Vague Space: Tracing Eyes, Edges, and the Indeterminate Limits of the Architectural Interior

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Figure 1. Eye-tracking saccades of 25 participants viewing Pieter de Hooch's Cardplayers in a Sunlit Room, 1658 (cardplayers deleted).

The perception of architectural space involves a visual understanding of objects, light, color, and the configuration of wall, floor, and ceiling elements. This eye-tracking study examines how architectural student viewers of two-dimensional scenes see these elements in images from 17th century Dutch paintings and photographs of mid-20th century modern architectural interiors. Results indicated significant patterns in how viewers observed these spaces, especially the attention given to *openings with space beyond* – the distant and vague regions of the scene. These patterns did not vary significantly between the three types of images viewed: historic color, historic black and white and modern black and white. Gender differences emerged, especially in participants' visual attention to foreground objects. In addition, there were distinct differences between the results proposed by a computer simulation model and those of the actual participants. This study elevates the significance of architecture as a spatial practice in contrast to its focus on the object.

INTRODUCTION[1]

> Next to the vertical line, whose living bearers resolve space by our bodily orientation into above and below, front and back, left and right, the most important direction for the actual spatial construct is the direction of free movement – that is, forward – and that of our vision, which, with the placement and positioning of our eyes, defines the dimension of depth.
>
> August Schmarsow, 1893[2]

Architectural space, since the development of 20th century modern architecture, has received a generous share of discussion, research, practice, and scholarship. From Bruno Zevi's claim on the fourth dimension of space in architecture, where bodies move about volumes and time in ways that distinguish it from the other visual arts, to Luigi Moretti's prewar writings concerning the autonomy of a spatial vocabulary that places space in the realm of dynamic action, pressures, and sequences, the notion of space has endured many interpretations.

With the introduction of computational models and tools, a renewed definition and set of parameters for architectural space has emerged in perception and cognitive studies that seek to better understand how volumes defined by normative architectural elements are recognized in our field of view. This paper describes a related experiment with human participants using eye-tracking techniques now readily available to designers. It summarizes these efforts and suggests some possible meanings and instrumental applications.

The study focused on *how viewers perceive architectural space given two-dimensional representations of interior rooms.*

Researchers observed how objects, elements, and/or visual phenomena functioned as stimuli in an architectural scene. Included in this field of view were objects (people, furniture, equipment, decorations, etc.) as well as the subject of architecture itself: walls, floors, stairs, apertures, and ceilings. In addition to these spatial constituents, the study was designed to see if the style or character of architecture might also contribute to the way spaces were perceived. To study this, historic European spatial interiors were used next to more modern renditions of space.

BACKGROUND

This study follows modern trends in the definition of architectural space. Space as a construct is rooted in 19th century German aesthetics built upon Kant's ideas of human anatomy and experience as the basis for moral and scientific understanding.[3] This era of discourse supports a view of form and space that places humans at the center of an empirical world where reason and judgement capture how we appreciate and take delight in the aspects of our environment. These ideas become instrumental in the visual arts, and in design disciplines where the human body participates with objects and surroundings via perceptual and physical means.

Much of architectural education and training has inherited ideas from these early 19th and 20th century movements, and architects continue to train in and practice the discipline according to these principles. This paper focuses on two of the resulting sub-discourses: space defined as physical determinants and as a perceptual realm.[4]

As a physical manifestation, the notion of space relies on the dimensional and geometric attributes of *form* in architecture. Shape, form, syntax, and dimensional attributes become factors for space when it is considered as a container or vessel for buildings and structures. The parameters of space in this definition comprise all three dimensions, and also include the factor of time.[5]

Space can also be *perceptual*, when considered as a human psychological experience related to principles that underscore visual phenomena and thus guide empirical observation and recognition. In this definition, the human means for perceiving space is a factor of distance, perspective, and the relation and interaction between objects in the field of view as suggested by Anton Ehrenzweig.[6] This *Gestalt* experience of space defines our modern paradigm of architecture and symbolizes the development of spatial realms that align with German aesthetic practice and French phenomenological positions.

