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Implementing Eye Tracking Technology in the Construction Process

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During the last decade, eye tracking technology has undergone rapid development and growth that has increased its popularity amongst practitioners and researchers from a wide variety of disciplines. In spite of widespread applications of eye tracking in the computing and human factor domains, considerably less attention has been paid to the potential of this technology to improve the design and construction processes. Currently, the ability of using eye trackers in construction applications is limited due to the lack of knowledge about this technology and its potential benefits. This paper provides an overview and guidance for the implementation of eye tracking technology in the construction process. The description of the technology and its current applications are also provided, with a brief discussion of potential application and the limitations. A description of a use case example is provided to investigate the use of eye tracking technology to measure and analyze the end-user satisfaction in the design process. This study provides the construction industry with information about how to design an eye tracking experiment and analyze the data generated by the eye tracking tools.

Keywords: Eye Tracking, Data Collection, Visual Attraction Experiment, Construction Management

Introduction

During the last decade, eye tracking technology has undergone rapid development and growth that has increased its popularity amongst practitioners and researchers from a wide variety of disciplines. Eye-tracking is the process of measuring the point of gaze (the spot a subject is looking at), and an eye tracker is a portable hardware device that performs this measurement by measuring eye movement (Murray et al. 2009). Eye-tracking is a great method to assess the eye movement (as a dependent variable) in the anticipation of stimuli (as an independent variable). Even though the application of eye tracking technique has been recognized in a wide variety of domains and the use of this technology has become prevalent in a number of industries, considerably less attention has been paid to its potential to improve the design and construction processes. Eye tracking science development is categorized into four periods, 1) finding of basic eye movement, 2) applied research development 3) eye movement recording systems enhancement, 4) increase in eye-tracking technology and its applications (Rayner 1998, Duchowski 2002).

Eye tracking is used to measure eye movement and eye positions and has several applications in aviation, driving safety, inspection, marketing, neuroscience, psychology, and others. Summary of eye tracking applications, its usage, and associated manufacturers are summarized in Table 1. Visual search has drawn much attention from researchers, who have attempted to examine the observer's cognitive process with the vast amount of visual information. This is a novel technology to analyze user's eye movement data in the disciplines of aviation, inspection, neuroscience, and psychology. The use of eye-tracking is highly recommended for design and marketing applications. Conducting a usability study with this technology provides an efficient way to understand where users actually look, for example, when they view a mobile device or a web page. Visual perception is another widely used application of eye tracking, often employed in simulation training and driving safety. The following section gives a brief overview of the eye-tracking technology. Then, along with description of data output, the main steps involved in conducting an eye-tracking research project are discussed. A flowchart illustrating the overall procedure for selecting the right eye-tracking system is developed in section 5. Finally, a description of a pilot test is provided to investigate the use of eye tracking technology to measure and analyze the end-user satisfaction in the design process.

Table 1

Summary of eye tracking applications

Application	Usage	Manufacturer
Aviation	• Detection of unexpected events (Thomas and Wickens 2004) • Eye-tracking technology in a flight simulator (Anders 2001)	• Pupil • SMI • TrackEye
Driving safety	• Eye tracking in a driving simulator (Duchowski 2002; Palinko et al. 2010)	• Pupil • SMI • TrackEye
Inspection	• To find the eye movement pattern during visual inspection (Duchowski et al. 2000)	• ASL • openEyes • SMI • TrackEye
Linguistic and bilingual research	• To explore bilingual speakers process linguistic input (Marian et al. 2003) • To understand the interaction between bilingualism and inhibitory processing of visual attention (Hernandez 2009)	• SMI • Tobii Technology
Marketing	• Web design • Product design • Mobile advertising • Print advertising • Advertising related to TV Sports	• ASL • S2 Eye Tracker • SMI
Neuroscience	• To identify functional brain structures implication in attentional behavior (Duchowski 2002) • To study eye fixation on the autism (Boraston and Blakemore 2007)	• Chronos Vision • SMI • Tobii Technology
Psychology	• Visual patterns in people with schizophrenia (Chen 2011; Richard et al. 2014)	• Chronos Vision • SMI • Tobii Technology

Eye Tracking Technology Description

The eye-tracking technology encountered some problems in the beginning stages with the researchers running self-built eye-trackers. Also, the interpretation of the data output from an eye-tracking system required some technical skilled until the researchers acquired a better understanding of the system knowledge on the user part. Improvements in the hardware and software technologies and eye tracking data analysis methods have increased the use of this technology and enabled researchers to focus on their research efforts rather than technical issues.

