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The effect of digital design representation on designers' visual attention

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Abstract: This paper presents the results of an exploratory study on the effect of observing different digital design representations on designers' visual attention. Forty-five third-year and fourth-year architecture students participated in an experiment, in which they were asked to view a floorplan, a computer-generated hidden-line perspective, and a digital photograph of the same space in varying orders. Their eye-tracking data was recorded using a Tobii eye-tracker. The results indicate that complex spaces receive more attention and foreground areas attract designers' visual attention more quickly than other spaces.

Keywords: digital design representation; visual attention; eye-tracking

1. Introduction

Design representation is a core issue in most design domains including product design, architecture and engineering. It is considered as an essential tool to support design thinking (Visser, 2006), reflection in action (Schön & Wiggins, 1992), facilitate dialogues of the designer with him/herself (Schön & Wiggins, 1992), and to communicate design intent to design team or clients (Cross, 2000). Past studies suggest that visual representations during the design process assist designers with their concept development (Schön, 1992). By exploiting the information of the design representation, the experienced designer can explore an infinite world of ideas and concepts (Akin, 2001). With the growing application of computational design tools, digital design representations are increasingly being used in the design process. One of the methods that can be used to explore the effects of different representations is to look into designers' physiological response such as eye movement, when they view different digital design representations. For example, Park et al. (2019) has explored the role of digital design representation in the architecture design process using eye tracking technology. The results of their study suggest that line drawings both attract and deflect visual attention, and practical drawing techniques have direct effects on visual perception. Using eye tracking technology to follow designers' visual attention, it is possible infer some of their design intentions. For example, Yu and Gero (2018) explored how a computer-aided tool is used by designers when they are carrying out architectural design tasks, by studying designers' eye movements. Their results suggest that designers spend more effort focusing on façades and relatively less on edges and corners, and that their eye gazes are focused primarily on the model, with only a few eye gazes at the menu of the user interface.

Despite the earlier research on the topic, currently there is a lack of knowledge regarding designers' physiological responses as they view different digital design representations of an architectural space. Also, given that architecture students view images of multiple designs and multiple images of the same design, what is not known is whether the order in which images are viewed affects their responses. We conducted a study utilizing eye tracking to collect physiological data, comparing responses to different digital design representations in varying orders. Researchers have been interested in how designers look at scenes (Rensink, 2000). Experiments typically present the scene on a computer screen, allowing for a high level of control over variables of the scene. The aim of this research is to determine the effects of different representation modalities and order of viewing images on the physiological response of architecture students as measured by eye-tracking. From the analysis of the relationship between designers' eye tracking data and different modalities of representation, designers' responses to digital design representation in varying order will be measured and compared. The remaining sections of the paper will describe the research background, experiment setting, analysis of the eye tracking data, and conclusions.

2. Research Background

2.1. Visual attention studies based on eye tracking

Early research into visual attention based on eye movement can be traced to Buswell (1935), who focused on the aesthetic impact of photographs of artwork, patterns and sculpture, particularly the layout patterns of advertisements. Kaufman and Richard (1969) measured eye fixation times in several pre-defined parts of figures. They identified that the centre of gravity is an attractor, as are the edges and corners.

Torralba et al. (2006) proposed visual attentional guidance through an experimental search task. Results of their study suggest that contextual information plays an important role in object detection and observation, and some parts of the scene attract more attention than others. While the relationship between eye movement and perception of artworks has been investigated, there has been very little study on the role of eye movement in the perception of three-dimensional architectural space. One of the few studies on this topic was conducted by Weber, Choi, and Stark (2002) in which they collected eye tracking data as participants were asked to look at three-dimensional models, or photographs of models, of architectural space. These models were constructed to collect data on the perception of the following architectural issues: empty space; symmetry vs. asymmetry; left and right reversed; obliquely-oriented elements; vista; and foreground. The research focused on comparing different arrangements of objects within a space, rather than different methods of representing the same spatial configuration. Their results showed that, the attention would fixate at the center; while the foreground was common for initial fixations, the eye did not typically scan the edges of interior space or rectilinearly-oriented contours; the objects on the left attract more attentions than the ones on the right. This confirmed the results by Arnheim (1985), who also claimed that fixations did not vary significantly when viewing the three-dimensional model compared with a photograph of the model, with the exception of the foreground, which attracted greater attention in the 3D model.