EYE TRACKING RESEARCH IN RELATION TO VISUAL REPRESENTATION AND ATTENTION

Eye tracking systems measure eye position, eye movement and pupil size to define the direction and duration of a person's gaze.[7] Since the 1970s there has been an increase in the use of eye-tracking applications, often driven by research in advertising, marketing, psychology, neuroscience, design cognition, and user interface design

Early research into visual attention based on eye movement was conducted by Buswell, who focused on the aesthetic impact of photographs of artwork, patterns and sculpture, particularly the layout patterns of advertisements.[8] Kaufman and Richard measured eye fixation times in several pre-defined elements of a scene, and identified that the center of gravity in a scene is an attractor as well as edges and corners.[9] Torralba, Oliva, Castelhano, and Henderson 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 that some parts of a scene attract more attention than others.[10]

Research and analysis on how representation is important to viewing architectural design was conducted by Park, Jin, Ahn, and Lee using eye-tracking technology with the use of photographs and line drawings.[11] This study involved eye-tracking data collected from participants viewing six pairs of photographs and line drawings and analyzed how representations affect people's perceptions of architectural scenes.

While the relationship between eye movement and perception of visual scene representation has been investigated, there has been little research on the role of eye movement in the study of three-dimensional architectural space. One of the few experiments on this topic was conducted by Weber, Choi, and Stark, who collected eye tracking data as participants were asked to look at three-dimensional models and/or photographs of models of architectural space.[12] Their results showed that a viewer's attention would fixate at the center, and while the foreground was common for initial fixations, the eye did not typically scan the edges of interior space or rectilinear-oriented contours.

The current study investigates viewer responses to two-dimensional representations of three-dimensional space. A key objective was to explore in more detail the attention viewers paid to *empty space* or *spaces beyond* in contrast to objects. The study used color and black and white scenes, as well as different styles of architecture.

There are two main types of eye-tracking devices – screen-based eye-trackers and mobile eye-tracking glasses. The data collected with these systems typically includes fixations, fixation duration, viewing sequence, and pupil size. This experiment involved a screen-based study that used *Tobii Studio®* and *GazePoint®* infrared light eye-tracking hardware and software in controlled environments.

It also made use of the visual attention simulation (VAS) software developed by the 3M™ Company that sets a number of parameters that can simulate the way viewers inspect static pictures. Studies by Auffrey and Hildebrandt show that this software provides a reasonable facsimile of human viewing behaviors under certain conditions.[13] The software simulates a visual field that plots heat maps for the first 3-5 seconds of viewing. As an example of this software use, researchers have employed VAS for determining a viewer's potential attention to signage and other wayfinding markers in a field of view.

Figure 2. All image sets used in the experiment.

RESEARCH INQUIRIES

As fundamental to the research, a series of questions were developed to guide the study:

Inquiry 1. Does participants' visual attention show significant differences between the types of images (historic vs modern, color vs black and white)?

Inquiry 2. Does participants' visual attention show significant preferences between the types of space vs. objects in the images?

Inquiry 3. Does the eye-tracking analysis of high fixation areas generated by the visual attention simulation software (VAS) differ from the high fixation areas of participants when viewing architectural space?

Inquiry 4. Do participants show similarities in the order in which they view high fixation areas?

Inquiry 5. Does participants' visual attention show significant differences when images are presented in a different order?

Inquiry 6. Does gender affect the visual attention on types of spaces/objects and types of images?