The main measurements used in eye-tracking researches are “fixations” and “saccades”. A fixation is when the user’s gaze is relatively motionless on a specific area and a saccade is a quick movement between fixations to another element (Ehmke and Wilson 2007). There are other eye movement events that stem from these basic measures, including “gaze”, “glissade”, “smooth pursuit” and “blink rate” measurements (Poole and Ball 2005). A brief description and typical values of these eye movement measurements are summarized in Table 2.

Table 2

Description and typical values of the common use of eye tracking measurements [adopted from (Holmqvist et al. 2011)]

Measurement	Description	Duration
Fixation	Eye movements with a series of short stops pauses in specific positions	200-300 ms
Saccade	Eye movement from one to another positions	30-80 ms
Gaze	The eye gaze pauses in a certain position,	-
Glissade	A gliding unintentional eye movement in replacing the point of fixation	10-40 ms
Smooth pursuit	Eye movements following a moving object	-

Several factors can affect the quality of the data. Examples of these factors include accuracy and precision of eye tracker, resolution of the system, and lighting level of the experiment room. The accuracy of an eye tracker refers to the difference between the actual gaze position and what the eye tracker captured as the gaze position. Accuracy is measured in the degrees of viewing angle (Mantiuk et al. 2013). For an eye tracker with one degree of average accuracy and distance of 28 inches from the monitor, the actual gaze location could be anywhere within a radius of 0.5 inch from its captured position. The saccade resolution shows the ability of system to detect saccade movement. For instance, an eye-tracker with 0.1^0 saccade resolution can detect movements as small as 0.1^0. The sampling frequency (measured in hertz) is the average number of samples (e.g. gaze direction) in one second. Thus, a 50 hertz (Hz) eye-tracker records a particular eye movement (or sample) 50 times per second. An eye movement is registered once every 20 ms. Many modern eye-tracker systems have sampling frequencies ranging from 25 - 2000 Hz (Andersson et al. 2010).

Data Recording and Outputs

Three steps are involved in conducting a research project using the eye tracking technology. First, the relationship between participant's eye-positions and scene coordinates are measured through a calibration procedure. The calibration is then followed by eye tracking and data recording. Finally, all collected eye tracking data is analyzed and subsequently presented in meaningful context. A calibration procedure for each individual is required in order to obtain a valid eye movement data before using the eye-tracker. Pupils of the eyes as well as corneal reflection are the main factors that eye trackers are designed for. Anything such as glasses and lenses that might disrupt the pupil and corneal reflection will make the calibration very difficult. In this case, the eye tracker needs to be relocated or change its angle to remove the reflection. The calibration procedure starts with the participants sitting relaxed on a chair and asked not to move while the user's eyes can be seen clearly in the camera. Consequently, the participant looks at 9 calibration spots on the screen (the number of corresponding points can be varied depends on the model of eye tracker and adjustment of the devices).

The eye tracking system can record a participant's visual behavior throughout different eye movement measurements (as listed in Table 2). Once calibration is complete, areas of interest (AOI) are defined to further analyze the gaze data for those attributes of interest, for example to compute the number of fixations and the fixation duration spent on the AOI. Figure 1-left shows three AOI as the static polygons encompassing the exterior walls, windows, and roof. While this static format is sufficient for most eye-tracking applications, it does not provide information for dynamic scenes and objects moving relative to the participant. For applications such as video simulation and outdoor scenes, a dynamic AOI may be preferred. As can be seen from Figure 1, AOIs are defined slightly larger than the objects of interest to ensure that we can record even eye movement data that are not completely on the AOI. The recorded eye tracking data for each AOI can then be exported to a desired format for further analysis. Figure 1-right shows the average percentage of time spent by the participant on each AOI. The use of eye movement data in combination with other types of data is a standard approach for facilitating a complete interpretation of the experimental data. The combination of eye tracking and mouse click data offers a promising approach for human computer interaction and usability research. The eye tracking system can be equipped with a microphone for audio (or verbal feedback) collection. An interactive 3D environment may require a combination of eye tracking and motion measurement sensors.

