Abstract. This paper examines the existence of a visual illusion with depth of sight involving a perforated panel layered above another plane, evaluates the illusion’s properties with virtual projection on a see-through, head-mounted display, and illustrates the relation between the veridical and perceived distances through a mathematical expression. The result would be indicative to egocentric spatial analysis research, and reveal potentials as a reference point for a new architectural design tool.

Keywords. Sight Depth; Kansei Engineering; Mixed Reality.

1. Introduction
According to recent market research reports, virtual reality (VR) would gain increasing popularity in fields such as video games, live events, healthcare, education, engineering, and military. The technology has been pointed out to have the possibility to become a platform of computing (Goldman Sachs Group 2016). Meanwhile, the terms of VR, augmented reality (AR), and mixed reality (MR) are gaining awareness but their differences are not clearly defined in general applications. In the field of architecture and construction, the technologies have been adopted in many way; proposed space design can be experienced in the virtual world without having to materialize CAD models, invisible phenomena can be attempted to be visualized and analyzed (Fukuda 2015), construction process can be guided digitally by utilizing a smart network on site. In this paper, VR technology would be used to evaluate the assumed illusion of sight depth associated with overlapping planes within the context of interior architectural design.
2. Aim of this paper

This paper proposes and defines an interior architecture finishing method, similar techniques of which may have been employed by designers and architects traditionally in the history, but are yet to be validated with scientific experiments. The method concerns a wall/ceiling finish with a perforated panel that creates an optical-space illusion, made of semi-transparent material and complemented with lighting effects from behind. The aim of such is to create an impression to the spectator of a bigger, deeper space than the actual environment which are often restricted to site constraints.

Secondly, this paper examines the validity of the design hypothesis, and evaluates its effectiveness. The evaluation is conducted through a series of subjective evaluation experiments that is supported by a see-through glass type mixed reality (AR/MR) head mounted display (HMD), which superimposes a virtual model on top of the reality. In the experiment, the participants are shown, through the HMD, random material configurations of the virtual, illusion perforated panel juxtapositioned in front of a real wall, to examine the relationship between veridical distance and the perceived depth with the intervention of the illusion panel.

3. State of Art

Originates from paintings, the practice of illusionism has seen a long history of application in various art forms, in which the subject is designed to deceive the spectator’s perception into sensing a reality that does not objectively exist, in another word, an intentionally caused misinterpretation. Such illusion is made possible by the brain’s fallibility to be persuaded of illogical concepts as the mind subconsciously assimilates inconsistent sensory information (Massey. 1997).

In the engineering field, there are papers studying subjective evaluation, namely Kansei Engineering. For example, there are car designers who found out the coefficient between the distance and width of a pillar in the interior of a vehicle (Takeda et al. 2013). The study concludes that there the difference between veridical distance and cognitive distance can be modeled with a sigmoid-like function, depending on the position of the object in one’s field of view.

There are several precedents concerning perceptual recognition in architecture and urbanism field too, a group in Nagoya Technical University referred it as sight-depth (Kitagawa et al. 1999). In the urban design field, the space syntax group (Hillier et al. 1984) have been conducting axial map researches. Those researches assessed intuitive feeling with mathematics and computational methods.
Traditional Japanese architecture in a city, as typified by tea room, has been designed with a dense in a small space in a small site. Its spatial impression be created beyond the actual conditions including not only distance but also the way of look at world. Even today, this method is effective in high-density cities such as Tokyo, creating ‘feeling of breadth’ in a limited space contributes greatly to building value improvement.

4. Problem statement

In such situation, though there are several theories about optical space cognition with a perforated panel (perforated wall) from interior view. Furthermore, there are few description about its details such as the translucence, reflection rate, as well as colors and objects behind such as top light or indirect lighting. This hypothesis came from author’s practical experience but had not yet been proved. Also, evaluation with physical models is difficult not only because of costs but the lack of a verified model of effect for the client’s reference. However, recent development in parametric modeling software and VR/AR/MR technology enables the material properties to be visualized and tested before built; furthermore, AR/MR when coupled with subjective evaluation method, has the capacity to assess the spectator’s sensational feedback of the design being reviewed.

