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An Eye-Tracking Study to Identify the Most Observed Features in a Physical Prototype of a Tiny House

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Abstract

This exploratory work aims to understand which elements of a building mostly attract visitors' attention. An experiment was conducted to allow participants to visit a prototype tiny house while wearing eye-tracking glasses. Identified gazed elements of the prototype were selected and the corresponding dwell times used as variables. The limited dwell times on structural elements show that they can be easily overshadowed by other features present in the building. This leads to a design problem when the novelty and the quality of a new product, markedly a building, reside in the materials used.

Keywords: human-centred design, interaction design, architectural design, eye tracking

1. Introduction

Neuroscience and cognitive studies are gaining traction in the design of buildings, architecture, and new urban environments (Hollander et al., 2018; Karaca et al., 2020). These studies investigate how people perceive and experience urban and architectural environments, offering new opportunities for urban and architectural design and planning. Several elements of urban space (edges, crossings, landmarks) or a building (facades, cornices, columns, materials, furnishings) have an impact on people's perceptual and mental maps. However, how these impact the visual perception of space remains unexplored (Sayegh et al., 2015). In particular, it is still unknown which urban, architectural, furniture or material elements are more attractive to human eyes and why people are more attracted to particular architectural aspects than others.

In a position paper, Albright et al. (2020) reveal how eye-tracking technologies can help address these questions by considering that humans visually focus on buildings' parts and features whose corresponding information they want to process. Still, with the help of wearable eye-trackers that allow recording of gaze data during a walk, scholars can measure the human's visual perception patterns in response to elements in an architectural environment (Karaca et al., 2020). However, even though the values of visual perception are widely accepted as a critical element to understand and plan new architectures and urban morphology, few studies analyse human perception in real buildings (De la Fuente Suárez, 2020). This paper aims to fill this gap in the literature by exploring visual perception within a prototype house, focusing on interior environments. Through mapping the eye gaze of participants, the present study gains some insights into the most explored features of a building and its interiors. In particular, the study addresses the balance between structural elements and other elements (furniture, doors and windows, objects present in rooms, etc.), which is a major point raised in (Albright et al., 2020) and sheds light into the consistency of exploration across participants.

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2. Background

The use of eye-tracking tools is increasingly diffused in various research areas, such as design (Borgianni and Maccioni, 2020), and human-machine interaction (Djamasbi et al., 2011, Stephane, 2017). Tracking eye movements captures information about gaze distribution and, consequently, understanding and studying human perception and cognition (Borgianni and Maccioni, 2020). Indeed, the concentration of the gaze on stimuli and consequently the visual engagement reflects human attention that, if studied, can help to decode human cognitive patterns (Sayegh et al., 2015).

Reflecting a general interest in the use of eye-tracking tools, empirical studies using eye-trackers have grown in the field of architecture to deepen the knowledge of human experience in the built environment (Karaca et al., 2020). The literature in this area differs mainly on the types of stimuli presented to participants in different experiments. It is possible to distinguish stimuli presented in the form of a) renderings, drawings or 3D models of buildings, architectural or landscape environments; b) immersive Virtual Reality (VR) of buildings, architectural or landscape environments; c) real buildings, architectural or landscape environments. These three categories are inherently explored by different eye-tracking systems, i.e. remote, VR-integrated, and mobile (or glasses), respectively. Table 1 shows the studies reviewed in the literature, divided into the three categories of stimuli and between indoor and outdoor examples. The main characteristics with relative advantages and disadvantages of each category are also shown in Table 1, with a focus on visual attention resulting from studies

Table 1. Comparison between existing architecture and building environment eye-tracking research.