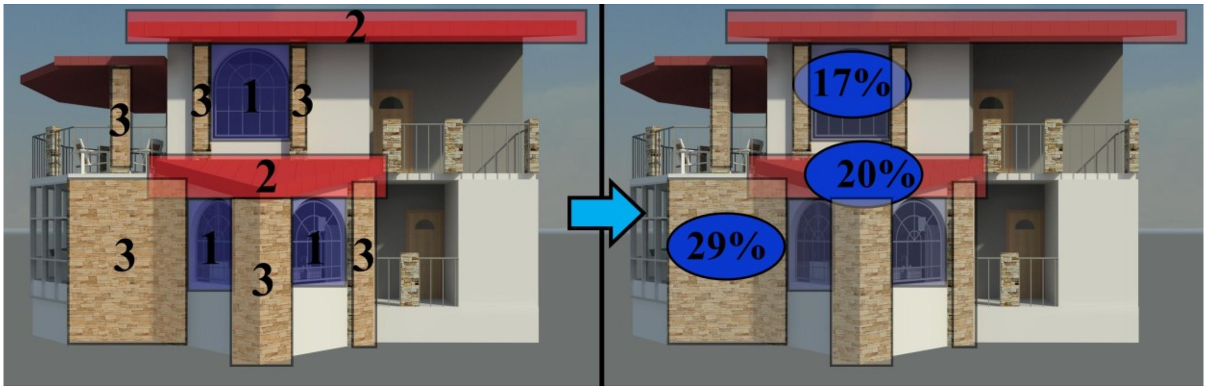

Figure 1: Areas of interest (AOI) polygons (left) and eye tracking data (right)

Heat maps (or hot spots) and gaze plots (or scan path) are two widely adopted visualization techniques for eye tracking studies. Heat maps show the areas with a large amount of interest and the aggregate eye fixations of those areas (see Figure 2-left). The eye-tracking software could automatically create a heat map based on the recorded gaze positions and then superimpose these maps on the stimuli used in the eye tracking experiment or test. Depending on the type of eye tracking software being used, heat map visualizations can be applied for slide shows and web pages or even for scenes within a screen movie (Manhartsberger and Zellhofer 2005). Gaze plots are line-based visualizations that connect fixations (illustrated with dots) and their sequence (illustrated with lines) and summarize the participant's eye-movement data related to the AOI. Each fixation dot is superimposed on the visual stimuli where the size of the dots represents the fixation duration (see Figure 2-right).