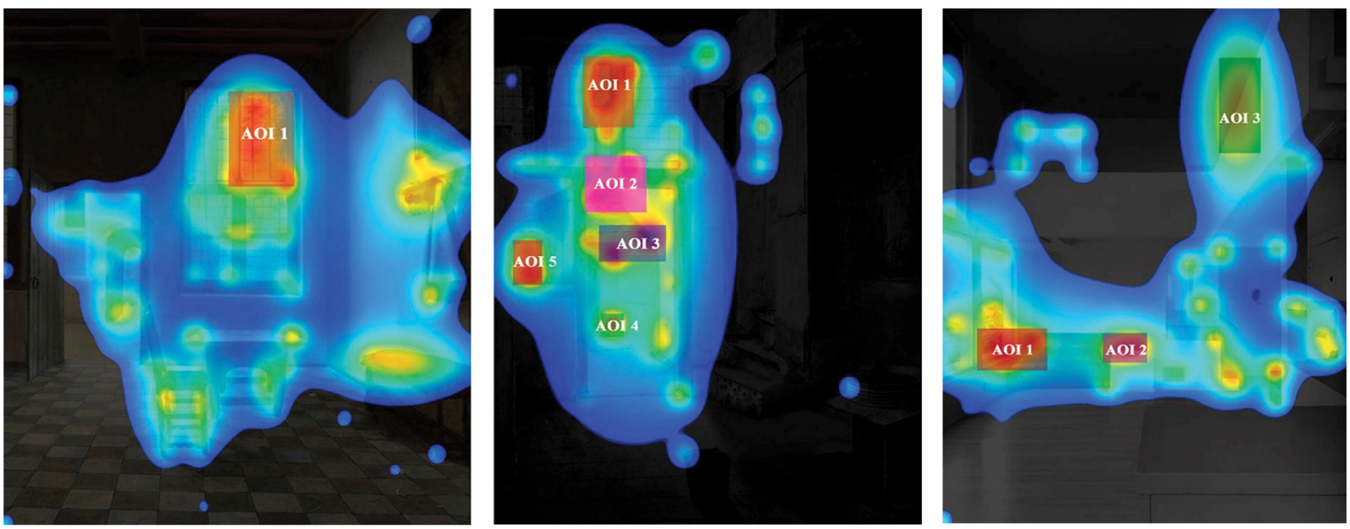
DESIGN OF THE EXPERIMENT

A convenience sample of 75 first and second year undergraduate architectural students at the University of North Carolina at Charlotte participated in the experiment. The students were divided into three groups with 25 students in each group. Each group of students was asked to view three types of images in different orders (Figure 2).

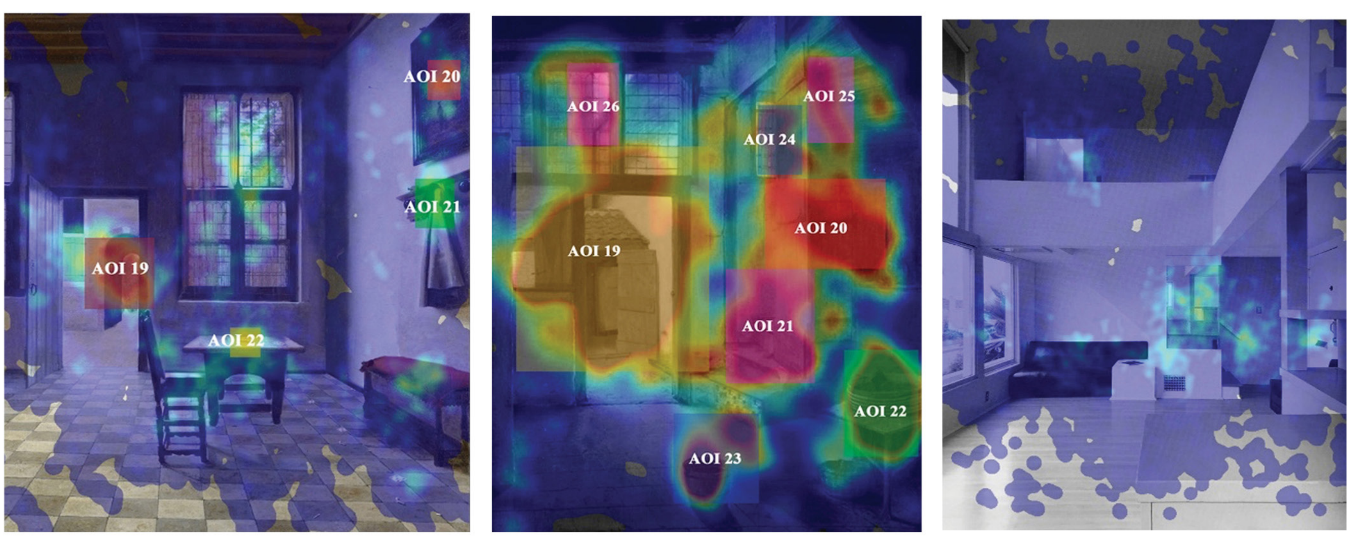
The experiment was set up to track two different spatial conditions. The first involved historic architecture portrayed in 17th century paintings of Dutch houses by the painter Pieter de Hooch (1629-1684). Painted in the tradition of the Dutch Golden Age of artists, de Hooch's works depict domestic interiors. The scenes are unique in that they are presented as one-point perspective spaces in color that demonstrate the common conditions of life during the times. These interiors display a strong sense of enclosed space with doorways, windows, and contrasting light conditions that enable a view of the environs beyond. For the purposes of the experiment, these traditional spaces can be defined as historic room-like interiors with walls and apertures portrayed as typical of subdivided architectural interiors.

