem, it suggests the ‘problem’ does not effect object-presence. For example, participants are asked ‘*The design system aims to give you the sense that the paper sleeves are inside the CD cases, and the images are physically printed onto them. Put the 4 sets in order based on how strongly you get this sense. You may give 2 or more sets same ranking.*’ (measure 6) (section 3.1.2). If the participants ranked the two PA models that felt correct to touch as joint 1st, and the two that felt incorrect as joint 2nd, then the projection problems have not affect the ranking. This

would suggest that people can suspend their sense of disbelief when they encounter the projection problems, but they cannot when they encounter the haptic problem. Thus, the haptic problems effect object-presence, but the projection problems do not.

A number of pilot studies (16 participants in total) were conducted to ensure that the participants understood the wording of the questions, and understood the questions were interested in their subjective opinion. After testing several versions of the questions and instructions, the following procedure was decided upon.

3.1.1 Part 1 (between-participants) procedure: In part 1 the participants completed a set of tasks which required them to touch just one of the 4 sets of CD cases (i.e. PA models). An additional condition was included in which participants used the Front-Projected+FeelsIncorrect (i.e. simple) PA model without touching it.

Each of the five conditions contained 10 participants. Firstly, the participants in the four ‘touch’ conditions touched each of the CD cases in the set that they were using. This was to ensure they had the opportunity to notice how the CD cases felt, however to make this appear to be a ‘natural’ activity they were told it was to calibrate the hand tracking device. Participants in the NoTouch condition had to look at each of the CD cases in the Front-Projected+FeelsIncorrect set; they were told this was to familiarize them with the system.

The participants in the four ‘touch’ conditions then did the following tasks by touching the CD cases to indicate their answer. The participants in the NoTouch condition did the tasks by saying the number on the CD cases.

The participants were asked to categorized the 7 CD cases into two groups based on the ones they thought ‘go together or are similar in someway’ (**Measure 1**). This was to investigate the attention they paid attention to how the CD cases felt to touch; the participants in the two FeelsIncorrect conditions could answer this question based on the images on the CD cases, or based on how they felt to touch (section 3.1). This approach to assessing object-presence is derived from the concept of Cognitive Presence, which argues the way in which people interpret a question signifies which reality they are in [21]. They then categorized the 7 CD cases into two groups based on the ones that they ‘would describe as sticky and those that they would describe as smooth’. (**Measure 2**). The aim of this measure was the same as the last, except the participants were prompted towards ‘sticky’ and ‘smoothness’.

They then completed a ‘realistic’ design task, in which they were asked to ‘select’ the CD cases in the order that they liked the images. It was this task and the ‘realistic’ design task in part 2 (section 3.1.2), that the participants believed was the focus of the experiment. However, this was simply a way of getting them to do a ‘realistic’ seeming task with the display, and nothing was recorded.

After completing these tasks, the participants faced away from the display and were asked to describe their ‘main memory of the design system’ (**Measure 3**) and their ‘main memory of what they saw’ (**Measure 4**). This was to investigate how noticeable the participants found the image

being projected on their hand, and the shadows. They also completed the following object-presence questionnaire by giving an answer on a five point Likert Scale, where 1 = strongly disagree and 5 = strongly agree (**Measure 5**). Reverse scoring was used for questions 3 and 7. They were told to answer the questions based on ‘their subjective sense or feeling, and not what they know to be true’.

- 1) *I had a strong sense or feeling that the CD cases had a smooth clear plastic front.*
- 2) *The design system was a very natural way of presenting information.*
- 3) *I constantly paid attention to the design systems deficiencies / problems.*
- 4) *I had a strong sense that the paper sleeve was inside the CD cases.*
- 5) *I had a strong sense that the images were physically printed in coloured ink.*
- 6) *I can easily believe that the front of all of the CD cases felt like plastic to touch.*
- 7) *I had a strong sense that parts of the design system were computer generated.*

3.1.2 Part 2 (within-participants) procedure: In part 2, all 50 participants did the same tasks using the four sets of CD cases (i.e. all 4 PA models) simultaneously.

The participants first completed another ‘realistic’ design task (related to their preference for the text colour), which ensured they touched all of the CD cases and nothing was recorded. The participants were then asked to put the four sets of CD cases in order based on the sense of object-presence that they felt. Specifically, they were asked: ‘*The design system aims to give you the sense that the paper sleeves are inside the CD cases, and the images are physically printed onto them. Put the 4 sets in order based on how strongly you get this sense.*’ (**Measure 6**). They were allowed to give two, three or all the sets the same ranking, and they could touch the CD cases to make their decision. The participants were then asked to decide for each set of CD cases, whether touching the cases increased or decreased their sense of object-presence. Specifically, they were asked: ‘*Consider each set in turn. Can you decide whether touching the CD cases increases or decreases your sense that the paper sleeve is inside the case and the image is physically printed onto it, or does touching make no difference?*’ (**Measure 7**). Again, they could touch the CD cases to make their decision.

After this, they were asked a direct question about their sense of object-presence with regards to how the CD cases felt to touch: ‘*Which set or sets gives you the strongest sense that the paper sleeve is inside the CD cases?*’ (**Measure 8**). And, they were asked a direct question about their sense of object-presence with regards to the projection problems: ‘*Which set or set gives you the strongest sense that the images are physically printed on the paper sleeve?*’ (**Measure 9**). For both questions they could touch the CD cases to make their decision.