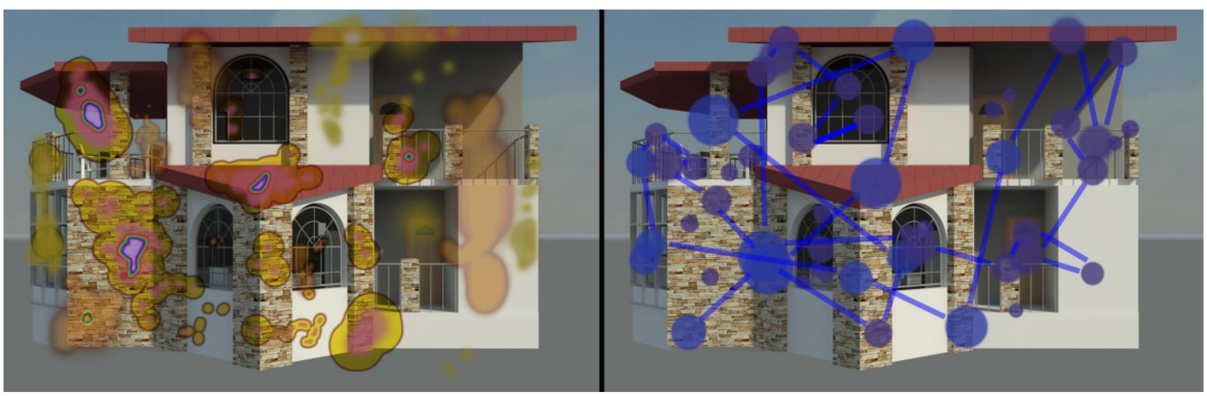

Figure 2: Heat map (left) and gaze plot (right) visualization techniques

Eye-Tracking System Selection

This section describes the types of eye-trackers and their properties for the development of a high quality research within the construction industry. The flowchart in Figure 3depicts a system selection process that works best for an eye-tracking application. Once a potential application is identified (step 1), we need to select a static or head-mounted (mobile) eye-tracker (step 2). Both static and head-mounted eye-trackers have an infrared or near-infrared illumination to create reflections in the eyes and a video camera to record one or both eyes' movement. Unlike the static eye-trackers that put the illumination and the video cameras on the table and usually in front of the participant, they are mounted on a helmet or glasses worn by the participant in the head-mounted eye-trackers. Therefore, the static eye-tracking systems can be used for on-screen studies on PC or laptop monitors like excavator or crane training simulation (step 3) and mobile eye-tracking systems are ideal for implementing the application in a real-world environment like walking in a construction site (step 4). The static eye-tracker is classified further into "remote/head free" and "head-supported" (restricted head movement) types. When the accuracy and saccade resolution are the most important considerations, the head-supported systems provide the greatest data quality by restricting the participant's head movement while being less realistic and natural (step 5). The average accuracy of a head-supported eye-tracker ranges from 0.25^0 to 0.5^0 that provides more accurate data than a remote/head free eye tracker (average accuracy around 0.5^0). The saccade resolution of a typical head-supported eye-tracker is two to five times more than a remote/head free eye tracker.