5. Hypothesis and Research Questions

If a perforated panel is layered on top of a wall as an interior finish, with a certain margin of space in between, the spectator is assumed to perceive an illusion that the space is deeper than the actual dimension. As independent variables, rate of perforation and the distance between panel and the spectator would affect the result.

The author expects the participant to overestimate the depth of the space, but also considers the possibility of underestimation. To quantify the assumed phenomenon, AR with HMD are used in the experiment to simulate the spatial setting. Parametric-modelling can be integrated into the AR environment, and hence design properties of the perforated panel material can be adjusted in real time. Under this agenda, there are six research questions:

1. If motion parallax caused by movement of the spectator contribute to depth
illusion
2. If illumination difference between the outer layer and inner layer contribute to depth illusion
3. If the texture and color of the inner wall contribute to depth illusion
4. If porosity of the outer layer affect depth illusion
5. If the distance between the outer layer and the spectator affect depth illusion
6. If the distance between the two layers affect depth illusion

Elements in question 1, 4 and 5 may be examined as parameters in the experiment in a simplified manner. Steinman et al (2000) has suggested dynamic-motion parallax to be an important depth cue for spatial cognition, and the use of Hololens HMD allows movement of the user, in comparison with wired VR headsets which restricts motion. Rate of perforation and the distance between two layers in question 4 and 5 are simplified as stepping values instead of continuous numbers in the experiment. Question 3 is reflected in the experiment conducted, by choosing an inner wall that is textured, but the question has to be proved by an counterexample. Variables mentioned in 2 and 6 are fixed in this case for simplification but are assumed to be correlated to the result, so further experiments are expected.

6. Tools

Hololens developed by Microsoft is hardware chosen to be evaluate the hypothesis. As a MR device, it differentiates from VR devices that provide the spectator with an immersive virtual environment. MR devices overlays virtual information on top of the reality through a HMD, and the spectator sees a world mixed with virtual and actual information. Most of perceptions are from the physical environment, the main issue of HMD is that virtual objects tend to appear transparent in bright environments. In this experiment, budget sun-glass-lens are attached on top of the HMD to alleviate the problem in holo-environment (fig. 2).

Figure 2. DIYed Hololens for as a countermeasure for virtual objects appearing translucent.

The stimulated environment in Hololens is created with the Microsoft developers kits (Microsoft 2017) for Unity. There are two standard developing environment in game engineering in 2017, Unreal Engine (Epic Games 2017) and Unity (Unity Technologies 2017), the latter was used. But for Hololens, there are almost one choice Microsoft provide tool kit so that developer does not necessitate to type code in most of the case. Other reason is the laboring time for constructing
experienced space is relatively light for MR because this can omit to make details such as modeling and lighting.

![Software development in Unity, left is working window, right is experiment set with/without textured wall.](image)

Figure 3. Software development in Unity, left is working window, right is experiment set with/without textured wall.

There are three merits in using developer environments. Firstly, trial-and-error in software development is easy to apply, because developer can program with looking at the actual space in real scale. The making of objects is done in Unity, then Hololens enables the developer to check the result immediately. As such experiment which has interaction virtual and physical objects within real sight, necessitate manual adjustment, many times. The iteration of this adjusting place, and sizing process is important to improve quality. The second merit is that this system environment can reconfigure space almost in real-time. The conventional ergonomics/Kansei engineering experiments need a full-scale, extensive mock-up for evaluation, as well as substantial manual labor in the setup. By utilizing virtual object in AR/MR, those operations became mere clicks of buttons. Thirdly, affinity between virtual and real is adjustable in MR. Concretely, VR-like immersive feeling can be amplified by adding a number of virtual object, which means more interference with real scene in MR too. In the initial stage, there were a discussion about whether the inner wall should be virtual or real, without having a conclusion, the examiner visited the site and decided not to use a virtual inner wall based on visual judgement. The point in here is that the user or developer can adapt adequate vitality and reality on demand.
7. Experiment