To explore the correlation of designers' visual attention with their design thinking process, Guan et al. (2006) studied the validity and reliability of the retrospective think-aloud method, based on design experiments in which participants' eye movements were recorded and then they thought aloud as they viewed their eye tracked activity. Results of the study show that the recounting of what went on in the exercise was consistent to the sequence of objects in the same order, and that the differing level of complexity did not interfere with the validity of the retrospective think-aloud method. Eye movement can also be used to measure the emotional response of visual stimulation. For example, Tuszyńska-Bogucka et al. (2020) conducted an eye tracking experiment to measure respondents' reactions while looking at visualisations of various interiors, with the aim of verifying whether certain parameters of an interior are related to emotional reactions in terms of positive stimulation, and the sense of security and comfort. The authors concluded that architectural spaces can have a diverse emotional significance and impact on an individual's emotional state.

2.2. Digital design representation

Design representations are made before, during and after the process of designing. External design representation is particularly necessary for the purpose of communication in a design collaboration setting, as well as a means of conversation with themselves for individual design processes (Goldschmidt & Porter, 2004). Design representation serves both as a tool for design thinking and communication (Self, Lee, & Bang, 2015). Traditionally designers use sketching as their main design representations, since sketching is an effective way of amplifying and extending mental imagery, not only a document for ideas but also generating them (Do, Gross, Neiman, & Zimring, 2000; Fish & Scrivener, 1990). Sketching as a design representation plays an important role during conceptual design, because of its ambiguous nature, semantic density and ability for transformations between and among design ideas.

With the development of computational modelling, digital design representation becomes possible during the design process, which assists designers in both off-loading cognition and providing the possibility to interact with their external representations (Schön & Wiggins, 1992). For example, BIM technology enables 3D (model check, design view, enhanced reality) and 4D visualization (plus time) (Eastman, 2008). Virtual reality (VR) can provide realistic virtual environments which enable navigational possibilities (Wang & Dunston, 2013). Augmented reality (AR) can enhance the user's perception by complementing the real world with 3D virtual objects in the same space (Morrison et al., 2011). These computational design tools allow designers to more readily explore design ideas and assist with the concept development of their designs. Digital design representation serves a similar purpose as traditional design representation such as sketching, in terms of facilitating design thinking and communication. However, to date there is insufficient knowledge about the physiological effects of digital representations on designers.

3. Experiment setting

To address this knowledge gap, we conducted an exploratory eye tracking experiment to examine the effect of digital design representation on designers' visual attention. In this study, 45 third-year and fourth-year architecture students at Harbin Institute of Technology (HIT) in China participated. The students were divided into three groups of 15 students per group. During the experiment participants were asked to complete demographic questions regarding their age, gender and native language. They were required to look at three images shown on a screen, Figure 1: Image 1 was a computer-generated floorplan, Image 2 was a computer-generated perspective drawing, and Image 3 was a digitised photograph of the same space when fully built.

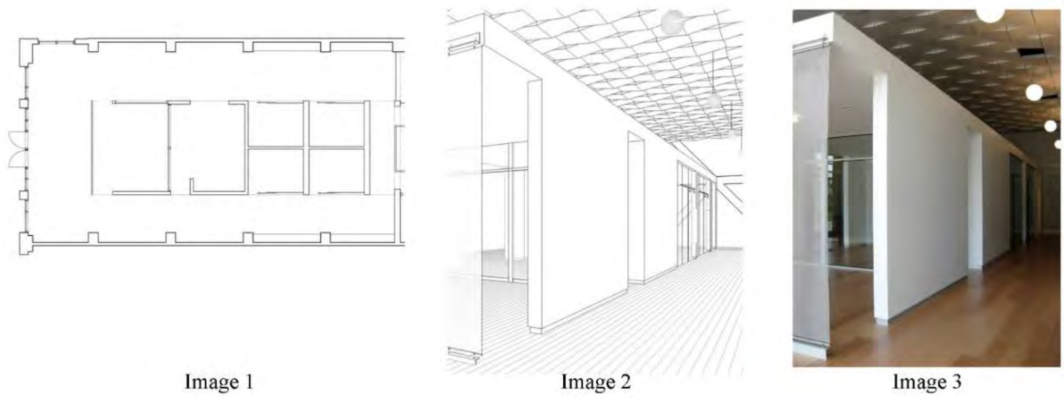

Figure 1 Images 1, 2 and 3

When the participants looked at the images, their eye tracking data was recorded by an eye tracking system (Tobii studio). Each of the images were displayed for 20 seconds, with a few seconds for recalibration in-between them. The images were shown in a different order to each group: the first group of participants were first shown Image 1 then Image 2. The second group was first shown Image 1 then Image 3, and the third group was shown Image 2 and then Image 3. Figure 2 shows the experiment setting.