Finally, the participants faced away from the display and were asked whether or not they had noticed the projected image on their hand, the shadows, and how the CD cases felt to touch. (**Measure 10**).

3.2 Results of the first experiment

3.2.1 Measure 1 (allocating the CD cases into two groups based on the ones which *'you think go together or are similar in some way'*). 48/50 participants did this task based on the images on the CD cases. 2 participants (who were unsurprisingly in the two FeelsIncorrect conditions) did this task based on touch.

3.2.2 Measure 2 (categorization of the CD cases based on *'those that you would describe as sticky and those that you would describe as smooth'*). As expected, all participants (except for one) in the two FeelsCorrect conditions and the NoTouch condition did this task based on the images on the cases. 7/10 participants in the Back-Projected+FeelsIncorrect condition, and 8/10 participants in the Front-Projected+FeelsIncorrect condition did this task based on how the cases felt to touch; therefore a significant number of participants in the FeelsIncorrect conditions (combined) categorized the CD cases based on how they felt to touch ($X^2(1)=5.0, p<0.05$).

3.2.3 Measure 3 (*'what did you find most noticeable?'*) and **measure 4** (*'what was your main memory of what you saw?'*). The participants responses to both measures were divided into the following categories; 'feels to touch', 'projection on hand', 'shadows hand cast', 'task', 'design on the CD case' and 'equipment setup'. The results were very similar for both measures and there was virtually no difference between conditions. For both measures, the majority of participants' responses (38/50 for measure 3 and 44/50 for measure 4) fell in the 'design on the CD case' category (e.g. they recalled the treacle); this figure was made up of an approximately equal number of responses from each condition. For both measures, only one participant's response fell into the 'image on hand' category (both in the Front-Projected+FeelsIncorrect condition), and no participants mentioned the shadows.

3.2.4 Measure 5 (questionnaire) (figure 3) .

Question	Condition / PA model				
	NoTouch	BP+FC	BP+FIC	FP+FC	FP+FIC
1 Mean	3.70	4.00	2.00	3.90	2.40
s.d	(0.82)	(0.94)	(0.82)	(0.88)	(0.97)
2 Mean	3.80	3.40	3.10	3.20	3.00
s.d	(0.92)	(0.84)	(0.88)	(1.03)	(1.05)
3 Mean	3.30	3.10	3.10	3.10	2.90
s.d	(0.95)	(1.10)	(0.88)	(0.87)	(0.74)
4 Mean	3.70	3.50	2.30	4.00	2.20
s.d	(1.49)	(1.18)	(0.82)	(1.05)	(0.79)
5 Mean	4.00	3.70	3.80	3.50	3.30
s.d	(1.15)	(1.49)	(1.03)	(1.35)	(1.25)
6 Mean	4.20	4.20	2.70	4.40	3.30
s.d	(0.92)	(1.03)	(1.16)	(0.69)	(1.16)
7 Mean	2.30	2.20	2.30	3.00	2.00
s.d	(1.16)	(1.14)	(0.95)	(1.15)	(1.15)

Figure 3. First experiment - measure 5 results.
(BP=Back-projected, FP=Front-projected,
FC=Feels correct, FIC=Feels incorrect).

A Cronbach Alpha test for internal consistency was found to not be significant (0.43). A principal component factor analysis was conducted on the results to determine whether groups of questions were measuring separate constructs. Three subscales were found; questions 1, 4, and

6 (which relate to how the CD cases felt), 2 and 3 (which relate to the 'naturalness' of the display) and questions 5 and 7 (which relate to the projection problems). However, when the analysis was conducted on each individual condition, this pattern was not found. Although this is unsurprising because each condition contained only 10 participants, it means that the questions must be analyzed separately.

Firstly, comparing between the four 'touch' conditions (i.e. not including the NoTouch condition), and hence investigating question 1. A suitable nonparametric test was not available (i.e. a nonparametric two-way ANOVA type test). Work is currently being done to develop this type of test [22], however a usable version is not yet available. It has been argued that ordinal data, such as Likert Scales, can be treated as interval data for the purpose of statistical analysis [23], therefore this approach was taken. Levene's test for equality of variance was conducted on each question and found no significant difference between conditions. Therefore a two-way between-participants MANOVA was conducted. A significant effect was found for the FeelsToTouch IV for questions 1 ($F(1,36)=37.63, p<0.001$), 4 ($F(1,36)=23.68, p<0.001$) and 6 ($F(1,36)=15.93, p<0.001$), but not for the other questions. No significant effects were found for the ProjectionDirection IV for any of the questions, and no significant interactions were found for any questions.

Now comparing the NoTouch condition to each of the four 'touch' conditions (i.e. which could confirm the conclusion from previous work). A Man Whitney test found a significant difference between the NoTouch condition and the Back-Projected+FeelsIncorrect condition for questions 1 ($U(18)=8, p<0.01$), 4 ($U(18)=23, p<0.05$) and 6 ($U(18)=16, p<0.01$), but not for the other questions. A significant difference was found between the NoTouch condition and the Front-Projected+FeelsIncorrect condition for questions 1 ($U(18)=15, p<0.01$) and 4 ($U(18)=22, p<0.05$), but not for the other questions. No significant difference was found between the NoTouch condition and the Back-Projected+FeelsCorrect condition, and the NoTouch condition and the Front-Projected+FeelsCorrect condition, for any of the questions.