<table>
<tr><th>Stimuli presented to the participants</th><th>Existing Studies</th><th>Advantages and Disadvantages</th><th>Visual attention</th></tr>
<tr><td>Photorealistic Pictures or Photos</td><td>Indoor: Cho and Suh (2020); Li et al. (2021); Song et al. (2016); Tuszynska-Bogucka et al. (2020)
Outdoor: Dupont et al. (2014); Hollander et al. (2018); Lisińska-Kuśnierz and Krupa (2020); Mohammadpour et al. (2015); Noland et al. (2016); Sussman and Ward (2019)</td><td>The use of remote eye trackers is exclusive to this category of research. On the one hand, the experiment is conducted so that the participant's attention is not disturbed. On the other hand, the scene is framed from only one point of view, and it is not known how the participant's attention would change if they had the opportunity to move freely around the scene.</td><td rowspan="3">Participants' attention was mainly focused on contrasting but soft colours (Cho and Suh, 2020; Tuszynska-Bogucka et al., 2020; Mohammadpour et al., 2015; Zou and Ergan, 2019) and decoration (Li et al., 2021; Schrom-Feiertag et al., 2016) with modest proportion of wood (Song et al., 2016). Open outdoor spaces (Dupont et al., 2014) or with details of facades (Lisińska-Kuśnierz and Krupa, 2020), windows (Hollander et al., 2018) and architectural elements (Kim and Lee, 2020; De la Fuente Suárez, 2020) have been preferred, ideally with little disturbance given by traffic (Noland et al., 2016)</td></tr>
<tr><td>Virtual Reality</td><td>Indoor: Schrom-Feiertag et al. (2016); Zou and Ergan (2019)
Outdoor: Kim and Lee (2020); Zhang et al. (2019)</td><td>Studies in this category allow a more realistic view of environments, features and details to be assessed. However, the space for movement in the experiments is still limited. The quality of the images on the participants' perception is still representing a drawback in the use of this technology</td></tr>
<tr><td>Real environment</td><td>Indoor: Ding (2020); Hermund et al. (2018); Pelowski et al. (2018); Tatler et al. (2016)
Outdoor: De la Fuente Suárez (2020); Rupi and Krizek, (2019); Sayegh et al. (2015); Simpson et al. (2019)</td><td>The use of mobile eye trackers allows participants to move freely within the experiment area. The main problem is the analysis of the results, as there might be many differences in the participants' exploration strategies. In addition, the presence of disturbing elements in the experiment is significantly higher than in a controlled environment, such as a laboratory.</td></tr>
</table>

In the first category, studies are mainly concerned with assessing the aesthetic and cultural appearance of buildings or city neighbourhood environments (Hollander et al., 2018) or expressing preferences

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regarding landscape features (Dupont et al., 2014). In the second category, the stimulus is represented by a virtual scene, presented to the participants in the study through both the use and the absence of a VR headset. The objectives in these cases are also to assess the aesthetic appearance of buildings (Kim and Lee, 2020) or to express preferences on the characteristics of indoor (Zou and Ergan, 2019) or outdoor environments (Zhang et al., 2019). The third category of stimuli involves studies performed in real-world environments by means of mobile instruments. These studies aim to understand the attention that people pay to different aspects during a wayfinding task in an architectural or urban environment (Ding, 2020). The interest in understanding the attention paid by participants is not only focused on building-related aspects but also on works of art in a museum (Pelowski et al., 2018), objects and materials in furniture (Tatler et al., 2016) or retail environments (Hermund et al., 2018). Instead, some studies focus on understanding how attention to different elements of a building changes over space-time (De la Fuente Suarez, 2020).
The advancement of technology and the availability of tools such as mobile eye-tracking has made it possible to obtain insights into a range of different everyday actions, e.g.

- how people visually choose different paths (Marius't Hart and Einhäuser 2012);
- how people distribute gaze differently across different light degrees (Fotios et al. 2014);
- how people use maps during real-world wayfinding (Kiefer, Giannopoulos, and Raubal 2013).

However, studies of optical behaviour in real environments using mobile eye-tracking tools are so far limited in number. A possible reason behind this circumstance is the fact that, while eye-tracking tools are appropriate to evaluate quality and perception of prototypes and representations of ideas and products during the design process, physical prototypes are never created in the construction industry. The few studies available are mainly focused on the exterior aspects of a building or wayfinding. Fewer are earmarked to studying real buildings' interior and how the materials, the furniture, the geometry and the shape can affect the human perception. Several authors have shown how the difference in gaze distribution changes considerably between case studies carried out in the laboratory and those carried out in natural environments, emphasising the need to conduct more experiments in realistic contexts (De la Fuente Suárez, 2020).
In this context, the paper presents a case study of using eye-tracking in a physical space of a prototype building (see Section 3). The objective is to get an understanding of the building areas that attract more attention under the circumstance that participants were recruited on site and, therefore, they could have no expectations of what could be found inside the prototype. In addition, the unevenness of explorations made by participants, and previously hypothesized, is qualitatively tested. Recommendations about the use of eye-tracking for free and unconstrained exploration, especially for the evaluation of buildings and spaces, are subsequently inferred based on the present experience.

3. Materials and Methods

The study is part of the project "Tiny FOP MOB - A Real World Laboratory made of wood and hemp travelling through the Vintschgau Valley"(Tiny FOP MOB). A prototype of a tiny house (then named Tiny FOP MOB) was designed and built on a trailer, which eased its transportation of the house in different municipalities of the Vintschgau Valley. The prototype and the choice of its materials provides a sustainable example in the building sector (see below), while the possibility to move the tiny house in different places of the Valley allowed researchers to spread knowledge about the scopes and characteristics of the Tiny FOP MOB. Beside the activities and the events organised within the scopes of the project, an experiment was conducted successfully involving 26 participants to gain information on human visual perception within the interior of the prototype. Participants were asked to visit the tiny house wearing eye-tracking glasses (Tobii Pro Glasses 2) and fill in a questionnaire at the end of the visit. Experiments were initially approved by the statistical office of the project leader and the ethical commission of the Institution the authors belong to. Further details are in the following subsections.