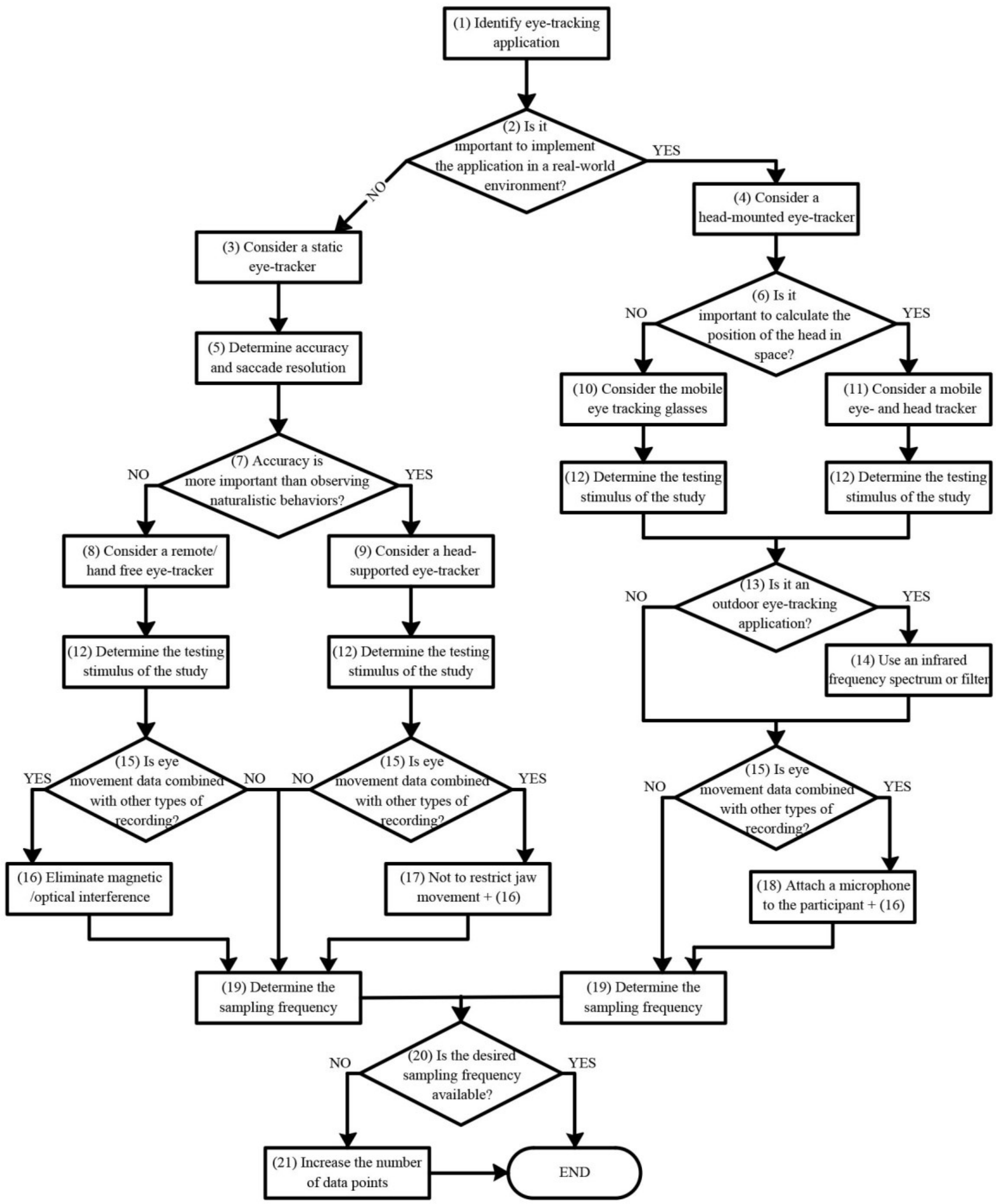

Figure 3: eye-tracking system selection flowchart

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There are circumstances (e.g. virtual reality applications) where it is important to determine the 3D coordination of the participant's point of gaze in respect to the objects in a real environment (step 6). In this case, a head-tracker is added to the mobile eye-tracking system. Although there are ergonomic issues related to mobile eye-trackers equipped with head-trackers or sensors, knowing the position of head facilitates, the calibration process improves the accuracy of eye tracking results. On the other hand, mobile eye-tracking glasses are lightweight systems consist of an illumination and an eye camera that records the scene image. These eye-trackers show the scene view with a superimposed gaze cursor, but they don't provide point of gaze location. The experimental stimulus is one of the important criteria in eye-tracking system selection (step 12). When using a head-supported eye-trackers (e.g. tower mounted eye-tracker), the stimuli are limited to 2-dimensional representations with artificial scenes (e.g. still-image viewing and video shown on a monitor). Absolute natural or real environment is often difficult to achieve in practice, but remote eye-trackers provide a more flexible solution than head-supported systems, where simulations and other virtual environments can be used as stimuli. Trade-offs between natural and artificial scenes must be made throughout the selection process; each has its own benefits and drawbacks. Head-mounted eye-trackers enable us to choose stimuli of real-world events, such as operating construction equipment on a job site, and make it possible to generalize the results across different experimental scenes while artificial scenes can be effectively used to manipulate the stimuli and other features.

Most of the eye-trackers are designed only for indoor use. The level of exposure to the infrared light, along with many other factors such as the contact lenses and glasses affect the quality of the data. The infrared radiation from sunlight makes it difficult (and many times impossible) for the infrared illumination to track reflections on the eyes. When it is not possible to conduct an experiment on a cloudy day or without exposure to the sunlight, it is necessary to use an infrared frequency spectrum or filter to alleviate the effect of sunlight on the eye-tracker (step 14). It is also recommended to use shading windows or no windows at all to prevent excessive sunlight gain for the static eye-trackers. The next step in the selection of eye-tracking system is for recording other types of data concurrently and in a manner that allows interaction with the eye movement data. Thinking aloud, for example, can be done concurrently during eye-tracking recording to understand what the participant is thinking while performing tasks. In this case, voice (verbal) data and eye movement are combined into one experiment. There are also many application cases for using motion trackers to capture user movements along with eye movement. If eye movement data is combined with other types of data (e.g. verbal, motion, etc.), possible task interferences should be taken into consideration in the system selection process. The eye-trackers are susceptible to magnetic and optical interference from optical and magnetic motion trackers in the environment (step 16). When using a head-supported eye-tracker, the forehead rest should be loose enough to not restrict the jaw movement (step 17). In addition, with a head-mounted eye-tracker, an additional microphone can be employed to collect participant's speech and detect environmental noise (step 18).

It is relatively straightforward to determine the speed of particular eye movement (refer to Table 2), in spite of the sampling frequency or amount of data selection (step 19). For oscillating eye-movements, such as tremors, we can refer to the Nyquist-Shannon sampling theorem (Shannon 1949) in which the sampling frequency should be at least twice the speed of the recorded movement (e.g., eye movements at 50 Hz requires >100 Hz sampling frequency). When using a video or animation analysis, the sampling frequency should be more than (preferably twice) the frame rate. Thus, if we use a common standard rate of 24 frames per second (FPS), a 50 Hz (or higher) eye-tracker is preferred. If we have the number of data points, we can use the following equation developed by Anderson et al. (2010) to determine the minimum sampling frequency:

$$f_s = \sqrt{\frac{c}{N}}$$

Where f_s is the sampling frequency, c is the constant 1208500, and N is the total number of data points. For example, if we conduct an experiment with 16 participants tested in 85 trials each (e.g. 85 fixation or saccade durations), then the total number of data point (N) are 16×85= 1360 and the minimum sampling frequency is 30 Hz. If the desired sampling frequency is not available, we should increase the total number of data points (step 21). Finally, it is important to start with a small-scale pilot study to evaluate the feasibility of implementing eye-tracking in the construction process.