3.2.5 Measure 6 (Putting the four sets of CD cases in the order of the sense of object-presence that they create). Although the data that this measure generates is ipsative (i.e. the ranking that a participant gives one set of CD cases affects the ranking they give another), previous research has concluded that it is valid to perform an ANOVA on this type of data [24]. Moreover, the participants were given the option of giving two (or more) sets of CD cases the same ranking (e.g. joint second place). This meant that the participants were not forced to create an 'artificial' rank order. Therefore the data was analyzed using an ANOVA by converting each ranking into a score of 1 (lowest) – 4 (highest). If a participant said that two sets gave them the same sense of object-presence, the mean between the two ranks was given for both. (Figure 4).

Condition	Mean (standard deviation)
Back-Projected+FeelsCorrect	3.13 (0.92)
Back-Projected+FeelsIncorrect	2.02 (1.00)
Front-Projected+FeelsCorrect	3.02 (1.01)
Front-Projected+FeelsIncorrect	1.83 (0.66)

Figure 4. First experiment - measure 6 results.

A within-participants ANOVA was conducted. A significant effect was found for the FeelToTouch IV ($F(1,49)=52.16, p<0.001$). No significant effect was found for ProjectionDirection IV ($F(1,49)=1.06, p=0.31$) and no significant interaction was found ($F(1,49)=0.08, p=0.78$).

3.2.6 Measure 7 (For each set of CD cases, what effect does touching have on object-presence.) (Figure 5).

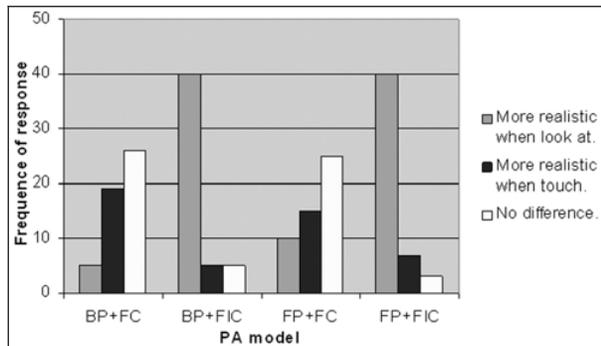


Figure 5. First experiment - measure 7 results. (BP=Back-projected, FP=Front-projected, FC=Feels correct, FIC=Feels incorrect).

3.2.7 Measure 8 ('which set or sets gives you the strongest sense that the paper sleeve is inside the CD cases?' i.e. direct question relating to how the CD cases felt to touch). 44/50 participants chose one or both of the sets of CD cases that felt correct to touch.

3.2.8 Measure 9 ('which set or sets gives you the strongest sense that the images are physically printed on the paper sleeve?' i.e. direct question relating to the projected image). 17/50 participants said the four sets of CD cases were the same. 4/50 participants chose both the Back-Projected sets, 4/50 chose the Back-projected+FeelsCorrect set and 16/50 participants chose the Back-Projected+FeelsIncorrect set. 6/50 chose either of the Front-Projected sets, and 3/50 chose both the FeelsIncorrect sets.

3.2.9 Measure 10 (did participants actually notice the projection and haptic problems). 19/50 participants noticed the image on the back of their hand, and 26/50 participants noticed the shadows that their hands cast. A 2x2 Chi-Squared test found a significant relationship between noticing the image on the hand and noticing the shadows ($X^2(1)=12.74, p<0.001$). 49/50 participants noticed the CD cases did not all feel the same to touch, and 49/50 noticed that some CD cases felt sticky.

3.2.10 Comparing between measures. The data can be split based on whether or not the participants noticed the projected image on their hand (measure 10). Re-running the within-participants ANOVA showed no difference in the pattern of results for any of the measures, except for measure 9. Measure 9 asked 'which set or sets gives you the strongest sense that the image is physically printed on the

paper sleeve?'. 74% of the participants who noticed the projection on their hand gave a back-projected set of CD cases as their answer, whereas only 32% of participants who did not notice gave a back-projected set as their answer. Splitting the data based on whether participants noticed the shadows that their hands cast on the CD cases (measure 10) showed no significant difference in the patterns of results for any of the measures.

3.3 Discussion of the first experiment

Participants did not question the true goals of the experiment, and they appeared to put much thought into the 'realistic' design tasks. Moreover, no participants questioned whether or not their hand was really being tracked. This suggests that they believed the scenario they were told, and hence the results can be considered to be a fair reflection of a real task. Although there was a slight possibility that using the visual design scenario could focus participants' attention towards the visual projection problems, this did not occur.

In fact, the experiment found that a surprisingly high number of participants did not actually notice the projection problems, whereas (virtually) all participants noticed the haptic problems (measure 10, section 3.2.9). This *Innattentional Blindness* is the failure to notice information in the visual angle of the fovea [25]. Object-presence is concerned with whether participants can suspend their sense of disbelief when they encounter a problem, which they obviously cannot do if they have not actually noticed the problem. Therefore only the results of the participants who noticed the problems should be taken into consideration when addressing the research questions. However, when the results were split based on whether the problems were noticed, the same pattern of results were found for the measures that directly addressed object-presence (i.e. 5, 6 and 7) (section 3.2.10).

The results confirm the finding of previous work [13]; the majority of participants reported that object-presence was lower when the Front-Projected+FeelsIncorrect (i.e. simple) PA model was touched, compared to when it was just looked at (figure 5).

