VISUAL BEHAVIOUR IN THE EVALUATION OF PHYSICAL AND VIRTUAL PROTOTYPES

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ABSTRACT

Product development stages are typically characterized by different forms of representations and degrees of specification, which potentially affect user's perception and evaluation. These effects are worth investigating more closely also because of the growing relevance of new technologies such as Virtual Reality (VR) in the design field. The objective of this paper is to elucidate the mutual relations between forms of representation, visual behaviour, and people's evaluations. The focus is on differences between virtual and physical prototypes. In the illustrated experiment, participants visited a tiny house in an immersive VR (360° images acquisition). The results were compared with a past experiment where the physical prototype of the same product was similarly evaluated. The dwell times on Areas of Interest (AOIs) pertaining to the tiny house were compared and correlated to variables concerning subjective evaluations. The results show just a few similarities of visual exploration in terms of gazed AOIs. Substantial differences in terms of how the duration of gazing affects evaluations have been found too. The larger number of significant correlations between observations and evaluations in the virtual exploration emerged.

Keywords: Representation form, Virtual reality, Prototype, Evaluation, Case study

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1 INTRODUCTION AND BACKGROUND

When designers develop a new product, they progressively translate their ideas into concepts and, eventually, more detailed representations, which can be supported by different illustration media and formats. Concepts need to be represented into a form that can be easily perceived from other stakeholders to facilitate the selection of the most promising ideas for further development. Hereinafter, the term "representation form" will be used to designate the way designs, concepts, products and prototypes are shown to possible evaluators.

In the literature, visual design representations have been classified based on their level of specification and detail (Pei et al., 2011). Similarly, Berni et al. (2020) listed the representation forms in relation to the their level of interactivity and completeness (static, dynamic, physical). The importance of representing the concepts within product development is highlighted in several contributions in the literature (Ozcelik et al., 2011; Lauff et al., 2020; Goudswaard et al., 2021). Goudswaard et al. (2021) claim that concept representation and prototyping is crucial for knowledge generation and communication among different stakeholders. In this way, the concept can be easily evaluated, and effective decisions can be made for improving the concept accordingly in the next design stages. Other scholars stress the importance of representing the concept as a prototype in early design stages in order to save resources (Samantak and Choi, 2017; Christoforakos and Diefenbach, 2018). The way a concept is represented plays an even more important role when the product needs to be evaluated by potential final users. Different representations should be used in specific design phases to test the potential of the product and its appreciation among users (Engelbrektsson and Söderman, 2004; Häggman et al., 2015).

The same design represented in a different way can affect perception with repercussions on people's evaluation of a product (Artacho-Ramírez et al., 2008; Reid et al., 2013). Understanding the patterns of perception and their effects on users' evaluation should raise designers' awareness of these effects while designing a new product. Verhagen et al. (2016) showed that a higher level of detail can provide an interaction that gets closer to the experience people would have with the real final product. The scholars compared and tested the effects of three e-commerce product representation forms with increasing levels of detail (a picture, a 360° spin rotation model, and a virtual mirror). The results show that the representation with the highest level of detail provided a superior sense of tangibility.

It is then expected that the closer the representation is to the final product, the more reliable the information from the user evaluation is. To confirm this assumption, all the different representation forms are worth studying along with comparing their effects on users' evaluation. Unfortunately, this is seldom investigated in the design literature (Berni et al., 2020).

Investigating representation forms is even more critical with the advent of new technologies and tools used in design, such as Virtual Reality (VR). VR transformed the way concepts can be represented as well as how users interact with them. VR can recreate virtual environments that are perceived as sufficiently close to the real interaction with the finished product. Moreover, VR proved to be a very flexible technology, which can be involved from the front to the back end of the design process (Berni and Borgianni, 2020). The literature offers examples where VR was used during idea generation processes, brainstorming and immersive sketching activities. Many scholars underline the benefits of such immersive technologies in the concept definition process (Rieuf et al., 2017; Eroglu et al., 2018; Song et al., 2018). Other scholars consider VR as a tool for 3D modelling, prototyping and assembly (Guo et al., 2020; Lukačević et al., 2020). In many cases, scholars prefer to take advantage of the combination of VR's high level of interactivity and immersiveness for product evaluation purposes (De Crescenzio et al., 2019; Violante et al., 2019).