The second set of images were defined as modern interiors, as seen through the cameras of mid-20th century photographers.

Experiment image types: left: image 2 (historic color); center: image 9 (historic black and white), right: image 12 (modern black and white).



Set 1 Heatmaps generated by 3M VAS software: image 2 (left), image 9 (center) and image 12 (right).



Set 1 Heatmap data of semantic AOI high fixations from the experiment: image 2 (left), image 9 (center) and image 12 (right).

Figure 3. Sample image types, VAS AOI Analysis, and Semantic AOI Analysis Comparisons.

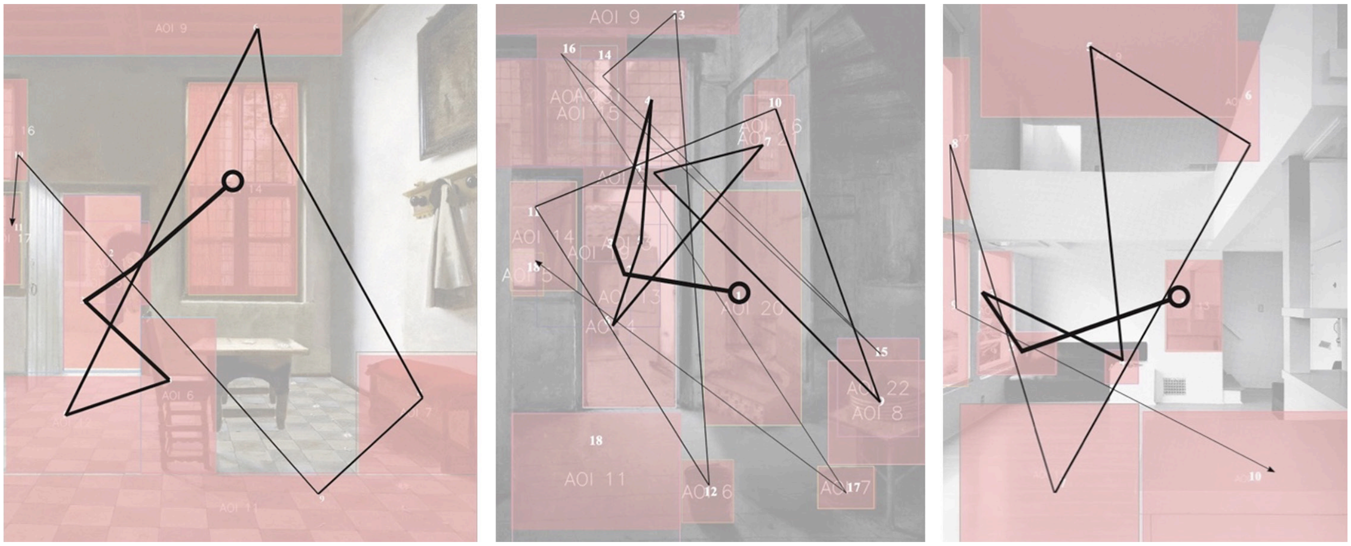


Figure 4. Eye saccades for image 2 (left), image 9 (middle), and image 12 (right). The diminishing line thickness indicates time from the start of the eye-tracking session.