The main research question asked 'When touching a PA model that represents a 'visual' object, to what extent is a person's sense of object-presence affected by the visual problems associated with the projection, and to what extent is it affected by the incorrect haptic feedback for material properties?'. The two measures directly addressed this question were the questionnaire (measure 5) and the ranking of the sets of CD cases based on the sense of object-presence they induce (measure 6). However, the questions in the questionnaire cannot be considered together because it was found they did not measure a unified construct (section 3.2.4), therefore the questionnaire cannot be used as a direct measure of object-presence.

Considering measure 6 (section 3.2.5); it was found that the two sets of CD cases that provided correct haptic feedback for material properties and hence felt correct to touch, were ranked significantly higher than the sets that did not. However, the direction of the projected image did

not effect how the sets were ranked. This suggests that it is how a ‘visual’ PA model feels to touch that effects object-presence, as opposed to the projection problems. The other measures provide more subtle indicators, which generally support this conclusion.

Firstly, when classifying the CD cases as ‘sticky’ and ‘smooth’ (measure 2, section 3.2.2), a significant number of participants in the two FeelsIncorrect conditions did this based on how the CD cases felt to touch. This shows that participants found how the cases felt very noticeable. The fact the results for this measure follow the same pattern as the other measures suggests that the Cognitive approach to investigating presence [21] is a reliable method.

The results from the questionnaire (measure 5, section 3.2.4) show a similar pattern. Although the questions cannot be considered together, the individual questions can be examined. It was found that the haptic feedback the CD cases provided for material properties significantly affected responses to the questions relating to how they felt to touch. Moreover, the results support the argument that the problems associated with the projection are less important because it was found the direction of the projected image had no significant effect on any of the questions.

Further support for this pattern of results can be found by examining the effect that touching the CD cases had on object-presence, in comparison to when they were not touched (measure 7, figure 5). It was found that object-presence was lower when the two sets of CD cases which felt incorrect were touched. Whereas the projection problems did not appear to reduce object-presence when the front-projected CD cases were touched.

When questioned separately about the haptic issues, a similar pattern was also found. The majority of participants (44/50) reported that the two sets of CD cases that felt correct to touch gave them a stronger sense that the paper sleeve was inside the CD case (measure 8, section 3.2.7); hence supporting the argument that the haptic feedback for material properties is important.

However, when questioned separately about the projection problems, the results are not as consistent (measure 9). This is the only measure that showed a different pattern between the participants who noticed the projected image on their hand and those who did not (section 3.2.10). 74% of the participants who did notice it, chose only the back-projected sets of CD cases when asked to say which set/s gave them a stronger sense that the image was physically printed, compared to only 32% of the participants who did not notice it. This suggests that if people notice the projection on their hand, it can have an effect when asked a more direct question.

The only measures that do not support the general pattern of results are measures 3 and 4. When asked questions about what they found most noticeable and what was their main memory of what they saw, the vast majority of the participants’ responses were related to the content of the projected image (e.g. they remembered the apple design). This suggests that how the CD cases felt to touch, or indeed the projection problems, were not considered important enough to mention. However, the participants were told that the experiment was investigating how people

evaluate the designs of CD cases, so it is possible that they were responding to demand characteristics.

To summarize, when a PA model is touched that represents a ‘visual’ object, object-presence is strongly affected by the haptic feedback provided for material properties, i.e. how it feels to touch. Although people tend not to find the visual projection problems noticeable, when they are noticed, they can affect responses to very direct questions relating to object-presence.

4. Experiment two – investigating question 2

4.1 Design and procedure

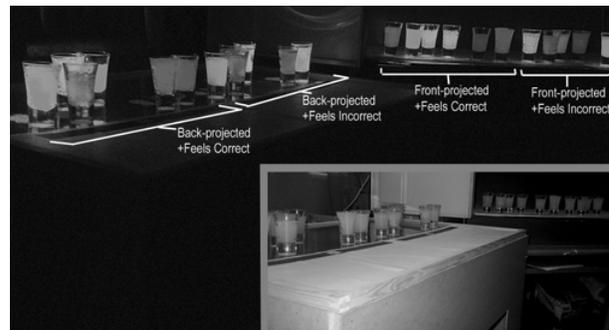


Figure 6. experiment 2 - ‘haptic’ PA models.

This experiment investigated the second research question (section 2). The same experimental design and procedure as the first experiment was used (section 3.1), however in this experiment the PA models represented ‘haptic’ objects. The specific objects that the PA models represented were vodka jellies (figure 6). (A vodka jelly is a fruit jelly, which is made with vodka and set into a shot glass; they are sold in many of the bars on the university campus). Vodka jellies are ‘haptic’ objects because their prominent feature is that they are made from, and hence feel like, jelly. Each of the four PA models used in this experiment consisted of a set of 6 vodka jellies. The models were actually made from gel candle wax, which was set into shot glasses. The vodka jellies in the two FeelsCorrect conditions felt like jelly to touch, and the vodka jellies in the two FeelsIncorrect conditions felt hard (this was achieved by setting a thin layer of clear resin on top of the wax). Importantly, all four sets of vodka jellies were visually identical, and they were all firmly attached to the base.

The same scenario as the first experiment was used; the participants were told that they were doing the experiment to investigate how people evaluate products using the system. The participants did equivalent ‘realistic’ design tasks as the participants in the first experiment, which involved them giving their preference for the colours. They had to touch the jelly itself (as opposed to the glass) to indicate their answer, which gave participants the opportunity to perceive both the haptic properties of the jellies and the projection problems. Again, they were told they were doing this because their hand was being tracked.