Figure 2 Experiment setting

Data collected during each session included eye fixations and saccades. For Images 2 and 3, we identified seven Areas of Interest (AOIs) in the visual scene presented, Figure 3. Each AOI defines an area where we wanted to gather data. AOIs defined the three doorways, the two wall surfaces between them, the terminus of the corridor and the ceiling.

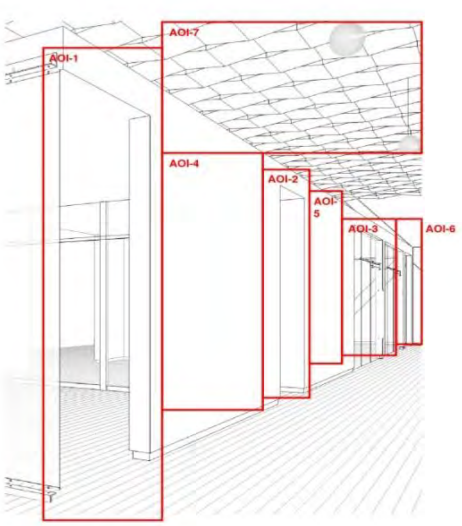

Figure 3 The seven Areas of Interest labelled AOI 1 through AOI 7 in Image 2, they occupy the same positions in Image 3.

4. Results

Figures 4 to 6 are the heatmaps of designers' viewing of the images in three of the different orders. Heatmaps represents the cumulative focus of visual attention of participants.

From a heatmap we can qualitatively observe that the participants' eyes focus area are similar regardless of the order of viewing of the images. This suggests that differences related to the viewing order are minor. For both Image 2 and Image 3, regardless of viewing order participants tended to focus on the complex spaces, such as AOI 3 and AOI 1. While for Image 1 which shows the floorplan, participant's eye gaze was located in the middle of the image, with a focus on spaces rather than edges.

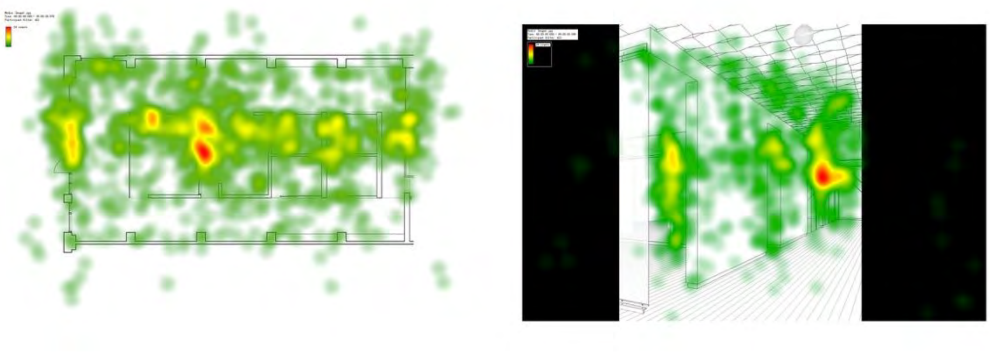

Figure 4 Heatmap for Image 2 (right) after viewing Image 1: experiment 1-2.

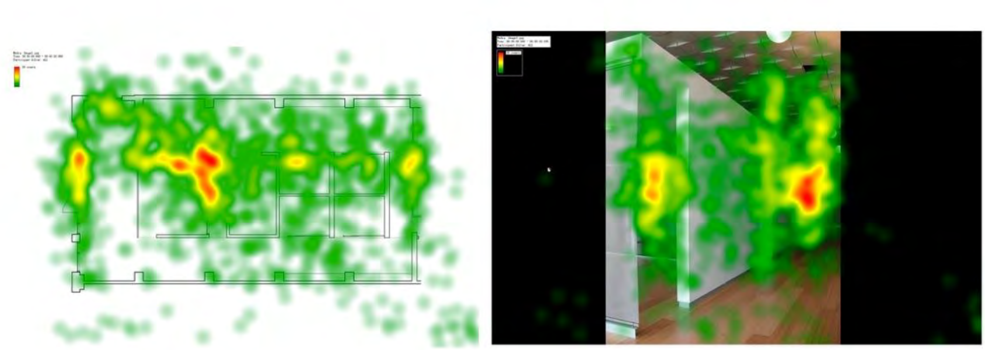

Figure 5 Heatmap for Image 3 (right) after viewing Image 1: experiment 1-3.

