ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 51, No. 3 July. 2022, pp. 163-174.
Journal Homepage: erj.bu.edu.eg

Using Eye-tracking tools in the visual assessment of architecture

Nader Samir Mahmoud [a], Eman Hanim Mohamed [b], and Ossama A. Abdou [c]

[a] MSc. Architecture Benha university

[b] Professor of architecture Benha university

[c] Professor of architecture MIU university

Abstract. The motivation for this research stems from the belief that some currently available technologies are overlooked in architecture practice, despite their significant potentials and capabilities. These potentials can help architects better understand the impact of architecture and design proposals in a more scientific way. Whereas the main purpose of this research is to review relevant studies, characteristics, and potentials of various types of modern eye-tracking technology in architectural design and architecture visual assessment. Such motivation and purpose arrived from recognizing the problem concerning the absence of an objective tool that can detect and analyze how observers visually perceive architecture. Moreover, as current visual assessment of architecture is widely conducted by reporting subjective opinions which can be biased, mis-expressed, or misleading.

Through the revision of eye-tracking technology`s characteristics, revision of recent academic research concerning the implementation of eye-tracking technology in architecture, and assessment of the technology from an architectural perspective, this study adds to the field of research in architecture visual perception and recognition by; (1) reviewing eye-tracking research, (2) expanding the knowledge regarding the role played by eye-tracking technologies in architecture, and (3) establishing a connection between eye-tracking technologies and architecture practice. Conclusively, the study concluded that eye-tracking technologies have some advantages to the field of architecture despite of having some disadvantages and incompatibilities that conflict with the architecture practice nature.

KEYWORDS: Architecture, Eye-tracking, Visual Perception, Gaze, Saccade

1. INTRODUCTION

The visual properties of the built environment have a significant impact on human behavior [1] that is why architects look for a way to register how architecture or an interior space is perceived by ordinary onlookers seeking answers to questions related to both practical skills and theoretical knowledge [2].

Architects generally conduct visual studies to their proposals, existing architecture, or spaces using traditional questionnaires and/or verbal reporting techniques. Despite of the fact that those techniques are widely used and can produce rather good conclusions, it can be affected by many subjective factors that can lead to questionable, biased, or misleading results depending on the design of the experiment, or the viewer`s bias himself, thus there is a need for a new tool that can objectively depict the visual behavior of the observer particularly concerning the eye`s focus location, the focus sequence, and the duration of focus on a particular part of designs , spaces, or architecture. Such tool can provide architects, artists, and designers with not only the information of the viewer`s ability to see or visually wander over the visual aspects of designs and report his/her experience and subjective opinion, nonetheless it can provide information that even the viewer himself is not aware of. Particularly, this tool should be able to communicate how an object is seen in a non-subjective and unbiased manner.

Among many available tools, this study found that eye-tracking technology is potentially capable of delivering architects` previously mentioned demands as it has been found useful in communicating eye movement in disciplines such as psychology, medicine, ergonomics, interaction man-computer, and marketing [3]. Also, research using eye-tracking has commenced concerning man's perception of works of art, industrial forms and products and their packaging. However, despite of the implementation of eye-tracking in many other fields, the application of Eye-tracking tools and technologies in the field of architecture has hardly been explored [4].

This study investigates eye-tracking tools and suggests that this technology – despite of having some disadvantages- have the potentials of communicating the visual experience of the viewer to the designer in a digital and graphical manner that is objective, unbiased, and cannot be either manipulated, altered, nor mis-expressed.

2. Overview of Eye-tracking technology

Eye-tracking is the process of calculating the motion of the eyes. According to Ebner et al. (2018) eye-tracking technology is defined as **"The technology that allows for the measurement of physiological process, such as (gaze) and (saccade) of the eyes, as well as the dilation of the pupil, and the comparison of these physiological process to neural process"** [5] , where the term *GAZE* according to Merriam Webster dictionary means; to fix the eyes in a steady intent look often with eagerness or studious attention [6], *SACCADE* is the eye`s rapid movement from one fixation to another [7], and *FIXATION* is the time between two saccades [8].

Thus, tracking and determining the observer`s eyes gaze, fixation, and saccades, can deliver insights about what the observer attended to, and what his/her visual interests are while visually perceiving a certain phenomenon [9].

History of eye-tracking

Eye-tracking technologies were implemented in many fields such as human factors, cognitive psychology, marketing, and human-computer interaction [10]. However, eye-tracking`s early studies were highly academic, complicated, and costly for commercial use, and focused on understanding the connection between the brain and visual system. [7]

According to Duchowisky (2003), eye-tracking research was started in the late 1800s [9].Early studies relied on putting coverings over the eyes similar to contact lenses with sticks attached pointing outwards indicating the eye`s direction in an unpleasant experience to the participants [9]. Later, while the technology became more accessible, participants had to be restrained to a highly intrusive devices **- Error! Reference source not found. -** that requires a head restraint and a bite bar [7].