In the 1950s and 60s, projects by architects such as Richard Neutra, Pierre Koeing, and Charles and Ray Eames were published as photographic essays in leading architectural journals as well as popular magazines, such as the *Ladies' Home Journal* and *Better Homes and Gardens.* The photographs were presented in black and white, as one-point perspectives with rich spatial interiors. These interiors, like the traditional spaces of de Hooch, feature spaces beyond the immediate environs of the scene. The primary difference is that spaces beyond the room are separated by planes and surfaces that often exclude the typical doorway and window treatments of traditional interior spaces.

In order to examine possible influences of color, select scenes from the traditional set of images were rendered in black and white. Human figures were removed from the scenes in all images.

The experiment asked individuals to view one of three sets of sequenced images with 25 architectural students in their first years of study viewing each set. Each set comprised 15 images, with each image viewable for 10 seconds. Each set had five historic color interiors, five historic black and white interiors, and five modern black and white interiors. The experiment included a questionnaire that obtained each participant's sex, age, ethnic group, and knowledge or training at viewing art and visual representations. The three sets are summarized below:

Set 1: Five historic/color, five historic/b&w, and five modern/b&w.

Set 2: Five modern/b&w, five historic/b&w, and five historic/color.

Set 3: A random arrangement of the three image types.

The critical data measurements in eye-tracking research include: area of interest (AOI), defined as an area that receives the most attention by observers, the time spent at particular locations of the scene, and the saccades or the movements and locations of the eye with the scene.

This study identified three types of AOIs: 1) AOIs identified by the VAS software simulation, 2) semantic AOIs defined by the spaces/objects in the images, and 3) high fixation AOIs.

Six types of eye movement were measured: 1) number of viewers, 2) average time to first view (secs), 3) average time viewed (secs), 4) average number of fixations, 5) number of revisitors, and 6) average number of revisits.

The 3M™ VAS software employed is a program analysis that tracks image brightness or color contrasts and generates a visual heat map of potential AOIs. In contrast to the computer generated AOIs of the VAS software, the experiment results were used to define five new types of *semantic* AOIs: foreground objects, ceilings, floors, openings with space beyond, and openings with brightness.

RESULTS

The research study resulted in a rich data set, which produced several intriguing observations.

Historic vs. Modern Interior Scenes

There were no significant differences found between the three types of images (Figure 3, top row). This indicates that the representation type and the style of architectural scene