The same procedure and measures as experiment 1 were used, except for measures 1 and 2 which were not used because it was not practical to create an equivalent

measure. However, the numbering of the measures starts at 3 to maintain consistency. The questions for each measure were reworded to assess the following operationalised definition of object-presence: high object-presence is ‘a strong sense that the glasses contained jelly that is physically coloured’. This was based on the notion that if participants found the projection problems noticeable, they may have troubling imagining the jelly is actually coloured when using the front-projected jellies. And, if they found the haptic properties of the jellies noticeable, they may have trouble imagining that the jellies which felt incorrect are actually made from jelly. Again, a pilot study was conducted before running the experiment. Detailed explanations of each stage of the procedure can be found in sections 3.1.1 and 3.1.2, however the following sections provide a summary. Again a total of 50 participants took part (not the same people as in experiment 1), who were students on computing degree courses.

4.1.1 Part 1 (between-participants) procedure: In part 1, the participants completed a set of tasks which required them to touch just one of the 4 sets of vodka jellies (i.e. PA models). An additional condition was included in which participants used the Front-Projected+FeelsIncorrect (i.e. simple) PA model without touching it. Each of the five conditions contained 10 participants. They first completed equivalent ‘calibration’ and ‘design’ tasks as the participants in experiment 1. The participants in the four ‘touch’ conditions did these tasks by touching the vodka jellies. The participants in the NoTouch condition did the tasks by saying the colour of the jellies. After this, they faced away from the display and were asked ‘*what did you find most noticeable?*’ (**Measure 3**) and ‘*what was your main memory of what you saw?*’ (**Measure 4**). They then completed the following object-presence questionnaire by giving answers on a five point Likert scale, where 1 = strongly disagree and 5 = strongly agree (**measure 5**) (questions 1 and 3 are reversed scored):-

- 1) *I had a strong sense that parts of the design system were computer generated.*
- 2) *The design system was a very natural way of presenting information.*
- 3) *I constantly paid attention to the design systems deficiencies / problems.*
- 4) *I had a strong sense that there were Vodka Jellies present in front of me.*
- 5) *I had a strong sense that each glass in the set that I focused on had a different colored material inside of it.*
- 6) *I can easily believe that there was jelly inside the shot glasses.*

4.1.2 Part 2 (between-participants) procedure: In the second part, all 50 participants completed the same tasks using the four sets of vodka jellies (i.e. PA models) simultaneously. They first completed an equivalent ‘design’ task as the participants in the first experiment, which required them to touch all four sets of vodka jellies. They were then asked to put the four sets of vodka jellies in order based on the sense of object-presence they felt

(**Measure 6**). Specifically, they were asked ‘*The design system aims to give you the sense that the shot glasses contain coloured jelly. Can you put the sets in order based on how strongly they give you this sense*’. They were allowed to give two or more sets the same ranking. After this, they had to decide for each set of vodka jellies, whether touching increased or decreased object-presence (**Measure 7**). Specifically, they were asked ‘*Consider each set in turn. Can you decide whether touching the vodka jellies increases or decreases your sense that the shot glasses contain coloured jelly, or does touching make no difference*’. They were then asked ‘*which set or sets gives you the strongest sense that the objects are made from the correct material?*’ i.e. a direct question about object-presence relating to how the PA models felt to touch (**Measure 8**). And, they were asked ‘*which set or sets gives you the strongest sense that the jelly is actually coloured?*’ i.e. a direct question about object-presence relating to the projected image (**Measure 9**). Whilst completing measures 6, 7, 8 and 9 the participants were allowed to touch the vodka jellies.

Finally, they faced away from the display and were asked whether they actually noticed the projection problems and the haptic feedback for material properties (**measure 10**).

4.2 Results of the second experiment

4.2.1 Measures 3 and 4. The same categories as in the first experiment were used to group the responses to measures 3 and 4 (section 3.2.3), except for the ‘design on the CD cases’ category which was replaced with ‘colours’. For both measures, the pattern of results was very similar and there was virtually no difference between conditions. For both measures, the majority of responses (31/50 for measure 3, and 40/50 for measure 4) fell into the ‘colours’ category (e.g. the participant listed all the colours of the vodka jellies); this figure was made up of roughly an equal number of responses from each condition. For measure 3, 3 of the participants’ responses fell into the ‘projection on hand’ category, and for measure 4, 4 of the participants’ responses fell into this category; all of these responses came from participants in the Front-Projected+FeelsIncorrect condition. For both measures 3 and 4 no participants mentioned the shadows their hands cast on the display.

4.2.2 Measure 5 (Figure 7).

Question	Condition / PA model				
	NoTouch	BP+FC	BP+FIC	FP+FC	FP+FIC
1 mean	3.40	3.60	3.40	3.70	3.20
s.d	(0.97)	(1.26)	(0.70)	(0.82)	(1.03)
2 mean	4.10	3.50	2.70	3.50	2.50
s.d	(0.99)	(1.35)	(1.25)	(0.97)	(1.08)
3 mean	4.00	3.80	2.80	3.50	2.60
s.d	(0.94)	(0.79)	(1.23)	(0.97)	(1.26)
4 mean	3.30	4.10	2.50	3.80	2.90
s.d	(0.95)	(1.10)	(1.43)	(1.13)	(1.52)
5 mean	3.80	3.80	3.80	4.10	3.30
s.d	(1.23)	(0.92)	(1.23)	(0.74)	(1.25)
6 mean	3.90	4.20	2.20	4.40	2.10
s.d	(1.19)	(1.03)	(1.40)	(1.26)	(1.19)

Figure 7. Second experiment - measure 5 results, (BP=Back-Projected, FP=Front-projected, FC=Feels correct, FIC=Feels incorrect).