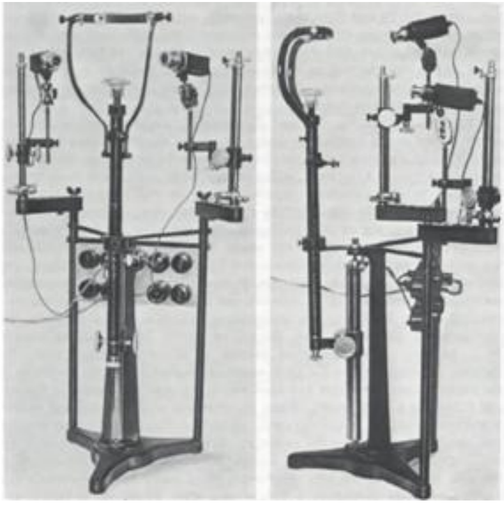

Fig 1. Early eye-tracker with head restraints and bite bars [7].

The earliest usability study wasn`t until 1947, when Paul Fitts used motion picture cameras to record pilots` eye movement when landing **- Error! Reference source not found. -** to investigate how pilots use cockpit controls [9]. A year after, in 1948 Hartridge and Thompson invented the first head-mounted eye-tracker that allows for free head movement [7].

In the 1970`s, the eye-trackers received a lot of improvements an became less intrusive, more accurate, and were able to dissociate eye movement from head`s movement by multiple reflections from the eyes [7].

In the 1980s, real-time eye-tracking became possible using video-based eye-trackers, as minicomputers became powerful enough [7]. Also, eye-trackers were used for the first time to assist users with disabilities [7].

from the 1990s up to now, there has been an increase in using eye-tracking in many fields due to the lowering of the prices and the increasing number of software and hardware dedicated tools [7] [11]. Reingold (2015) assures that, we are at the begings of the golden age fro eye-tracking in user experience research [11].

Nonetheless, despite of the fact that there has been a quantatative increase regarding the studies employing eye-tracking technologies, there has been little emphasis in the literature on the development of tools and methods despite the growing popularity of the technology [11]. The chart below demonestrates the number of publications with the phrase "eye-tracking" or " eye-tracker" (the Y axis) over the past 50 years (the X axis) in which each pin (column) represents a period of five years [11].

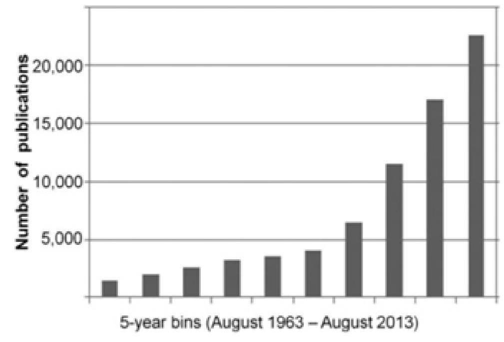

Fig 2. The number of eye-tracking articles over the past 50 years [11].

2.2 Types of eye movement

Types of eye movements can be classified according to their characteristics. There are four main classes of eye movements as shown below in Fig 3.

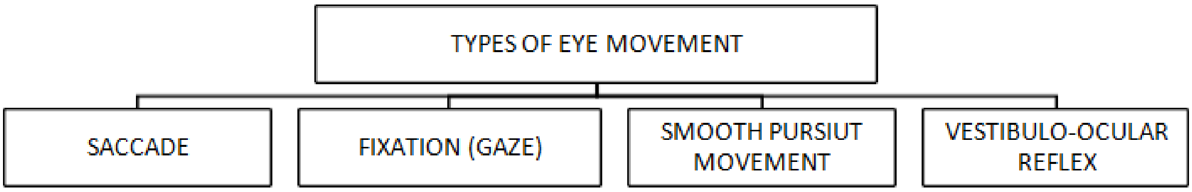

Fig 3. Types of eye movement [8]

- ***Saccade***

The word saccade was coined in the 1880s by the French ophthalmologist Emile Java l [12] and means the rapid eye`s movement between fixations - Figure 4 - to allow the eye to complete the visual scene [10], it typically takes place 3- 4 times every second [13] and is considered to be the most frequent and fastest movement produced by an external part of the human body [10].