AOI categories	Data set		Viewers (#)	Ave Time to 1st View (sec)	Ave Time Viewed (sec)	Ave Fixations (#)	Revisitors (#)	Average Revisits (#)
AOIs of foreground objects	1	Mean (SD)	15.21(6.26)	4.78(1.34)	0.51(0.22)	1.96(0.62)	7.2(4.76)	1.37(0.31)
	2	Mean (SD)	15.33(6.55)	4.54(1.20)	0.50(0.25)	2.09(0.74)	7.59(4.99)	1.49(0.60)
	3	Mean (SD)	15.79(5.01)	4.97(1.29)	0.48(0.21)	4.78(2.09)	6.50(3.99)	1.41(0.31)
AOIs of ceilings	1	Mean (SD)	12.60(6.29)	4.25(1.42)	0.54(0.28)	2.66(1.02)	7.20(5.55)	1.98(0.59)
	2	Mean (SD)	15.40(4.90)	4.09(1.41)	0.60(0.34)	3.06(1.34)	10.67(5.15)	2.04(0.58)
	3	Mean (SD)	11.73(6.64)	4.16(1.42)	0.55(0.38)	5.48(3.79)	7.60(5.87)	1.90(0.57)
AOIs of floors	1	Mean (SD)	10.14(4.86)	4.69(0.84)	0.42(0.17)	1.93(0.51)	3.24(2.66)	1.47(0.53)
	2	Mean (SD)	10.00(4.45)	4.68(1.16)	0.37(0.17)	1.96(0.65)	3.81(3.08)	2.04(1.13)
	3	Mean (SD)	9.81(4.34)	4.69(1.21)	0.32(0.19)	1.72(0.71)	3.24(2.88)	1.14(0.80)
AOIs of openings with space beyond	1	Mean (SD)	22.58(3.34)	2.35(1.05)	1.35(0.63)	4.79(1.92)	17.85(5.18)	2.47(0.57)
	2	Mean (SD)	23.35(2.31)	2.36(0.95)	1.32(0.66)	4.93(1.95)	18.50(5.40)	2.56(0.50)
	3	Mean (SD)	22.62(2.38)	2.23(0.91)	1.45(0.75)	5.11(1.96)	18.04(4.54)	2.59(0.54)
AOIs of openings with brightness but no space beyond	1	Mean (SD)	11.63(6.81)	5.26(1.65)	0.33(0.13)	1.70(0.46)	5.06(3.91)	1.43(0.83)
	2	Mean (SD)	10.93(5.34)	5.49(1.30)	0.27(0.11)	1.57(0.34)	4.50(3.01)	1.28(0.65)
	3	Mean (SD)	11.13(7.28)	4.92(1.90)	0.26(0.17)	1.54(0.54)	4.73(4.83)	1.19(0.87)

Figure 5. Semantic AOI participant results from all sets of images. Note *opening with space beyond* data is highest in all eye movement categories.

(historic or modern) were not primary factors that affected participants' visual attention.

Visual Attention

In terms of the five semantic AOIs, *openings with space beyond* received fastest (first view) and longest attention (Figure 5). Foreground objects came second. Floors received the fewest fixations. This suggests that viewers sought out areas of the scene beyond the immediate interior limits of the space. It also raises important questions about our attention preference for voids vs. objects in an architectural scene.

VAS Simulation Data vs. Participant Data

The results of the VAS computer simulations differed significantly from the participant data gathered from the experiment. VAS is set up to recognize objects, faces, color and light differences. Since the software depends heavily on the brightness of areas in an image, which is more varied and diverse in the spatial scenes used in the study, this suggests VAS is not a viable model for simulating how humans view interior realms (Figure 3, middle vs. bottom rows).

Sequence and Position of The Gaze within a Scene

Participants tended to look at the center of images first and scan to the left of the images followed by other areas (Figure 4.). This shows results similar to a larger body of research, including a Yu and Gero study, that suggests designers tend to focus on the middle or left of an interface .[14] Also noted was the consistent manner in which participants' saccades moved next to far ground apertures as if seeking for relief from the confines of the room.

Order of Images and Visual Attention

Other than AOIs of high fixation, the order in which images were shown to the three groups of participants had a minor impact on participants' visual attention. This indicates that no particular bias was created in the data due to "learning effects" sometimes resulting from view order.

Gender Differences

A variety of gender differences were identified, especially in visual attention on foreground objects. This coincides with a previous study by Abdi Sargezeh et al. and warrants further investigation.[15]

SUMMARY AND FURTHER STUDY

Understanding where individuals look in three-dimensional realms provides valuable insight into how we grasp a sense of space that expands beyond the limits of our surroundings. Of interest is the way we quantify how these spaces, irrespective of their particular architectural style and character, operate in similar ways revealing the means by which eyes perceive visual information. Furthermore, the ways in which we scan these environments suggest that design can lead our eyes to distant spatial realms beyond our immediate environs, dependent on how we design apertures, create visual contrasts and relief, and position objects.