The immersive capabilities offered by VR are typically considered useful while designing a product. However, it is insufficiently investigated when it is convenient to create a virtual environment instead of building a physical one. Comparisons between user interactions with physical and virtual representation of the same product are surprisingly seldom performed. Among the few examples, Felip et al. (2020) compared the evaluation of the attributes of a product represented by tangible VR and in a real setting. The results show that the representation means influenced the evaluation of almost all the attributes. In addition, these comparisons have failed to include, to the authors' best knowledge, data about people's visual behaviour, which has turned to be a critical determinant of users' response (Crilly et al., 2004). Otherwise said, the intricate network between chosen visual representation forms, visual behaviour and product evaluation has been investigated just superficially.

Accordingly, the objective of the paper is to elucidate the mutual relations between representation forms, visual behaviour, and people's evaluations; the focus is on differences between interactions with virtual and physical prototypes. More in details, the authors summarize their research objectives in the following Research Questions (RQs), which are answered in Section 4:

- **RQ1** *Are there differences in the visual exploration behaviour when observing a real prototype and the same object in an (immersive) virtual setting?*
- **RQ2:** *Does the observation of certain product elements affect the product evaluation irrespective of its representation through a physical or virtual prototype?*

To the scope, the authors compared the observation (through eye-tracking tools) and their effects on the evaluation of the interior of a tiny wooden house represented both physically (physical 1:1 scale prototype) and virtually following the acquisition of its interior though multiple 360° images. As an additional output of this research, the use is explored of 360° images, relatively uncommon in the design field but increasingly diffused in other domains. These images can result useful when it is difficult to make evaluators interact with a physical prototype, which applies to large-sized products belonging not only to the building sector, but also, e.g., to the aerospace industry.