Vision is mostly suppressed during saccades to prevent vision blurring [10] and the duration of saccades is typically from 10 MS to 100 MS and depends on the angular distance that the eyes travel during this movement which is called saccade amplitude [12]. The saccade`s velocity is about 600O/s and is a way to characterizing saccades [8].

Figure 4. Saccade illustration [12].

- ***Fixation and Gaze***

Visual information is extracted during fixation only [10] which are the time between two saccades [8]. Fixations are the stationary state of the eyes during which gaze is held upon a specific location in the visual scene [8], or the pause of the eye movement on a specific area of the visual field [7]. Whereas, according to the Meriam-Webster dictionary, gaze is to fix the eyes in a steady intent look often with eagerness or studious attention [6].

Fixations occur in the foveal vision shown in Fig 5, which is highly detailed and provides complete clarity, also accounts of nearly half of the visual information sent to the brain [7]. Fixations last between 1/10th and ½ a second after which the eye moves via saccade to the next part of the visual field [10].

Eye-trackers track only what is registered in the observer`s foveal vision which accounts for less than 8% of the visual field [7].

Fig 5. Foveal vision [10].

- ***Smooth Pursiut Eye Movement (SPEM)***

Smooth pursuit eye movement (SPEM) is the voluntarily tracking performed when stabilizing gaze on a moving visual target. It differs from saccade with its slower velocity and longer duration [10] [8] and is Controlled cortically by the frontal eye fields, or subcortically by the superior colliculus [10].

- ***Vestibulo-Ocular Reflex (VOR)***

The vestibulo-ocular reflex (VOR) is a fast eye movement triggered to stabilize gaze on a stationary object during head movements. The VOR movement compensates for such head movements by moving the eye in the opposite direction. The VOR is difficult to differentiate from smooth pursuits only using eye-tracking data, i.e. without any information on head movements [8].

Eye-tracking methods

Most modern eye-trackers rely on Corneal reflection to detect the eye`s location while moving [10]. Using a light source to illuminate the eyes - Fig 6 - and causes corneal reflection, cameras are used to identify the reflection on the cornea and the pupil then advanced algorithms are used to calculate the point of gaze related to the eye and the stimuli [10]. From relative position of multiple corneal reflections and center of the pupil, binocular horizontal and vertical eye positions are estimated as well as the angular position of the eye [14].

Fig 6. The relative position of the pupil and corneal reflection [10].

According to Burch et al. (2017), to provide a systematic overveiw of typical eye-tracking analysis task, there are three independent data dimensions must be drived which answers the question related to **- Error! Reference source not found. -** space , time, and participant [15] , with these independent dimensions, visualization can be applied to display data constructs as follows;

- ***The space-based tasks (where?)***

The space is the most relevant data dimension in this task, where in typical eye-tracking experiments the location of where the participant is looking at is investigated.

- ***The time-based tasks (when?)***

In this task time plays the most important role, as within this task the duration and the timing order of where the participants look at are investigated.

- ***Participant-based tasks (who?)***

In this task, when investigating the eye-tracking of a multitude of participants, it is important to know who shows a certain viewing behavior [15].

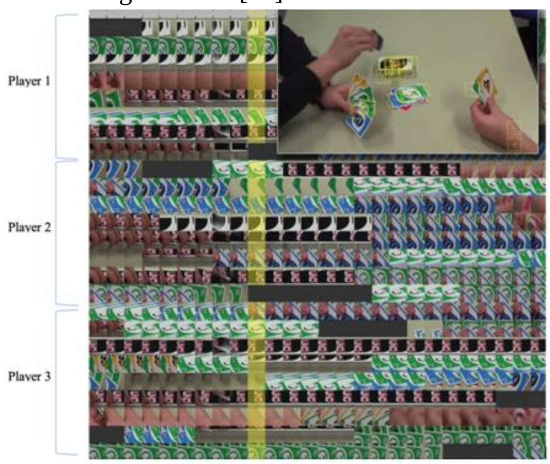

Fig 7. Visualization tasks analysis technique presenting the photos of players` gazing areas with the yellow vertical line presents the time [15].

Types of eye-trackers

Recently, eye-tracking technology has been undergoing rapid development that improved accuracy and stability [16] as involving tools such as head mounted devices, glasses, table mounted, and embedded systems are now largely enhanced. Those technology vary in accuracy and are compared to each other based on how accurately they reflect where the user is looking using the measurement of visual angle in degrees [17].