3.1. Materials

Two South Tyrolean companies from the Vintschgau Valley designed and built the Tiny FOP MOB prototype. The main structure of the house is made of hemp bricks (mixture of hemp, limestone

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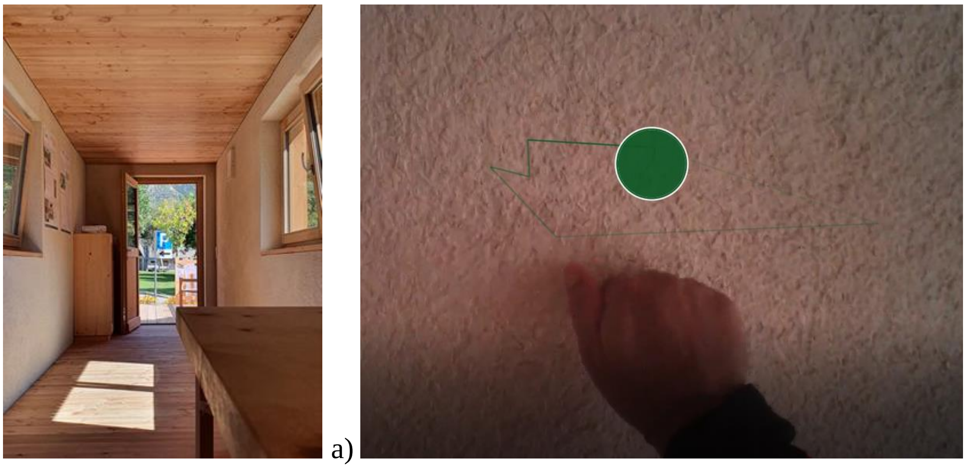
powder and water) and wood (structure and external coating). Due to the combination of these materials, the walls resulted to be thicker than the walls of standard wooden houses. Some wood furniture has been included in the prototype as well (a table, chairs, and a cabinet). The local materials used, and the hemp bricks play a role in the environmental impact of the Tiny FOP MOB, which is CO_2 negative based on first estimates. The Tiny FOP MOB is thus intended to be a sustainable example to make people think about sustainability in the building sector. The trailer where the prototype is built on enabled its transportation in five pilot locations in the Vintschgau Valley in the period of July - November 2021. Figure 1 shows the interior of the tiny house prototype. By means of Figure 1. a), it is possible to notice some of the wooden furniture, door and windows, and informative materials (to be used as a communication requirement for the project) beyond the structure of the Tiny FOP MOB (walls, ceiling, and floor). Figure 1. b) shows a detail of the wall and its texture.



a) b)

Figure 1. Interior of the tiny house used in the experiment (a) and details of the wall during an observation (b)

3.2. Participants

28 participants took part in the experiment on a voluntary basis. However, two participants were excluded from the sample because of the failure to answer the questionnaire (hence the motivation of this subject could be different from others and represent a bias), and a malfunctioning of the eye-tracking device, respectively. The number of valid experiments is therefore in line with eye-tracking studies in the field of design, markedly (Lohmeyer et al., 2014). Volunteers were recruited among by-passers on three of the location sites where the prototype was placed. The participants were not informed about the sustainable qualities of the prototype and the type of materials used to avoid influencing them during the execution of the experiment. All adults were considered eligible to take part in the experiment with no restrictions apart from visible physical impairments. To be allowed to visit the tiny house and be equipped with the eye-tracking glasses, perspective participants should just confirm to be at least 18 years old due to legal issues. The final sample included Vintschgau Valley inhabitants, tourists, and university students taking part in a teaching excursion.

3.3. Procedure

People accepting to participate were recruited and informed that no personal or sensitive data was acquired, mainly due to privacy reasons imposed by the project. A code would have been assigned to each participant to ensure the anonymousness of data and to match eye-tracking data with questionnaire results (which are not treated here because of the different scope of the paper). The code reported initials of the town where the experiment took place and an ordinal number of the participant, e.g. Schl01.