A Cronbach Alpha test for internal consistency was found to not be significant (0.52). A principal component factor analysis was then conducted on the results. Similar subscales to the first experiment were found; questions 2, 3 and 4 (“naturalness of the display”), questions 1 and 5 (projection problems) and question 6 (how the display felt to touch). However, when the principal component factor analysis was conducted on each condition, this pattern was not found. This means that the questions will have to be analyzed separately.

Firstly, comparing between the four ‘touch’ conditions (i.e. not including the NoTouch condition), and hence investigating question 2. Levene’s test for equality of variance was conducted on each question and found no significant difference between conditions. Therefore a two-way between-participants MANOVA was conducted (see section 3.2.4 for justification of test). A significant effect was found for the FeelsToTouch IV for questions 2 ($F(1,36)=4.41, p<0.05$), 3 ($F(1,36)=5.48, p<0.05$), 4 ($F(1,36)=5.53, p<0.05$) and 6 ($F(1,36)=21.62, p<0.001$), but no significant effects were found for questions 1 and 5. No significant effects were found for the ProjectionDirection IV for any of the questions, and no significant interactions were found for any questions.

Now comparing the NoTouch condition to each of the four ‘touch’ conditions. A significant difference was found between the NoTouch condition and the Back-projected+FeelsIncorrect condition for questions 2 ($U(18)=20.00, p<0.05$), 3 ($U(18)=23.00, p<0.05$), and 6 ($U(18)=19.50, p<0.05$), but not for the other questions. A significant difference was found between the NoTouch condition and the Front-Projected+FeelsIncorrect condition for question 2 ($U(18)=14.00, p<0.05$), 3 ($U(18)=19.00, p<0.05$), and 6 ($U(18)=16.50, p<0.05$), but not for the other questions. No significant differences were found between any questions when comparing the NoTouch condition to the Back-Projected+FeelsCorrect condition, and to the Front-Projected+FeelsCorrect condition.

Condition	Mean (standard deviation)
Back-Projected+FeelsCorrect	3.42 (0.52)
Back-Projected+FeelsIncorrect	1.85 (0.67)
Front-Projected+FeelsCorrect	3.39 (0.64)
Front-Projected+FeelsIncorrect	1.69 (0.70)

Figure 8. Second experiment - measure 6 results.

4.2.3 Measure 6. (Figure 8). A within-participants ANOVA was conducted (see section 3.2.5 for justification of test). A significant effect was found for the FeelsToTouch IV ($F(1,49)=317.14, p<0.001$). No significant effect was found for the ProjectionDirection IV ($F(1,49)= 0.91, p=0.35$) and no significant interaction was found ($F(1,49)= 0.39, p=0.54$).

4.2.4 Measure 7. See figure 9.

4.2.5 Measure 8. 48/50 participants chose one or both of the sets of the vodka jellies that felt correct to touch.

4.2.6 Measure 9. 23/50 participants chose either one or both of the back-projected sets of vodka jellies, 10/50 participants chose either one or both of the front-projected sets, 17/50 participants said the four sets were the same.

4.2.7 Measure 10. 29/50 participants noticed the image on the back of their hand, and 34/50 noticed the shadows their hands cast on the PA model. A 2x2 Chi-Squared test found a significant relationship between noticing the image on the hand and noticing the shadows ($X^2(1)=20.00, p<0.001$). All of the participants noticed the vodka jellies did not all feel the same to touch.

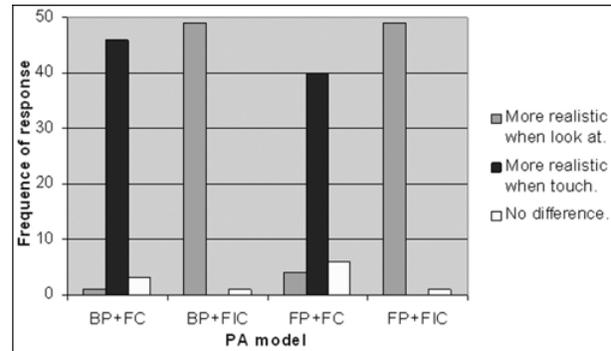


Figure 9. Second experiment - measure 7 results. (BP=Back-projected, FP=Front-projected, FC=Feels correct, FIC=Feels incorrect).

4.2.8 Comparing between measures. Splitting the data based on whether participants noticed the projected image on their hand showed no difference in the pattern of results, and neither did splitting the data based on whether they noticed the shadows that their hand cast on the display.

4.3 Discussion of the second experiment

The results of the second experiment are very similar to those of the first experiment. The participants accepted the scenario that they were told, which indicates that the results can be considered to be a fair reflection of a real task. Again, there was a slight possibility that using the design scenario could focus participants’ attention towards the visual projection problems, however, this did not occur.