Generally, an eye-tracker is a device that can register and recording where eyes are looking, and

most modern eye-trackers use video-based technology to measure the position of the eyes using a camera - Fig 8 - that records the reflection of infrared light on the eye`s cornea or retina [17]

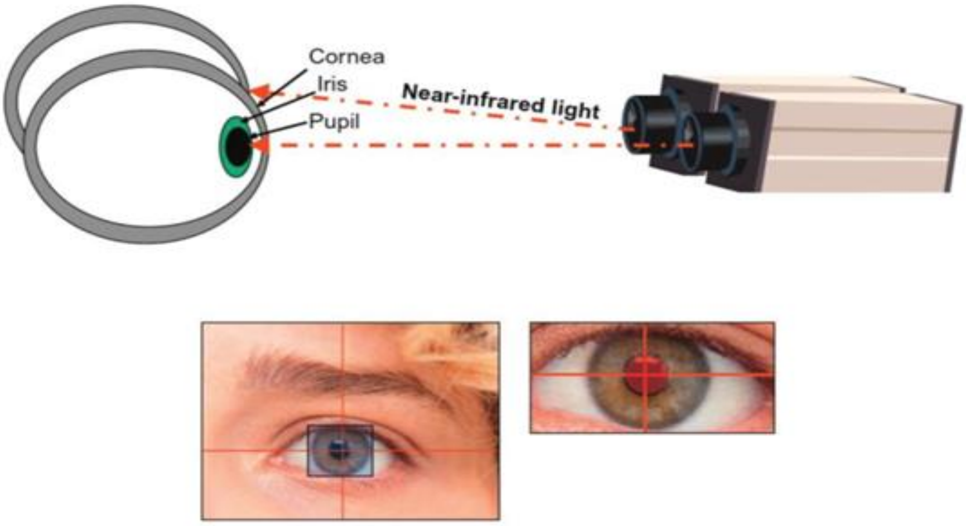

Fig 8. A conceptual illustration of how eye-tracking technology [10].

As shown in Fig 9, there are two main types of eye-trackers.

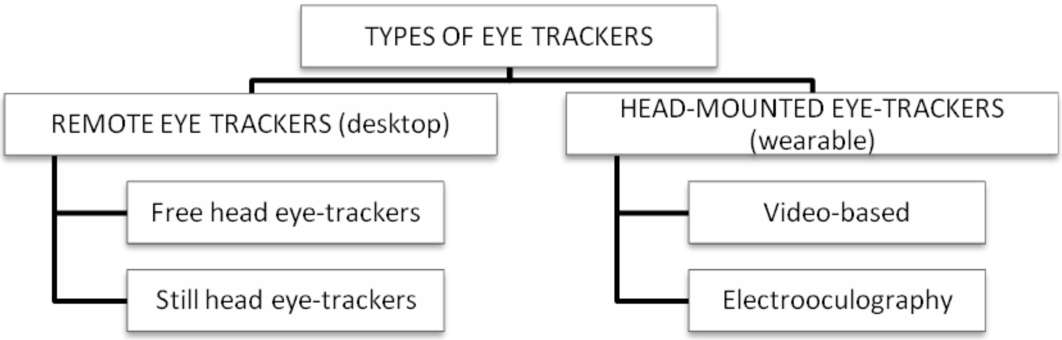

Fig 9. Main Types of eye-trackers.

Remote eye-trackers

Also called desktop eye-trackers [17], consist of cameras - Fig 10 - that are integrated into a separate box placed in front or attached to a computer monitor, or the cameras are integrated into the monitor causing remote eye-trackers to be less intrusive and to be considered as a better option compared to head mounted eye-trackers [17]. Remote eye-trackers deliver accuracy typically between 0.5 and 1 degree [17].

There are two types of remote eye-trackers, the free head eye-trackers in which the participant can move his head freely while in the other type which is the still head eye-trackers the participant`s head is held stationary using a chin rest or a bite bar [17].

Fig 10. Participant using a computer equipped with eye-tracker [10].

Head-mounted eye-trackers (wearable)

In Head mounted eye-trackers the user wears equipment on his/her head which makes it more invasive than remote eye-trackers [17] and might influence the accuracy as the user is aware he is being watched [17]. Nonetheless, head mounted eye-trackers have the advantage to record activities that are not confined to what is displayed on a computer monitor [17]. Free head mounted accuracy is typically about 0.5 degrees [17].

There are two different types of head-mounted eye-trackers: the video-based and the eye-trackers using electrooculography.

Video-based eye-trackers - Fig 11 - make use of infrared components as it illuminates the eye while a video camera records an image of the eye , then the images are processed to extract the center of the pupil and the infrared reflection on the cornea from which gaze position it calculated [8]. Nonetheless, while this technique is accurate, it obstructs a part of the visual field with the LED and the camera [8].

Fig 11. Video based wearable eye-tracker [8].