After the recruitment, they were informed that they could visit the tiny house as long as they wanted and with no restrictions after being equipped with the eye-tracking glasses. It was specified that they were left free to observe the interior of the tiny house with no specific task to be performed during the

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visit and the exploration. This is a standard procedure derived from the literature analysis in urban and architectural environments. In fact, with a few exceptions (e.g. Cho and Suh, 2020; Ding, 2020; Hollander et al., 2018), most studies have preferred not to guide participants with an assigned task during the experiment to allow the individual participant to explore freely. The participants were nevertheless aware of the request to fill in an evaluation questionnaire after the visit; this was thought to encourage a thorough exploration beyond serving different scopes of the project. The following additional measures were taken and communicated to recruited participants.

1. Detailed information about the Tiny FOP MOB was given only if explicitly requested by the participant; informative materials were present in any case inside the tiny house.
2. Participants were asked to visit the Tiny FOP MOB with eye-tracking glasses one at a time. They were informed about the sanitary rules to be followed regarding the pandemic-related restrictions at the time of experiments.
3. Participants were free to interrupt the experiment in any moment without any required explanation and to ask for the deletion of their data.

The first measure was taken to allow a free and unbiased exploration of the prototype. To maximize participants' and experimenters' safety, the Tiny FOP MOB was regularly aired out and sanitized.
After the instructions, participants were asked to wear the eye tracking glasses during the visit of the interior of the prototype. Prescription lenses were available for participants with long- or short sightedness problems. The participants were helped by a researcher to wear the device correctly and avoid ailments. After the calibration process, the data acquisition started. The recording of the visual data was interrupted as soon as the participant exited the house. The researchers helped the participants to take the device off and proceeded to the disinfection of all the parts that were in contact with the participant's skin (interchangeable nose support, glasses arms, and battery room).
In the meanwhile, participants were invited to answer the paper-based questionnaire. Once the participant submitted the evaluation questionnaire, they were thanked for the availability and discharged. No reward was given since participation was on voluntary basis.
Figure 2 summarizes the experimental procedure described above, which highlights the willingness of the participation and the attention paid to avoid recruited people's discomfort. No participant reported any kind of uneasiness at the end of the experiment.

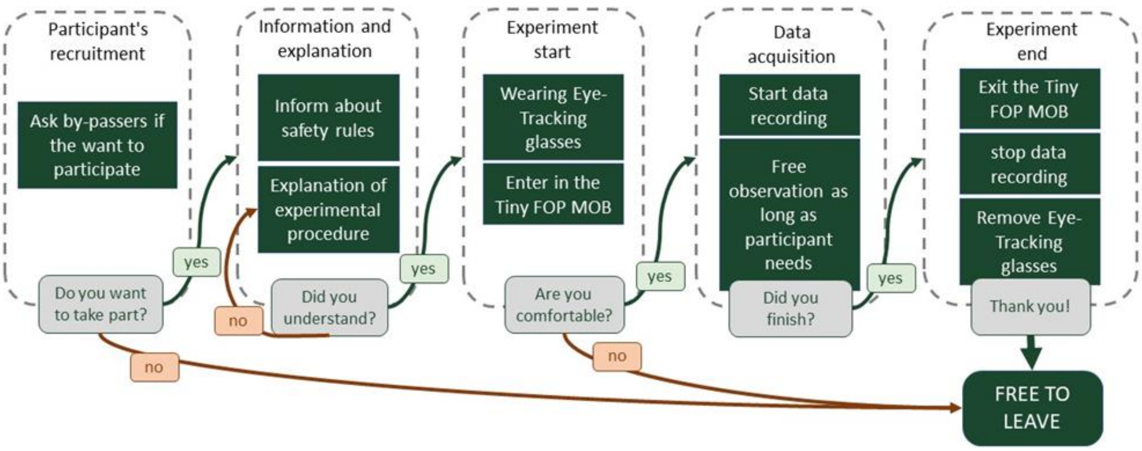

Figure 2. Scheme of the experimental procedure form participant's recruitment to their discharge

4. Data collection, Post-Processing and Analysis

Since the objective of the work is to detect the most observed areas within the building, the present section presents the methodological steps to process acquired data to eventually compute dwell times. Dwell times are the amount of time spent in gazing distinct elements, which are frequently used as proxy of attention aroused in design studies, e.g. (Lohmeyer et al., 2014). In the field of eye-tracking,

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consistent and well-defined elements are commonly referred to as Areas of Interest (AOIs), for which dwell times and other measures are typically calculated or extracted.
As mentioned, the authors used the Tobii Pro Glasses 2 to acquire data about participants' visual behaviour inside the tiny house prototype. A laptop equipped with bespoke software to control the functioning of the eye-tracking recording (Tobii Glasses Controller) and subsequent analysis (Tobii Pro Studio) was used to store and process all the acquired visual data. It is worth noting that none of the data gathered allows the identification of participants or the existence of medical problems.
For the scopes of the paper, it can be stressed that the used tools allow the recording of a first-view visual experience, resulting in the creation of a video showing instantaneous gaze points. The display of fixations, which are routinely represented by gaze plots, support the process of identifying instantaneously gazed elements, as shown in Figure 1. b). The recordings have been processed to recognize and identify different gazed elements of the tiny house during the experiments, which were categorized into ten AOIs, listed, numbered and extensively described in Table 2. On their turn, the chosen AOIs can be grouped into three classes.