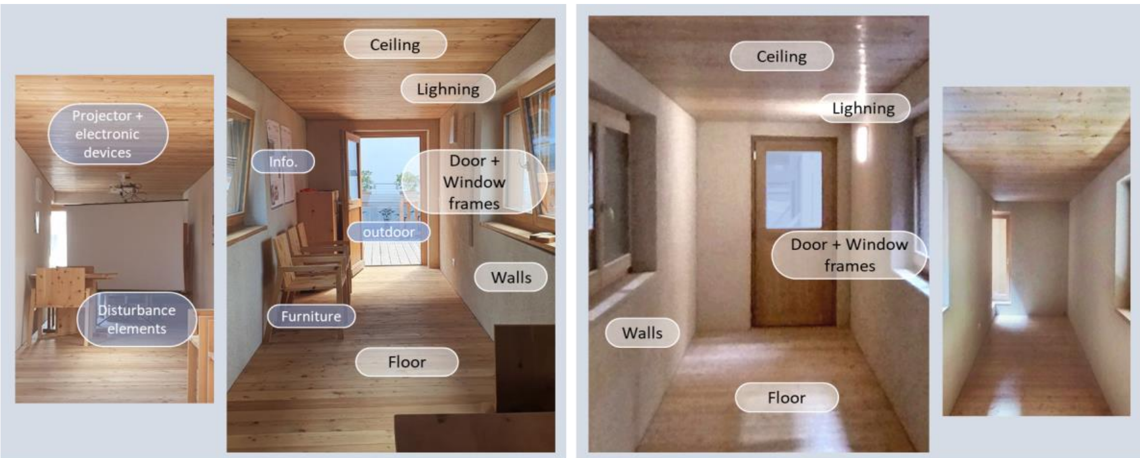
2 MATERIALS AND METHODS

The study takes advantage of the project Tiny FOP MOB, where a physical prototype of a tiny house was built. The experiments conducted with the physical prototype are described in (Berni et al., 2022; Nezzi et al., 2022; Berni et al., 2023). 360° images of the interior of the physical prototype were acquired using a 360° camera after the fabrication and assembly of the prototype was completed. The lab experiment presented in this paper to answer the RQs consists in a virtual tour of the prototype through an immersive VR headset equipped with an eye-tracker. 50 participants, involved as a sample of convenience, were asked to fill in an evaluation questionnaire after the virtual tour. Quantitative data on participants' visual behaviour (dwell times) are acquired and correlated to the qualitative answers provided in a 5-point Likert scale questionnaire. The experiment was initially approved by ethical commission of the Institution the authors belong to. Further details are to be found in the following subsections.

2.1 Materials

2.1.1 The tiny house and its characteristics

The investigated product is a prototype of a tiny house built by local companies of South Tyrol, Italy. The tiny house represents a sustainable case study due to the choice of its materials. The external wooden coating protects the wooden structure, and the bricks are made of hemp and limestone powder. A mixture made of lime and hemp fibres finished the interior of the walls providing them with a peculiar texture. The wooden ceiling, floor, door, windows, the textured walls, and the lightning system are well visible in both the physical prototype and its virtual representation. Figure 1 shows a representative corner where most of the mentioned elements are visible (Figure 1a depicts the physical prototype; Figure 1b. is the same point of view in the virtual representation).



a. b.

Figure 1: Highlights shared Areas of Interest (AOIs) between the real (a) and virtual (b) prototypes, with white indicating shared AOIs and blue indicating non-shared AOIs.

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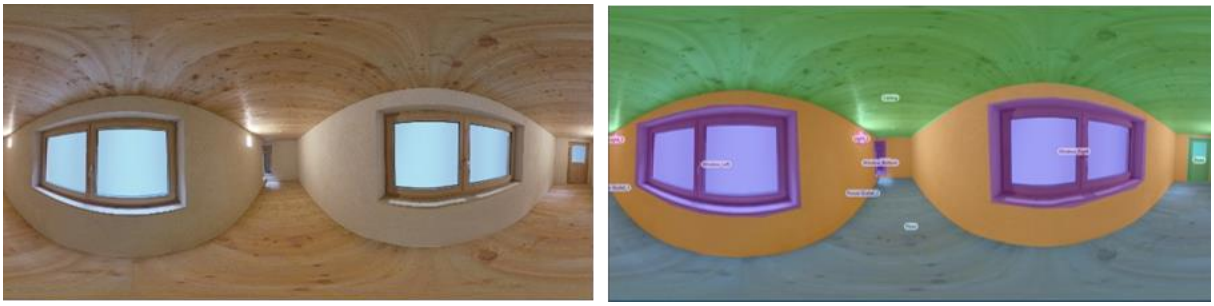
2.1.2 360° images as to represent the tiny house as virtual model

An Insta360 camera was used to acquire 360°images of the empty interior of the tiny house. The camera was placed at the entrance, in the centre and at the rear of the tiny house. Altogether, these positions allowed the capture of all the elements characterizing the interior. A generic tripod was used to hold the camera in place. To limit the presence of disturbance elements, the tripod was deleted, and the windows glass was blurred during the editing process using Photoshop CS6 (the final outcome is in Figure 2 a.). The final image shows the empty interior of the finished product with all its structural elements (ceiling, walls and, floor) and architectural ones (door and windows frame).