Electrooculography - Fig 12 - is the result of the effort to obtain a lightweight technology [8]. In this technique, the eye can be modelled as a dipole with its positive pole (+) at the cornea and its negative pole (-) at the retina. The electrical signal that can be measured from this field is called the electrooculogram. With using two pairs of electrodes placed at opposite sides of the eye and an additional reference electrode on the forehead, two signal components, corresponding to two movement horizontal and vertical components can be identified [8].

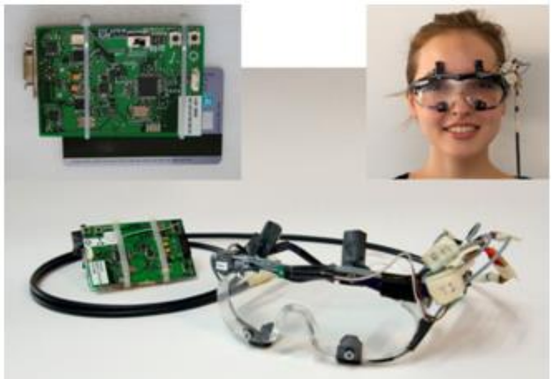

Fig 12. Wearable EOG googles [8].

Despite the recent technological advances, the development of mobile eye-trackers is still and active topic. Thus, if eye-trackers are intended to be used in daily life, it need to be portable and capable of real-time processing [8]. Nonetheless, the frequency of user experience (UX) activities using eye-tracking has recently exploded and eye-tracking is now accepted as a proven contributor in the (UX) evaluation tools [10].

3. Eye-tracking implementation in the architectural field

In the Architectural domain, eye-tracking has not received much recognition until the past decade due to some technological obstacles, such as the cumbersome size of eye-trackers, non-reliable eye-tracking outcomes, and hard to interpret results. Currently, With the rapid technology development, and the minimizing of eye-trackers to the size of a pair of glasses, and the development of eye-tracking data analyzing tools, it is possible for a larger number of researchers to utilize eye-tracking in their architectural workflows. Nonetheless, few studies focused on the implementation of eye-tracking in architectural research and practice were found and will be described in the following section.

Eye-tracking architectural representations

Park (2019) conducted a study Investigating how representations of architectural scenes affect people's perceptions, and the impact of the educational background and the sensitivity of the viewer to a change in the given architectural scene. In the study, Park (2019) recorded eye movement while looking at six pairs of presentations containing line drawings and photographs of the same buildings **-Fig 13 -** using an eye-tracker (SMI REDn Scientific eye-tracker) along with a specialized analysis software (SMI BEGAZE analysis software) [18].

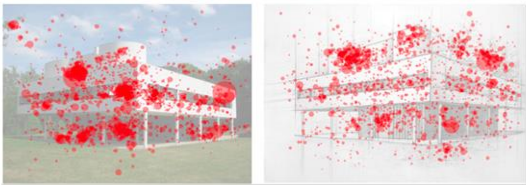

Fig 13. Visualization of fixation on a photograph (left) and line drawing (right) [18].

.

The study found that the visual perception differs according to the type of representation – a sketch or a photograph- and points of focus and attention beside gaze and fixation duration varies in each case. Moreover, the study concluded the following: (i) the sketch line itself sometimes becomes the focus of attention. (ii) the reduction of the level of detail in the line drawing resulted in the decrease of high fixations, particularly near information-intensive areas. (iii) foreground objects were given higher attention compared to background objects, but their relative order change by their rendition in the line drawing as in the trees and the roof in Fig 14. (iv) longer fixations were moved from the ground level in the case of a photograph to the roof structure in the line drawing case [18]

Table 1. Fixation count and mean fixation duration by presentation [18].

	Photograph	Line drawing	t-value
Fixation count	42.85±6.633	44.11±6.342	-2.128*
Average duration (sec)	0.307±0.064	0.291±0.048	2.982**