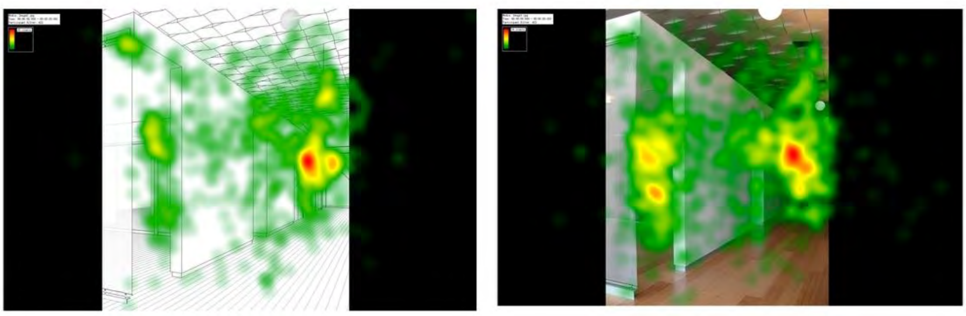

Figure 6 Heatmap for Image 3 (right) after viewing Image 2: experiment 2-3.

Tables 1 and 2 present the results of eye-tracking data for Images 2 and 3 in the three viewing orders. Four metrics for eye movement data were measured during the experiment: Time to First View (secs), Time Viewed (%), Fixations and Average Revisits. Time to First View measures how long it takes before a participant fixates on an active AOI for the first time. Time Viewed (%) is the percentage of time viewed within an active AOI of the total viewing time (total viewing time was 20 seconds in this experiment). Fixations measure the number of times the participant fixates on an AOI. The Average Revisits measures the number of visits within an active AOI. A visit is defined as the time interval between the first fixation on the active AOI and the end of the last fixation within the same active AOI where there have been no fixations outside the AOI.

From Table 1 we can see that in the experiments where eye tracking was measured related to Image 2, AOI 3 is the first area of interest viewed irrespective of the order of viewing that participants looked at. AOI 1 is an opening with a complex space behind it, so would be expected that it would be a primary visual attractor. This is not the case here. Participants were initially attracted to AOI 3, which in Image 2 is a visually complex opening where the space behind it is unclear. AOI 3 was more attractive, presumably because the opening and the space behind required more cognitive effort to understand. AOI 6 is the last area to be viewed in both cases. It is the back wall of the hallway and has no distinguishing characteristics, so this result is to be expected. In experiment 2-3, AOI 3 has the longest time viewed, while in experiment 1-2, AOI 1 has the longest time viewed. These two AOIs have similar architectural features, i.e., they both are openings with spaces behind them. For both experiments, AOI 1 receives the most fixations. This may be because AOI 1 is in the front or the space through the door is relatively complex. The AOI with least fixation and time viewed is AOI 5 in both experiments, which may be due to the simplicity of the space of AOI 5. For both experiments, AOI 1 and AOI 3 show high revisit numbers presumably due to the complexity of the space behind them.

Table 1. Average eye-tracking data of participants – Image 2

Experiment	AOI name	Time to First View (secs)	Time Viewed (%)	Fixations	Revisits
Image 2 followed by Image 3; experiment 2-3	AOI-1	1.80	19.28	15.40	6.20
	AOI-2	2.45	6.94	5.27	4.00
	AOI-3	0.76	23.65	12.80	8.13
	AOI-4	1.28	5.37	5.27	3.87
	AOI-5	2.63	2.60	2.27	1.93
	AOI-6	6.27	7.42	5.73	3.27
	AOI-7	3.45	11.53	9.40	4.33
Image 1 followed by Image 2; experiment 1-2	AOI-1	1.03	26.76	21.53	6.80
	AOI-2	3.92	7.15	6.47	4.07
	AOI-3	1.14	19.22	10.87	6.07
	AOI-4	1.59	6.71	7.33	4.93
	AOI-5	2.95	1.59	1.40	1.33
	AOI-6	5.58	5.82	4.20	2.67
	AOI-7	1.55	12.67	10.00	4.27

From Table 2, we can see that for Image 3, unlike for Image 2, AOI 1 was the first to be viewed in one case, while AOI 4 was the first viewed in the other case, indicating that the sequence on viewing affects the how an image is viewed. AOI 6 was the last AOI that participants looked at in one case, while AOI 2 was the last viewed in the other case. In both experiments, AOI 1 received longest time viewed, highest number of fixations and the highest number of revisits. This indicates that AOI 1 attracted the visual attention of the participants more than any other area. AOI 1 is an opening with a complex set of spaces behind it that requires more cognitive effort to read. This higher cognitive effort is reflected in these results.