This study raises additional questions about design and practice. For example, how might these quantitative findings inform architecture to meet the need for more spatially compact, economical, and affordable living scenarios? Could the research impact new ways of producing an architecture that is spatially efficient while at the same time lend an expanding sense of spatial richness in urban settings of increasing density? To this end, further research might incorporate a more precise taxonomy of architectural elements in order to test specific responses in architecture's expanding field of view.

ENDNOTES

1. The author would like to acknowledge the contributions to this paper by Professor John Gero, Department of Computer Science and School of Architecture, University of North Carolina at Charlotte and Professor Rongrong Yu, Griffith Centre for Design and Innovation Research, Griffith University.
2. August Schmarsow, "The essence of architectural creation," *Empathy, Form and Space: Problems in German Aesthetics 1873-1893*, trans. H. F. Mallgrave and E. Ikonomou (Santa Monica, CA: Getty Center, 1994), 289. Essay originally published in German, 1893.
3. Mallgrave, H. *Empathy, Form and Space: Problems in German Aesthetics 1873-1893*, trans. H. F. Mallgrave and E. Ikonomou (Santa Monica, CA: Getty Center, 1994), 6.
4. Norberg-Schulz, C. *Existence, Space & Architecture* (New York: Praeger Publishers, 1971),12-16.
5. Zevi, B. *Architecture as Space* (New York: Horizon Press, 1972).
6. Ehrenzweig, A. *The Hidden Order of Art* (Berkeley, CA: University of California Press, 1967), 21-31.

7. Gonzalez-Sanchez, J., Baydogan, M., Chavez-Echeagaray, M. E., Atkinson, R. K., & Burleson, W. "Affect measurement: a roadmap through approaches, technologies, and data analysis," M. Jeon (Ed.), *Emotions and Affect in Human Factors and Human-Computer Interaction* (San Diego: Academic Press, 2017), 255-288.
8. Buswell, G.T. *How people look at pictures: A Study of the Psychology of Perception in Art* (Chicago: University of Chicago Press, 1935).
9. Kaufman, L. & Richard, W. "Spontaneous fixation tendencies for visual forms," *Perception and Psychophysics*, 5, 1969, 85-88.
10. Torralba, A., Oliva, A., Castelhano, M. S., & Henderson, J. M. "Contextual guidance of eye movements and attention in real-world scenes: The role of global features in object search," *Psychological Review*, 113(4), 2006, 766 –786.
11. Park, J., Jin, Y., Ahn, S., & Lee, S. "The impact of design representation on visual perception: Comparing eye-tracking data of architectural scenes between photography and line drawing," *Archives of Design Research*, 32(1), 2019, 5-29.
12. Weber, R., Choi, Y., & Stark, L. "The impact of formal properties on eye movement during the perception of architecture," *Journal of Architectural Planning and Research*, 19(1), 2002, 57-68.
13. Auffrey, C. & Hildebrandt, H. "Utilizing 3M's visual attention service software to assess on-premise signage conspicuity in complex signage environments found in urban neighborhood and suburban strip business districts: lessons learned from a graduate seminar," *Proceedings of the 2014 National Signage Research and Education Conference*, Cincinnati, 2014. Last accessed November 7, 2020: http://www.signresearch.org/wp-content/uploads/New-Tools-for-Looking-at-the-Importance-of-Signage.pdf.
14. Yu, R. & Gero, J. S. "Using eye-tracking to study designers' cognitive behaviour when designing with CAAD," P. Rajagopalan (ed), Engaging Architectural Science: Meeting the Challenges of Higher Density, *Proceedings of the 52nd International Conference of the Architectural Science Association*, Melbourne, 2018, 443-45.
15. Abdi Sargezeh, B., Tavakoli, N., & Daliri, M. R. "Gender-based eye movement differences in passive Indoor picture Viewing: an eye-tracking study," *Physiology & Behavior*, 206, 2019, 43-50.

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