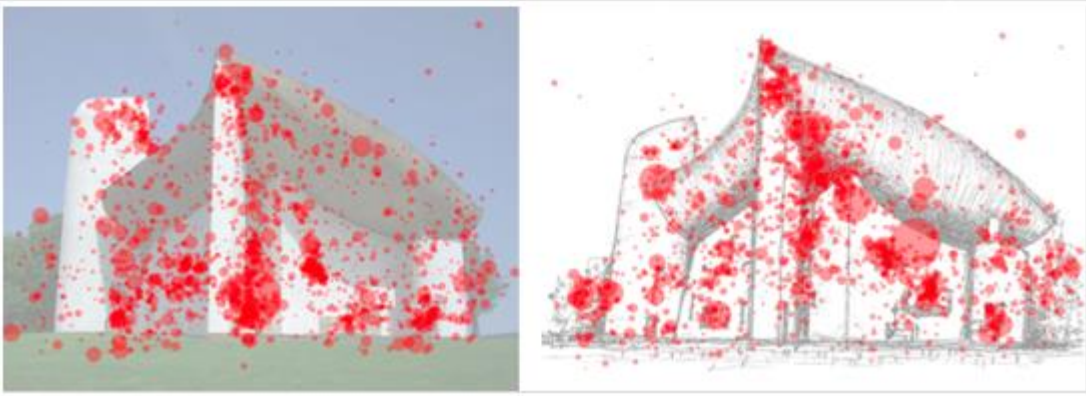

Fig 14. Fixation difference between line drawing and photograph [18].

Eye-tracking the perception of objects and spaces

In implementing eye-tracking in the study of perception of objects and spaces ,And determining the usefulness of eye-tracking research in learning the range and manner of perceiving architectural objects and urban spaces by people looking at them and using a stationary eye-tracker, Kuśnierz (2018) found that, Applying the eye-tracking method allows for (a) learning the range and manner of perceiving objects and spaces by people looking at them (b) allows for obtaining objective information concerning external stimuli such as details of architectural objects and spaces with their information content, which are merely noticed in the process of perception [3]. As shown in **Fig 15** (right) the areas of interest are indicated with the colors green (low), yellow(medium), and red (high) according to gazing intensity, where the (left) images indicates the three areas of interest found each with a different color.

Fig 15. Results in form of heat map (right) Established areas of interest (left) [3].

Eye-tracking pedestrians' critical visual tasks

In a study investigating different approaches to the interpretation of eye-tracking video records of pedestrians walking outdoors to determine the apparent importance of fixation on other pedestrians and how this is influenced by the frequency of occurrence, Fotios (2014) conducted the study Using Eye-tracking to record the visual fixations of test participants walking outdoors in daytime and after dark. The used eye-tracking system (SensoMotoric Instruments iView X HED) comprised two cameras mounted on a cycle helmet worn by the participant. One camera recorded the scene facing the participant and the second captured an image of the right eye [19].

The conclusion of the study drawn from the all-fixations data (Fig 16) is that path is the most important category of object as it has the highest proportion of fixations; observing other people appears less important. The critical-fixations approach reveals higher proportions of fixations on people and vehicles than did all fixations, although these differences did not reach significance. This increase in apparent importance reflects the increase in visual attention expected for objects of whose behaviours are less predictable than typically static items such as objects and goals [19].

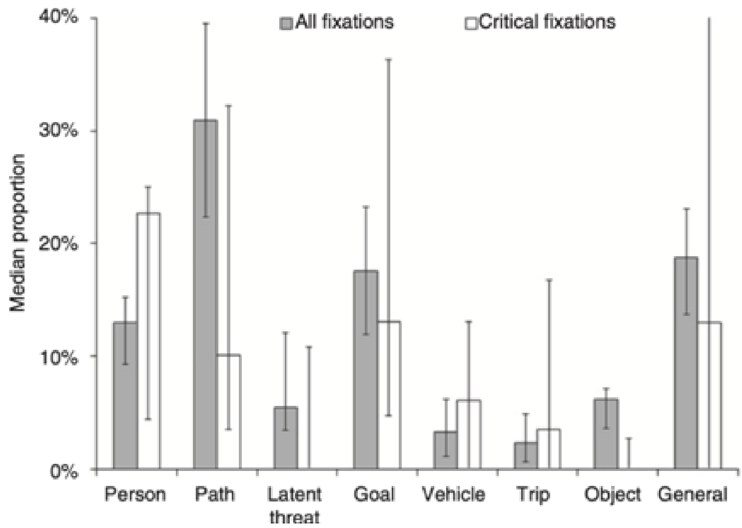

Fig 16. Fixations and critical fixations per category during after-dark sessions [19].

Eye-tracking Architectural features in building design

In a study aiming at providing empirical quantification on human experience in architectural spaces using an integrated and rapidly replicated VR and eye-tracking and attempting to answer the question "where do we look?", Zou (2019) studied the impact of architectural design features (e.g., presence/size of windows, level of natural light and nature view) on human experience in buildings using a mobile eye-tracking to capture the subjects' attention toward various design features.

Zou (2019) conducted the experiments with human subjects to monitor their attention while they were interacting with spaces configured with various design features positive and negative. The positive environment was designed with larger windows, ample natural light, and a view of green plants outside of the glass curtain walls - Fig 17 - while the negative environment was designed with smaller or no windows, only artificial lights, and closed concrete walls with no nature view.