- AOIs 1-3: structural elements of the building; in the present case study, those are supposed to be the main qualifiers of the tiny house, especially from the viewpoint of sustainability, because of the materials used.
- AOIs 4-7: elements typically found in buildings and houses.
- AOIs 8-10: elements present as a result of different circumstances, especially project requirements.

Table 2. Areas of Interest and visual triggers for the subdivision of eye-tracking recordings

Area of Interest	Description and details
1. Walls	Internal walls of the tiny house
2. Ceiling	Wooden top covering (including its perimeter and the piece of the wall in the immediate nearby)
3. Floor	Wooden floor of the tiny house (including its perimeter and the piece of the wall in the immediate nearby)
4. Window and door frames	Perimeter of the windows and door wooden frame and their handle (the glass of the window was excluded since it was considered as "outdoor")
5. Furniture	Wooden table, chairs, and cabinet
6. Lightning	Hanging lamps and switches
7. Outdoor	Everything visible from the windows of the Tiny house (it was considered when the participant looked in the middle of the window)
8. Information materials	Informative posters and brochures about the project, its aim and materials.
9. Projector screen + electronic devices	Projector screen and electronic devices present in the tiny house for the scope of the project, e.g. projector, temperature sensors
10. Disturbance elements	Experimenters' personal belongings, bags and everything not directly related to the project, which could not be removed at the time of the experiment because of peculiar contextual factors

As the experiment involved a physical space and eye-tracking glasses, the extraction of data concerning AOIs is not automatically performed by the software, as the observed picture is not known a priori, like in the case of exposing pictures and using remote eye-tracking. Therefore, the analysis included the manual processing of the 26 recordings; here ten kinds of different triggers were introduced to mark the beginning of the exploration of specific AOIs. Those are shown with different colours in the part highlighted through a red box in Figure 3, which depicts the timeline of an illustrative recording and the working environment. Reportedly, the time needed to introduce triggers was approximately three times the duration of the recordings. After the introduction of triggers, data was then processed with Tobii Pro Studio and some parameters exported in the fashion of a spreadsheet file. The time spent on an AOI in a single instance for a specific participant could be calculated as the time elapsed from the introduction of its corresponding trigger to the introduction of

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a new one. As participants could gaze at the same AOI in multiple instances, total dwell times were then calculated by summing the duration of each instance.

Figure 3. Timeline of an illustrative recording; the introduction of triggers is emphasized

5. Results and Discussion

Table 3 reports some of the summative outcomes of dwell times for each AOI, class of AOI, and the total duration of the visits of the tiny house. All the variables have been subjected to a Shapiro-Wilk test by using the software Stata13 (function *swilk*) to verify their normal distribution; the last column of Table 3 indicates the p-value of the test. As a common rule of thumb, the rejection of the null hypothesis of the non-normal distribution takes place when the confidence level is greater than 0.05. It follows that the dwell times on the AOI "Lightning" only can be considered distributed normally. By the way, this AOI is on average the least observed.

Table 3. Dwell times for studied Areas of Interest and outcomes of the Shapiro-Wilk test

Area of Interest	Average dwell time (ms)	Standard deviation (ms)	Maximum (ms)	p-value (Shapiro-Wilk)
1. Walls	19106	18155	92358	0.00001
2. Ceiling	5214	6476	29713	0.00002
3. Floor	3855	4194	12873	0.00025
4. Window and door frames	23846	23214	100552	0.00006
5. Furniture	17403	15284	64463	0.00708
6. Lightning	2151	1650	5087	0.05149
7. Outdoor	4629	4628	16699	0.00080
8. Information materials	111362	163013	507857	0.00001
9. Projector screen + electronic devices	17644	14633	61315	0.00016
10. Disturbance elements	8533	5451	25616	0.00177
Class of AOIs 1-3 - structural elements	28175	21039	94627	0.00437
Class of AOIs 4-7 - ordinary elements	48028	33528	130643	0.02794
Class of AOIs 8-10 - peculiar elements	137540	166995	540949	0.00002
TOTAL	213743	175030	675741	0.00011

The failure to attain normal distributions along with the large values of standard deviations, which exceed or are comparable to mean values in several cases, support the tenet that the visual and exploration behaviour across participants is extremely various. The distribution of mean dwell times across different AOIs (Table 3) indicates that the presence of visual elements potentially considered as

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"outliers" in a given environment can capture an extensive amount of people's attention. In the specific case, the consideration of information materials was likely heightened by the awareness of the request to fill in an evaluation questionnaire and the presence of written text on posters and brochures. Here, the prominence of textual stimuli in eye-tracking research is actually largely recognized, not only in psychology and consumer behaviour, but also in design, e.g. (She and MacDonald, 2018).