This experiment also found that Inattentional Blindness occurred for a high number of participants and they did not notice the projection problems (measure 10, section 4.2.7). Again, this raised the issue that object-presence is concerned with whether participants can suspend their sense of disbelief when they encounter a problem, which they obviously cannot do if they have not actually noticed the problem. Therefore only the results of the participants who noticed the problems should be taken into consideration when addressing the research questions. However, similar to the first experiment, when the results were split based on whether the problems were noticed, the same pattern of results were found (section 4.2.8).

The results from measure 7 (figure 9) confirm the finding of previous work [13]; touching a simple PA model reduces object-presence. Considering how the results relate to the main research question: *Question 2. ‘When touching a PA model that represents a ‘haptic’ object, to what extent is a person’s sense of object-presence affected by the visual problems associated with the projection, and to what extent is it affected by the incorrect haptic feedback for material*

properties?. The two measures that aimed to directly address this question were the questionnaire (measure 5) and the ranking of the sets of vodka jellies based on the sense of object-presence that they induce (measure 6). However, the questions in the questionnaire cannot be considered together because it was found that they did not measure a unified construct (section 4.2.2). This means that the questionnaire cannot be used as a direct measure of object-presence.

Measure 6 found (section 4.2.3) the two sets of vodka jellies that provided correct haptic feedback for material properties, and hence felt correct to touch, were ranked significantly higher than the sets that did not. However, the direction of the projected image did not effect how the sets were ranked. The results indicate that how a 'haptic' PA model feels to touch is important, whereas the problems associated with the projection are relatively unimportant. The other measures generally support this conclusion.

The results from the questionnaire (measure 5) show a similar pattern. Although the questions cannot be considered together, the individual questions can be examined. The haptic feedback provided for material properties significantly affected the responses to the questions relating to how the vodka jellies felt to touch. Additionally, the results suggest the problems associated with the projection are relatively unimportant because no significant effect was found for the ProjectionDirection IV on any of the questions.

Further support for this pattern of results can be found by examining the effect that touching the vodka jellies had on object-presence, in comparison to when they were not touched (measure 7, figure 10). It was found that object-presence was lower when the two sets of vodka jellies that felt incorrect were touched. Whereas the problems associated with the projected image did not appear to reduce object-presence when the Front-Projected vodka jellies were touched.

Finally, when questioned separately about the haptic issues and projection problems, a similar pattern was found again. Virtually all participants reported that the two sets of vodka jellies that felt correct to touch, gave them a stronger sense that the objects were made from the correct material (measure 8, section 4.2.5); hence supporting the argument that the haptic feedback for material properties is important. Moreover, participants did not tend to select back-projected PA models when asked which set/s gives the strongest sense that the jellies are actually colored (measure 9, section 4.2.6), which supports the argument that the projection problems are relatively unimportant.

Similar to the first experiment, the only measures that do not support the general patterns of results are measures 3 and 4 (section 4.2.1). When asked questions about what they found more noticeable and what was their main memory of what they saw, the vast majority of the participants' responses were related to the colors (e.g. they remembered the green jelly). This suggests that how the vodka jellies felt to touch, or indeed the projection problems, were not considered important enough to mention. However, the participants were told that the experiment was investigating how people evaluate the

designs of vodka jellies, so it is again possible that they were responding to demand characteristics.

To summarize, when a PA model is touched which represents a 'haptic' object, object-presence is strongly affected by the haptic feedback provided for material properties, i.e. how it feels to touch. However, there is no evidence to suggest that object-presence is affected by the visual problems associated with the projection.

5. General discussion

The two experiments can be examined together to investigate the 3rd question: *'Does the extent to which object-presence is affected by the projection problems and by the haptic feedback for material properties differ depending on the type of object (visual/haptic) that the PA model is representing?'*. The overall pattern of results suggest that how a PA model feels to touch is the most important factor, and the projection problems are relatively unimportant (sections 3.3 and 4.3). In fact, Inattentional Blindness often occurred, and many participants did not notice the projection problems (sections 3.2.9 and 4.2.7).

However, the results do suggest that the projection problems are more of an issue for PA models that represent 'visual' objects, than for those that represent 'haptic' objects. It was found that if participants did notice the projection problems when using the 'visual' PA model (CD cases), they tended not to suspend their sense of disbelief when questioned directly (section 3.2.10). However, this did not occur when the PA model represented 'haptic' objects (vodka jellies) (section 4.2.8). Further support comes from measure 7. Measure 7 investigated whether the participants' sense of object-presence increased, decreased or stayed the same when touching each PA model, compared to when it was not touched. Touching the two 'haptic' PA models (vodka jellies) that felt correct always increased the participants' sense of object-presence (figure 9). Whereas when the participants touched the two 'visual' PA models (CD cases) that felt correct, similar numbers reported their sense of object-presence remained the same as those who reported it was increased (figure 5). This suggests that whilst providing incorrect haptic feedback for material properties will always decrease object-presence regardless of the object that the PA model represents, providing correct haptic feedback is more important for PA models that represent 'haptic' objects.

To conclude the answering of the third research question; the results suggest that how a PA model feels to touch is the most important factor regardless of the object that it is representing. However, the results support the original argument (section 2) that the projection problems are more important when a PA model represents a 'visual' object, and providing correct haptic feedback is more important when the PA model represents a 'haptic' object.