Fig 17. Design features in positive (left) and negative (right) environments [20].

The results show that in the positive environment the subject is more focused on the navigational task, whereas in the negative environment, the subject showed a more distracted attention with several separated hot spots [20].

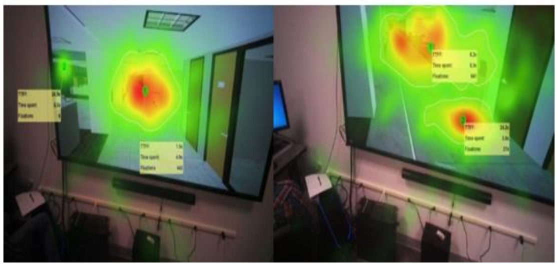

Fig 18. Heat Map result from eye-tracking data for AOI amount of natural lighting (left Positive, right Negative) [20].

Zou (2019) also conducted data analysis for the other eye-tracking metrics. On average, the subjects showed less time spent in the positive environment for each Area Of Interest (AOI) than the negative one, indicating the subjects were faster on the executing tasks in the positive environment. The subjects also had less number of fixations in the positive environment for all AOIs comparing to the negative one [20].

Table 2. Eye-tracking Metrics for AOIs in Positive/Negative Environments [20].

AOI	Time Spent (seconds)		Number of Fixations (times)		Time to First Fixation (millisecs)	
	Pos	Neg	Pos	Neg	Pos	Neg
Presence of windows	3.0	3.5	268	290	1.0	3.0
Size of windows	3.0	7.0	300	335	5.5	3.8
Level of natural light	5.0	5.4	421	630	1.5	5.2
Exposure to nature view	6.8	8.4	647	902	2.1	2.9

Moreover, subjects showed smaller Time to First Fixation (TTFF) which is calculated as the time in milliseconds that the subjects took to notice a specific AOI - and smaller TTFF indicates the high attention level and more focused mind - for the AOI: presence of window, level of natural light, and exposure to nature views [20].

Eye-tracking visual attention of architectural elements

In an attempt to understand the impact of specific architectural elements on viewers' visual attention using an eye-tracker to record participants' eye movements, the research conducted by lee (2015) investigated the relationship between gaze patterns and the formal properties of architectural elements as viewed by architecture majors and non-majors. In order to test the research hypotheses, a series of nine architectural scenes was presented to two groups of participants, one with architectural training and one without. The scenes consisted of pairs of images; the second image in each pair was manually edited - Fig 19 - to remove the architectural element(s) under control. Then, the images were divided into two experimental sessions to record participants' eye movements. the selected images for this study were grouped into three categories of architectural elements based on their formal and functional attributes: vertical components (columns and stairways), horizontal components (ceiling and floor patterns), and other visual attractions (wall patterns, signboards, and people).

Fig 19. An image used in the investigation. The space with a column (left) and with the column removed (right) [1].

Fig 20. Sample scan-path of a major (top) and non-major (bottom) [1].

The research results suggest that (1) majors focus more on three-dimensional architectural elements than do non-majors, who focus more on two-dimensional visual elements, and (2) the aesthetic effects of architectural elements as reflected in a viewer's visual attention conform to Gestalt principles of perception [1].

4. Discussion

Eye-tracking technology is an innovative way of directing the attention of future architects and designers to the issue of the objective visual assessment of either architecture or design proposals representations. Nonetheless, the introduction of eye-tracking studies into architecture and related studies relates to several advantages and disadvantages, which include the following:

- ***Advantages***

- Rising the interest in the experimental aspect of architectural research and design, which may lead to solving design challenges in a more innovative way.
- Providing a way of communicating the visual experience of the viewer graphically, numerically in an objective, accurate and unbiased manner.
- Enables to accept non-standard design orders in the future that will require in-depth analysis of visual needs of the users.
- Highlighting the importance of the visual perception of architecture and bringing it close to its everyday users and promoting the profession of the architect.

- ***Disadvantages***

- Eye-tracking equipment, maintenance, and conservation is relatively complex and not available for public use.
- Eye-tracking devices only allows for the investigation of one person`s visual experience at a time.
- Eye-tracking devices are not mobile which limits it only to indoor experiments using representations of the actual object of study.

- Eye-tracking tools still have some technical limitations regarding latency and accuracy.

This study believes that, if those drawbacks were addressed it can alter the manner and sequence of architecture design process in a more positive, informative, and innovative manner that involves and integrates visual behavior and response of the public objectively.