With respect to the overall exploration and attention paid to different elements of a building, this research objective was addressed by testing the differences in terms of distributions of dwell times. Due to the mentioned lack of normal distributions of variables, non-parametric tests were preferred. Still by benefitting from Stata13, the Wilcoxon matched-pairs signed-rank test was used. The outcomes of test (function *signtest* in the used software) include outputs of one-tailed and two-tailed tests, thus allowing researchers to verify if two variables are comparable or if the former can be assumed as significantly greater than the latter (or vice versa). As the structural elements were mainly in focus, as stressed in the Introduction, the dwell times of the corresponding class of AOIs were firstly compared against the other two classes. It emerged that dwell times devoted to structural elements are significantly lower than those ascribable to both:

- ordinary elements; $p=0.005$;
- peculiar elements; $p=0.038$.

Within structural elements, the dwell times on walls are significantly longer than on ceiling and floor (p-value<0.0001). No significant differences were found between the observation of the ceiling and the floor. The outcomes concerning the larger amount of attention paid to walls than to other structural elements can be motivated by at least two aspects.

- The peculiarity of the walls in the present experiment, whose texture was visibly different from ordinary ones whether participants understood that the material used was hemp, plainly less diffused than other construction materials.
- Walls are found at eye level, while the other elements were found in the peripheral vision.

6. Conclusions and Outlook

The paper has shown which elements of a building attract major attention in a visitor. The original elements of this study follow the scarcity of eye-tracking experiments conducted through a physical prototype in the fields of architecture, the construction industry and, the built environment in general. The presented results, while contributing to the understanding of what is actually observed in a building, show that the dwell times spent on structural elements are relatively limited. In other terms, structural elements can be easily overshadowed by other features present in the building. This applies not only to disturbing elements, but also to other things that are normally present in buildings and rooms. These outcomes represent a straightforward design problem when the novelty and the quality of a new product, markedly a building, reside in the materials used. For instance, in the specific case study, structural elements were thought as the key to communicate the tiny house's sustainable performances. Here, it can be assumed that this might have not taken place in absence of information materials.

The results have also confirmed the disparity of people's behaviour during the observation of an artefact, and markedly a large object that cannot be manipulated, such as a building. This can be inferred, among the others, by paying attention to the variability of visit durations (last row of Table 3). The lack of a standard behaviour represents a problem for both designers and scholars, as an even larger number of evaluators would be required to attain results that are more generalizable, while eye-tracking experiments are relatively complex and ordinary participants are recruited with many difficulties. From a methodological point of view, the time needed to process results, is a clear obstacle to the wide-scale diffusion of the approach followed in the present paper.

It is worth mentioning other limitations and making further remarks. The classification of AOIs is original and potentially usable in other studies in the construction sector, but elaborated in an intuitive way, and hence subjective. The accuracy and the process repeatability in the subdivision of recordings cannot be assessed; however, the large variability found makes the authors think that errors in the order of magnitude of milliseconds would not be critical. Yet, the authors believe that the presented classification of eye-tracking studies in architecture, interior design and the built environment (Table 1) can be a valuable starting point for other scholars, beyond an analysis conducive to the present research. Moreover, the fact that a task was requested to participants after the use of eye-tracking tools, makes the results of the present study hardly comparable with both with-task and without-task experiments. Future work is intended to link eye-tracking results with questionnaires' data, markedly with evaluations and perceptions of the tiny house. Further insights could be gathered by analysing individual recordings more in details and extrapolating typical behaviours.

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References

Albright, T. D., Gepshtein, S., and Macagno, E. (2020), "Visual Neuroscience for Architecture: Seeking a New Evidence-Based Approach to Design", Architectural Design, Vol. 90 No. 6, pp. 110-117. https://doi.org/10.1002/ad.2639

Borgianni, Y., and Maccioni, L. (2020), "Review of the use of neurophysiological and biometric measures in experimental design research", Artificial Intelligence for Engineering Design, Analysis and Manufacturing. Cambridge University Press (AI EDAM), Vol. 34, No. 2, pp. 248-285. https://doi.org/10.1017/S0890060420000062

Cho, J. Y., and Suh, J. (2020), "Spatial Color Efficacy in Perceived Luxury and Preference to Stay: An Eye-Tracking Study of Retail Interior Environment", Frontiers in psychology, Vol. 11, p. 296. https://doi.org/10.3389/fpsyg.2020.00296