Focusing on the implications that the results have for PA models; the results suggest that technology needs to be developed to overcome the problems associated with a PA model feeling incorrect to touch. One possibility is to create the physical model which naturally provides haptic feedback for material properties, for example giving it a

physical texture. This is suitable for displays that have a fixed physical shape, and only their colour and visual information are altered. For example, a PA model that represents a fossil could have a fixed shape and only the text annotations on the fossil may be altered depending on whether an expert or novice is viewing it, e.g. [4]. However, this approach reduces the flexibility of a PA model to a level that may be unacceptable for some applications. Additionally, for many objects it is not possible to create a PA model that provides accurate haptic feedback for material properties because it would not provide a suitable surface on which to project an image.

An alternative solution is to provide some form of haptic feedback through a separate device. For example, a hand-held tracked tool could be used to provide vibration feedback to simulate the feeling of physical texture, e.g. [26]. Indeed, it has been found that humans are good at perceiving material properties, such as texture, through vibrations simulated using a probe [27]. Another solution is to use a visual cue to indicate texture. For example, a PA model could be interacted with using a normal mouse, whose cursor could be animated so that it deforms to suggest that it is moving over a textured object. This type of 'pseudo haptic' feedback has been shown to be effective for flat screen displays [28]. It should be noted that a user should not touch a PA model with their bare hand if haptic feedback is provided through a separate device because the illusion would be broken. However, the visual effect of the physicality that a PA model gives to computer graphics is still compelling.

The results also suggest that developing technology to overcome the projection problems may be useful when a PA model represents a 'visual' object. This could be achieved by using a back-projected PA model, however there are some practical issues that need to be considered. Firstly, back-projected PA models can only be constructed for a limited range of shapes because the projection needs to be directed from behind. Secondly, the projection has to travel through the PA model, which means the material the PA model is made from is important. These factors mean that the construction is more complex and probably best suited to 'one-off' installations, such as a museum display. An alternative to using a back-projected PA model is to track the users' hands and 'turn off' the pixels that would be projected onto them. This technique has already been developed for eliminating the shadows cast by people using flat projection screens [29]. Although this does not overcome the shadow problem, the results suggest that it is the projected image on a user's hand that reduces object-presence, as opposed to the shadows (section 3.2.10).

The results also have implications for the design of other types of computer generated displays. The results suggest that the object a display is representing should be taken into consideration when predicting the effect adding feedback to different modalities will have on object-presence/presence. However, the finding that participants always noticed how a PA model felt to touch suggests that when designing a haptic device, one cannot rely on people not noticing any inconsistencies in haptic feedback.

Finally, considering the results reported in this paper together with the results from previous research, predictions can be made about the effect of adding feedback to different sensory modalities to different types of computer-generated displays. Computer-generated displays range from '*non-realistic*' to '*realistic*', where realism is determined by the naturalness and unintrusiveness of the equipment, in addition to the fidelity of the graphics. A PA model is a type of realistic computer-generated display, whereas displays such as a head-mounted-display may be considered to be non-realistic because the user is required to wear the equipment. Sensory feedback can range from being '*basic*' to '*advanced*'. 'Basic' feedback is when feedback is only provided for one aspect of the environment, for example the PA models that felt incorrect to touch provided 'basic' haptic feedback for shape. Whereas 'advanced' haptic feedback is when feedback is provided for several aspects of the environment, for example shape and texture. Previous research has shown that 'basic' haptic feedback increases presence when added to a non-realistic computer-generated display e.g. [30]. However, the experiments reported in this paper found 'basic' haptic feedback reduced object-presence. This suggests the addition of 'basic' haptic feedback to a 'realistic' computer-generated display will reduce object-presence.

This argument supports Mori's 'uncanny valley' hypothesis, which predicts that the believability of a simulation increases as its fidelity increases, until it reaches a point where only the differences with the real world are noticed, and hence believability decreases [31]. Whilst this hypothesis originally comes from the field of robotics, it has recently been applied to virtual environments, e.g. [32]. With regards to haptic feedback, Mori theorized that a person can accept a realistic looking android as being human when they look at it, however when they touch the androids 'skin' and find it to be cold, it becomes very unrealistic and 'horrific' [31]. Thus it seems likely that adding 'basic' haptic feedback to a 'realistic' display will decrease a user's sense of presence/object-presence because they will only notice how it differs from the real world. For example, a person viewing an extremely realistic looking cushion 'placed' on a real chair through a light-weight unintrusive Augmented Reality display, may feel that they are viewing a real cushion. However, if only 'basic' haptic feedback is provided, for example it feels hard and solid as opposed to feeling soft, when the user 'touches' it the sense that they are perceiving a real cushion may disappear. This suggests the assumption that the addition of feedback to extra sensory modalities always increases presence is flawed, and caution needs to be taken when considering the value of adding such feedback to 'realistic' computer-generated displays. This will become more important as displays become more 'realistic'.

Conclusion

Currently Projection Augmented models are nearly all front-projected, and do not provide haptic feedback for material properties and hence feel incorrect to touch. This research compared the effect the projection problems and

incorrect haptic feedback for material properties have on a user's sense of object-presence. It was found that overall for both PA models that represent 'visual' objects and those that represent 'haptic' objects, the incorrect haptic feedback for material properties is always the most important factor. However, the results also indicate that the projection problems are more important when a PA model represents a 'visual' object, and the providing correct haptic feedback is more important when it represents a 'haptic' object. Suggestions as to how technology could be developed to overcome these problems, and the implications the results have for other displays were discussed.

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