5. Conclusion

Eye-tracking technology as it is a relatively a new technology and is still under research and development and is generally directed to marketing and related psychological studies other than architecture practice, it has some drawbacks when used in architecture realm due to the nature of its tools and equipment.

Thus, this study concludes the following;

- Eye-tracking is an innovative and powerful technology that enables architects to detect how their designs and buildings are visually perceived.
- Eye-tracking technology highlights new aspects and factors that are overlooked in current architecture practice.
- Eye-tracking technology facilitates decision making concerning the visual and formative aspects of designs and proposals.
- Eye-tracking technology enables architects to understand not only if their architecture, spaces, and urban spaces are seen but how it is seen in an objective and unbiased manner.
- Eye-tracking technology provides a new methodology to test space perception [1] and the order of architecture elements within based on the visual interest of the viewers.
- Eye-tracking technology assists the communication between the architect and the laymen.
- Eye-tracking technology explains the difference between how professionals and non-professionals visually perceive architecture and representations [18].

References

[1] S. Lee and E. Cinn, "Using an eye tracker to study three-dimensional environmental aesthetics: The impact of architectural elements and educational training on viewers' visual attention," *Journal of Architectural and Planning Research*, June 2015.

[2] M. Rusnak, "Eye-tracking support for architects, conservators, and museologists. Anastylosis as pretext for research and discussion," *Heritage Science,* 2021.

[3] M. Kuśnierz and M. Krupa, "Eye-tracking in research on perception of objects and spaces," *TECHNICAL TRANSACTIONS,* December 2018.

[4] J. Dijkstra and H. Timmermans, "EYE-TRACKING AS A USER BEHAVIOR REGISTRATION TOOL IN VIRTUAL ENVIRONMENTS," in *Proceedings of The Third Conference on Computer Aided Architectural Design Research in Asia*, Osaka, Japan, 1998.

[5] N. C. Ebner, D. H. Weir and R. D. Rainer, "Eye tracking," *Encyclopedia of clinical neuropsychology,* 20 September 2018.

[6] Merriam-webster.com, "Gaze," 25 August 2021. [Online]. Available: www.merriam-webster.com/dictionary/gaze.

[7] J. R. Bergstorm and A. J. Schall, Eye-tracking in user experience design, Wlatham: Elsevier, 2014.

[8] M. Vidal, J. Turner, A. Bulling and H. Gellersen, "Wearable Eye-tracking for mental health monitoring," *Computer Communications,* 2012.

[9] A. T. Duchowisky, Eye-tracking methodology: theory and practice, London: Springer, 2003.

[10] A. Bojko, Eye-tracking the user experience, Brooklyn, New York: Rosenfeld Media, 2013.

[11] E. M. Reingold, "Eye-tracking Research and Technology: Towards Objective Measurement of Data Quality," *Visual Cognition,* 22 April 2015.

[12] wikipedia.org, "Saccade," 25 August 2021. [Online]. Available: https://en.wikipedia.org/wiki/Saccade.

[13] D. Richardson and M. Spivey, "Eye-Tracking: Characteristics and Methods," *Encyclopedia of Biomaterials and Biomedical Engineering,* February 2004.

[14] R. S. Allison, M. Eizenman and B. S. K. Cheung, "Combinedl Head and Eye-tracking System for Dynamilc Testing of the Vestibular System," *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING,,* vol. 43, November 1996.

[15] M. Burch, L. chuang, B. Fisher, A. Schmidt and D. Weiskopf, Eye-tracking and visualization, Switzerland: Springer, 2017.

[16] H. Fu, Y. Wei, F. Camastra, P. Arico and H. Sheng, "Advances in Eye-tracking Technology: Theory, Algorithms, and Applications," *Computational Intelligence and Neuroscience,* July 2016.

[17] K. T. Hvelplund, "EYE-TRACKING AND THE TRANSLATION PROCESS: REFLECTIONS ON THE ANALYSIS AND INTERPRETATION OF EYE-TRACKING DATA," *MonTI Special Issue,* 5 September 2013.

[18] J. Park, Y. Jin, S. Ahn and S. Lee, "The Impact of Design Representation on Visual Perception: Comparing Eye-Tracking Data of Architectural Scenes Between Photography and Line Drawing," *Archives of design research,* February 2019.

[19] S. Fotios , J. Uttley and B. Yang, "Using eye-tracking to identify pedestrians' critical visual tasks.," *Lighting Res. Technology,* 13 January 2015.

[20] Z. Zou, "Where Do We Look? An Eye-Tracking Study of Architectural Features in Building Design," in *Proceedings of the 35th CIB W78 2018 Conference: IT in Design, Construction, and Management,* January-2019.