The method of experiment utilizes the ‘Perceptual Matching Method’ for examination, which is typical method in VR thesis (Swan 2006) though there are several projection-ergonomics measurement. That examiners would verbally ask the participant how far away a specified point seems to be in meters in different conditions. Verbal questions are only limited to how far away the second wall looks to you in meters, and scale in comfort-ability. The experiment needs the questionnaire to be repeatedly tested for at least ten times, with different people (more than eight) and different eye positions and different material properties, so you get a database for generating a reliable model. In this experiment, the procedures were conducted 27 times and 8 samples including different gender, and professions. The goal of this experiment and evaluation is to establish difference the coefficient between real sight depth and cognitive depth, in order to make analyzing tool which based on ergonomics but also appropriate indicator for designer/architect.

The experiment with HMD was done in an interior space with 8 participants and several examiners. The participant on chair is allowed to move only in X direction. The examiner asked questions, such as “Tell me the distance between the inner wall and current position of you in meters”. The same procedure was repeated three times. To avoid conjecture, the following conditions are set; 1) Chair moves randomly in the switch of distance between the participant (the spectator) and the inner wall, 2) The rate of perforation of the perforated panel is not mentioned to the participant.
8. Result data

The below figures show the average result of 8 participants in 27 examinations, abnormal values being taken out. The right axis indicates that the actual distance between virtual wall and the participant, the left axis is the percentage of porosity of virtual wall. Those two are apparently variables in this experiment. The vertical axis shows the reported value (m), the distance participant feels there is between him and the inner wall behind the virtual perforated panel.
Generally, this graph shows same rough tendency such as right upper part goes higher, than left bottom part, but not easy to see accumulate information and consideration in this representation.

Figure 8. Average of distance all examinee perceived.

Same as the previous axis definition, the above figure shows the average result of all participants as the green surface, on the other hand the orange surface indicates the real distance between the second wall and the participant. The Graph shows that, 1) the larger distance between the participant and the virtual wall, the larger the perceived space is in general. 2) In the case, the distance between the virtual panel and participant is, with 20% porosity, less than 2 meter, as illusion becomes bigger, while 40% and 60% almost accord.
Finally, again in same measure rules, the slope shows the difference between the value of real distance and perceived distance. The magnitude of illusion distance is always positive value instead of the case people goes closer to virtual panel, and high porosity. (the value of it nearly equals zero). Besides the case, the lager distance from a object and a person, makes the lager feeling of distance.

9. Conclusion and Prospect

The assumption that an inner wall with a perforated panel on top creates an perceptual illusion that exaggerates the in-between depth is valid with limitations. Two of the conditions are examined and revealed here. Firstly, the distance between the spectator and the perforated panel has to be wider than 1 meter. Secondly, the transmittance, which in here is translated into rate of perforation in perforated panel, has to be of a certain percentage. 20% proved to be the most effective in this experiment. While these figures work in this given environmental conditions, but are more related to the perceive-able scale of the perforated panel.

However, some issues are yet to be addressed. One is whether the experimented parameter range was appropriate, because the graph of the result seems to be a continuous one. Another point is that if other untested variables would carry a bigger impact to the outcome, such as the distance between inner and outer wall, illumination level between interior space and, interstitial space, as pointed out in heading 5. Thus further experiment would be expected.
This time authors quantitatively assessed how much impression of the distance over the punching panel is amplified with respect to the actual situation while utilizing MR. Based on these studies, one of the authors starts utilizing this effect as a design tool, above figure shows an example application of ceiling finish in a project. With the limited size of sites in urban area, this office space is designed to expand the perceived spatial boundary.

References


Hillier, B. and Hanson, J.: 1984, The social logic of space, Cambridge University Press, UK.


Massey, L.: 1997, Anamorphosis through Descartes or Perspective Gone Awry, Renaissance Quaterly, US.