De la Fuente Suárez, L. A. (2020), "Subjective experience and visual attention to a historic building: A real-world eye-tracking study", Frontiers of Architectural Research, Vol. 9, No. 4, pp. 774-804. https://doi.org/10.1016/j.foar.2020.07.006

Ding, N. (2020), "The effectiveness of evacuation signs in buildings based on eye tracking experiment", Natural Hazards, Vol. 103, No. 1, pp. 1201–1218. https://doi.org/10.1007/s11069-020-04030-8

Djamasbi, S., Siegel, M., and Tullis, T. (2011), "Visual hierarchy and viewing behavior: An eye tracking study", In 14th International Conference, HCI International 2011, Orlando, FL, USA, July 9-14, 2011, Springer, Berlin, Heidelberg, pp. 331-340. https://doi.org/10.1007/978-3-642-21602-2_36

Dupont, L., Antrop, M., and Van Eetvelde, V. (2014), "Eye-tracking analysis in landscape perception research: Influence of photograph properties and landscape characteristics", Landscape research, Vol. 39, No. 4, pp. 417-432. https://doi.org/10.1080/01426397.2013.773966

Fotios, S., Dong, M., Yang, B., and Lin, Y. (2014), "Interpersonal judgements, lamp spectrum and task difficulty", In Proceedings of CIE 2014 Lighting Quality & Energy Efficiency, 23-26 April 2014, Kuala Lumpur, Malaysia, pp. 357-366.

Hermund, A., Klint, L., and Bundgård, T. S. (2018), "BIM with VR for architectural simulations: building information models in virtual reality as an architectural and urban designtool", In ACE 2018 Singapore: ACE 2018 - Global Science and Technology Forum, Singapore, Singapore, Singapore May 14 - 15 2018, pp. 378-385.

Hollander, J. B., Purdy, A., Wiley, A., Foster, V., Jacob, R. J., Taylor, H. A., and Brunyé, T. T. (2018), "Seeing the city: Using eye-tracking technology to explore cognitive responses to the built environment", Journal of Urbanism: International Research on Placemaking and Urban Sustainability, Vol. 12, No. 2, pp. 156-171. https://doi.org/10.1080/17549175.2018.1531908

Karaca, F., Guney, M., Kumisbek, A., Kaskina, D., and Tokbolat, S. (2020), "A new stakeholder opinion-based rapid sustainability assessment method (RSAM) for existing residential buildings", Sustainable Cities and Society, Vol. 60, pp. 102155. https://doi.org/10.1016/j.scs.2020.102155

Kiefer, P., Giannopoulos, I., and Raubal, M. (2014), "Where am I? Investigating map matching during self-localization with mobile eye tracking in an urban environment", Transactions in GIS, Vol. 18, No.5, pp. 660-686. https://doi.org/10.1111/tgis.12067

Kim, N., and Lee, H. (2020), "Evaluating visual perception by tracking eye movement in architectural space during virtual reality experiences", Proceedings of the 2nd International Conference on Human Interaction and Emerging Technologies: Future Applications (IHIET – AI 2020), April 23-25, 2020, Lausanne, Switzerland, Vol., 1152, pp. 302-308, Springer, Cham. https://doi.org/10.1007/978-3-030-44267-5_45

Li, Z., Sun, X., Zhao, S., and Zuo, H. (2021), "Integrating eye-movement analysis and the semantic differential method to analyze the visual effect of a traditional commercial block in Hefei, China", Frontiers of Architectural Research, Vol. 10, No. 2, pp. 317-331. https://doi.org/10.1016/j.foar.2021.01.002

Lisińska-Kuśnierz, M., and Krupa, M. (2020), "Suitability of eye tracking in assessing the visual perception of architecture—A case study concerning selected projects located in Cologne", Buildings, Vol. 10, No. 2, p. 20. https://doi.org/10.3390/buildings10020020

Lohmeyer, Q., Matthiesen, S., and Meboldt, M. (2014). "Task-dependent Visual Behaviour of Engineering Designers-an Eye Tracking Experiment", In DS 77: Proceedings of the DESIGN 2014 13th International Design Conference, Dubrovnik, Croatia, May 19 - 22, 2014, The Design Society, Glasgow, pp. 549-558.