Table 2. Average eye-tracking data of participants – Image 3

	AOI name	Time to First View (secs)	Time Viewed (%)	Fixations	Revisits
Image 2 followed by image 3;experiment 2-3	AOI-1	1.03	32.79	35.87	9.13
	AOI-2	5.52	4.62	6.00	4.00
	AOI-3	1.51	14.33	13.40	7.87
	AOI-4	0.43	7.27	9.73	5.47
	AOI-5	4.85	2.47	3.93	3.27
	AOI-6	4.92	4.76	5.07	3.67
	AOI-7	3.94	8.79	8.33	4.20
Image 1 followed by image 3; experiment 1-3	AOI-1	0.52	25.99	23.67	9.00
	AOI-2	3.74	7.02	5.87	3.60
	AOI-3	3.18	14.62	10.93	5.67
	AOI-4	1.09	5.88	7.20	5.07
	AOI-5	2.56	3.68	3.73	3.33
	AOI-6	9.63	3.65	2.87	2.00
	AOI-7	5.78	9.18	9.20	3.67

To further explore the effect of viewing order on designers' visual attention, we conducted paired t-tests to determine statistically whether the eye-tracking measurements of the same images when shown in different order are significantly different.

Table 3 shows the paired t-test comparison of Image 2, when viewing Image 1 to Image 2 and Image 2 to Image 3. From the table, we can see that time to first view only for AOI 7 is significantly different between the two experiments. Showing the floorplan before the computer-generated perspective, has a small effect on how Image 2 is read. There is a significant difference in revisits only for AOI 3. There are no other statistically significant differences.

Table 3. Paired t-test comparison of Image 2 when viewing Image 1 then Image 2 and viewing Image 2 then Image 3

	Sig. (2-tailed)						
	AOI 1	AOI 2	AOI 3	AOI 4	AOI 5	AOI 6	AOI 7
Time to First View	.423	.403	.163	.742	.869	.761	.015*
Time Viewed (%)	.136	.917	.256	.451	.386	.566	.672
Fixations	.352	.507	.223	.129	.309	.447	.833
Revisits	.843	.946	.011*	.316	.379	.461	.939

*$p<0.05$

Table 4 shows paired t-test comparison of Image 3, when viewing Image 1 before Image 3 and viewing Image 2 before Image 3. From the table, we can see that there are no significant differences in the eye tracking measurements, except for time to first view of AOI 6. The difference in AOI 6 means that designers who view the floorplan first, will look at AOI 6 much later. This may due to the understanding provided by the floorplan reducing curiosity about the complex space.

Table 4. Paired t-test comparison of Image 3 when viewing Image 1 then 3 and viewing Image 2 then 3

	Sig. (2-tailed)						
	AOI 1	AOI 2	AOI 3	AOI 4	AOI 5	AOI 6	AOI 7
Time to First View	.772	.343	.151	.068	.230	.026*	.367
Time Viewed (%)	.185	.547	.913	.576	.267	.397	.888
Fixations	.090	.184	.564	.304	.905	.186	.784
Revisits	.904	.624	.163	.754	.957	.139	.613

*$p<0.05$

5. Conclusion

This paper presents the results of an exploratory study, aiming to examine the effect of digital representations on designers' visual attention. From analysing eye tracking data of participants, the following conclusions can be drawn:

Firstly, when designers are viewing images, complex spaces usually receive more visual attention, for both perspective drawing and photographic images. This finding aligns with Gero, Sheilds, and Yu (2016), who suggested that eye fixation is focused on complex spaces. Certain features are more likely to attract the eye focus, for example on a face image the eye focus is usually on "eye" and "mouth" (Gould & Peeples, 1970). In architecture, past studies suggest that architects pay more attention to the spatial arrangement of various architectural elements (Weber et al., 2002).

Secondly, complex spaces in the front of an image are likely to attract attention faster, for both perspective drawing and the photographic image. This complies with Weber et al. (2002)'s study which showed that the foreground was common for initial fixations. Gould and Peeples (1970) suggest that a subject's interpretation of a figure does not affect eye movements, which means that only "physical attributes" have influence on the eye movements. This means the foreground space which attracts more attention may not be affected by the interpretation of designers.

Thirdly, the order of displaying images had only a minor effect on designers' attention. For most of the areas, designers' visual attention did not change based on varying the order of images shown. However, differences were found in two AOIs, suggesting that displaying the floorplan first affects their later reading of the 3D space. This may possibly also be a result of all participants being architectural students who understand floorplans and have enhanced capabilities to imagine such spaces.

The findings of this research have provided a preliminary understanding of designers' visual attention for different digital representations. Digital representation plays an important role in designers' design processes. This study has measured designers' visual attention on various types of digital representations and examined the effect of different viewing orders for the digital representations shown to the designers. The results of this paper add to our understanding of designer's visual attention, providing insights for design cognition studies.

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