Use Case Example

Assume we would like to measure and analyze the end-user attention during the design process. To test the hypothesis that the users' satisfaction of design variations is related to their visual attention, the users are asked to rate their level of satisfaction with each design alternative, while their interaction with the virtual models is recorded using eye-tracking. Based on the findings of the use case example, we might be able to conclude that design alternatives with high level of users' satisfaction attract more attention, and therefore, quantify the level of user attention. An experiment using four alternatives for the design of a façade is performed. The design alternatives are developed in a virtual 3D environment and displayed on the screen. The main factors affecting the façade design include: (1) opening (mainly windows that can be defined based on composition and shape), (2) texture, and (3) color of its components. A set of images of the building from different views (e.g. north, east, south, and west) is placed in a slideshow with automatic timing and each slide is shown for 10 seconds. Consequently, participants are asked to rank the given façade designs and circle the part of the design (without surfaces and color) that is most appealing to them. The main measurements used in the eye-tracking pilot test are "fixations" and "saccades". Using the flowchart in Figure 2, a static 50-60 Hz eye tracker is employed. The collected eye movement data is analyzed to find out whether fixations at hotspots are directly related to the user's satisfaction. Figure 4 shows a sample of questions from the questionnaire.

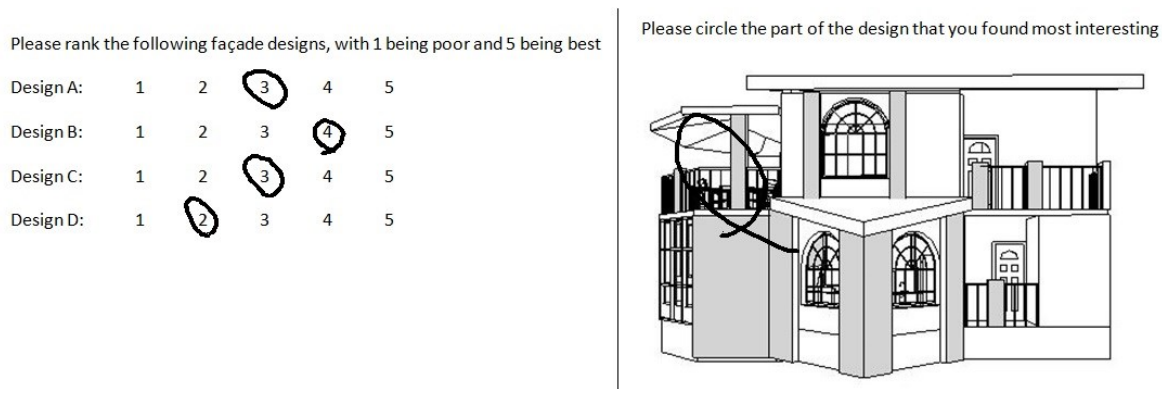

Figure 4: Template of the questionnaire used in the use case example

Recommendations and Conclusions

It is evident that the use of eye-tracking in a variety of disciplines yields several benefits. Eye-tracking technology enables practitioners and researchers to detect unexpected events, explore visual pattern in psychology and neuroscience, usability problems and search patterns in marketing, and many other advantages. Based on the preliminary study and literature review, it was concluded that there are several benefits associated with eye-tracking technology. The application of eye-tracking techniques can be explored further in the construction industry. The conclusions from this study can be summarized as follows:

- Output from an eye-tracking system required technical skills that enable the researchers to have a better understanding of the system knowledge from the users point of view;
- There is a limited understanding of eye-tracking application in building and construction industry;
- Eye tracking is a promising technology that can be employed during the construction safety process. The worker's perceptions of hazards play a key role in the overall safety performance of construction sites. Eye-tracking can be used to measure the worker's perception of risks and its relationship with his/her visual attention;
- Researcher and practitioners need to examine the potential application of this technology based on existing opportunities in the construction industry;
- Future research should focus on the eye tracking application that involve end user and consider user satisfaction through visual perception.

While these applications have shed some light on the eye-tracking technology, it also has limitation since it only measures visibility and visual attention. The increased visibility or visual attention does not necessarily convert to high levels of end-user satisfaction. In the use case example, for instance, different design alternatives are shown to the individuals to understand how changes in design might impact their level of satisfaction. However, these multiple alternatives of the same building alter the participant's behavior. In order to overcome this limitation, we should not use eye-tracking in isolation. The above items are being explored further in a detailed case study to have a better understanding of potential and challenges related to implementing eye-tracking technology in the construction industry.

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