Marius't Hart, B., and Einhäuser, W. (2012), "Mind the step: complementary effects of an implicit task on eye and head movements in real-life gaze allocation", Experimental brain research, Vol. 223No. 2, pp. 233-249. https://doi.org/10.1007/s00221-012-3254-x

Mohammadpour, A., Karan, E., Asadi, S., and Rothrock, L. (2015), "Measuring end-user satisfaction in the design of building projects using eye-tracking technology", In 2015 ASCE International Workshop on Computing in Civil Engineering, IWCCE 2015 - Austin, United States, June 21- 23 2015, pp. 564-571, American Society of Civil Engineers (ASCE). https://doi.org/10.1061/9780784479247.070

Noland, R. B., Weiner, M. D., Gao, D., Cook, M. P., and Nelessen, A. (2017), "Eye-tracking technology, visual preference surveys, and urban design: preliminary evidence of an effective methodology", Journal of Urbanism: International Research on Placemaking and Urban Sustainability, Vol. 10, No. 1, pp. 98-110. https://doi.org/10.1080/17549175.2016.1187197

Pelowski, M., Leder, H., Mitschke, V., Specker, E., Gerger, G., Tinio, P. P., and Husslein-Arco, A. (2018), "Capturing aesthetic experiences with installation art: an empirical assessment of emotion, evaluations, and mobile eye tracking in Olafur Eliasson's "Baroque, Baroque!", Frontiers in Psychology, Vol. 9, p. 1255. https://doi.org/10.3389/fpsyg.2018.01255

Rupi, F., and Krizek, K. J. (2019), "Visual eye gaze while cycling: Analyzing eye tracking at signalized intersections in urban conditions", Sustainability, Vol. 11, No. 21, pp. 6089. https://doi.org/10.3390/su11216089

Sayegh, A., Andreani, S., Li, L., Rudin, J., and Yan, X. (2015), "A new method for urban spatial analysis: measuring gaze, attention, and memory in the built environment", In Proceedings of the 1st International ACM SIGSPATIAL Workshop on Smart Cities and Urban Analytics UrbanGIS'15, Bellevue, WA, USA November 03-06 2015, pp. 42-46. https://doi.org/10.1145/2835022.2835030

Schrom-Feiertag, H., Settgast, V., and Seer, S. (2017), "Evaluation of indoor guidance systems using eye tracking in an immersive virtual environment", Spatial Cognition & Computation, Vol. 17, No. 1-2, pp. 163-183. https://doi.org/10.1080/13875868.2016.1228654

She, J., and MacDonald, E. F. (2018). "Exploring the effects of a product's sustainability triggers on pro-environmental decision-making", Journal of Mechanical Design, Vol. 140, No. 1, p. 011102. https://doi.org/10.1115/1.4038252

Simpson, J., Freeth, M., Simpson, K. J., and Thwaites, K. (2019), "Visual engagement with urban street edges: insights using mobile eye-tracking", Journal of Urbanism: International Research on Placemaking and Urban Sustainability, Vol. 12, No. 3, pp. 259-278. https://doi.org/10.1080/17549175.2018.1552884

Song, S. S., Wan, Q., and Wang, G. G. (2016), "Eye movement evaluation of different wood interior decoration space", Wood Research, Vol. 61, No. 5, pp. 831-843.

Stephane, A. L. (2017), "Eye tracking from a human factors perspective", In The Handbook of Human-Machine Interaction, pp. 339-364.

Sussman, A., and Ward, J. (2019), "Eye-tracking Boston City Hall to better understand human perception and the architectural experience", New design ideas, Vol. 3, No. 1, pp. 53-59.

Tatler, B. W., Macdonald, R. G., Hamling, T., and Richardson, C. (2016), "Looking at domestic textiles: an eye-tracking experiment analysing influences on viewing behaviour at Owlpen Manor", Textile history, Vol.47, No. 1, pp. 94-118. https://doi.org/10.1080/00404969.2016.1144865

Tuszynska-Bogucka, W., Kwiatkowski, B., Chmielewska, M., Dzienkowski, M., Kocki, W., Pelka, J., ... and Galkowski, D. (2020), "The effects of interior design on wellness–Eye tracking analysis in determining emotional experience of architectural space. A survey on a group of volunteers from the Lublin Region, Eastern Poland", Annals of Agricultural and Environmental Medicine, Vol. 27, No. 1, pp. 113-122. https://doi.org/10.26444/aaem/106233

Zhang, L. M., Zhang, R. X., Jeng, T. S., and Zeng, Z. Y. (2019), "Cityscape protection using VR and eye tracking technology", Journal of Visual Communication and Image Representation, Vol. 64, p. 102639. https://doi.org/10.1016/j.jvcir.2019.102639

Zou Z., Ergan S. (2019), "Where Do We Look? An Eye-Tracking Study of Architectural Features in Building Design", In: Mutis I., Hartmann T. (eds) Advances in Informatics and Computing in Civil and Construction Engineering. pp. 439-446, Springer, Cham. https://doi.org/10.1007/978-3-030-00220-6_52