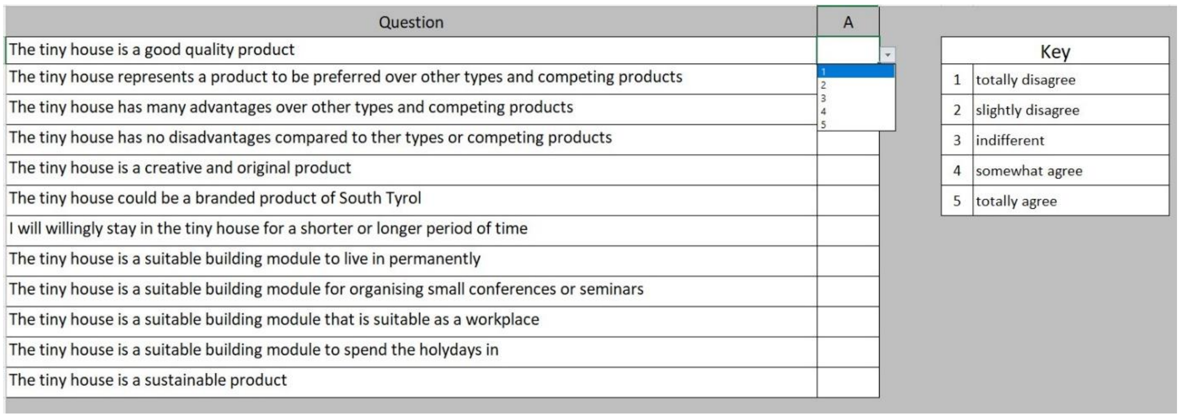
a. b.

Figure 2: a*. 360° image after the editing process. b. 360° image with the indication of Areas of Interest*

The HTC Vive VR headset combined with a Tobii eye-tracking system was used for both performing the immersive virtual tour and acquire participants' visual behaviour data.
Eye-tracking glasses were used to acquire visual data in the real prototype prototype (Berni et al., 2022; Nezzi et al., 2022; Berni et al., 2023)

2.1.3 The questionnaire

The evaluation questionnaire was intended to assess the participants' perception of the tiny house. To make evaluations comparable, the same assessment terms as in (Nezzi et al., 2022) were used. Details will be provided in Section 3.2., where such terms are presented as variables. Nevertheless, the included questions can be read in Figure 3. The questionnaire was developed and provided in three languages (English, Italian and German) depending on the preference of each participant. The questionnaire was submitted in the form of an Excel spreadsheet, where participants were asked to read each sentence in the first column and choose their answers from a drop-down menu, as shown in Figure 3. A key box was available to remind participants the meaning of the used 5-point Likert scale rating.



Question	A
The tiny house is a good quality product	
The tiny house represents a product to be preferred over other types and competing products	
The tiny house has many advantages over other types and competing products	
The tiny house has no disadvantages compared to ther types or competing products	
The tiny house is a creative and original product	
The tiny house could be a branded product of South Tyrol	
I will willingly stay in the tiny house for a shorter or longer period of time	
The tiny house is a suitable building module to live in permanently	
The tiny house is a suitable building module for organising small conferences or seminars	
The tiny house is a suitable building module that is suitable as a workplace	
The tiny house is a suitable building module to spend the holydays in	
The tiny house is a sustainable product	

Key	
1	totally disagree
2	slightly disagree
3	indifferent
4	somewhat agree
5	totally agree

Figure 3: The answer selection system used to rate the sentences

2.2 Participants

50 people took part in the experiment as volunteers. An email was sent to PhD students and academic staff of the authors' institution. Students and externals were recruited also via word-of-mouth. All the people willing to participate were adults. As spontaneously reported by participants, most of them had

no previous experience with VR, while a few just had had a previous brief experience. People with substantial visual impairment were not accepted due to the impossibility of acquiring visual data. The collection of sensitive or personal data such as gender or age were not acquired because they were not required by the study aim and in line with the procedure approved by the authors' institution, which assessed the experiment's compliance with ethical principles, privacy and data management. A code was assigned to match the data of the virtual tour with the evaluations obtained from the questionnaire. To compare evaluations of the virtual prototype with the real prototype, the dataset considered of the latter involved 26 volunteers from Val Venosta, Italy, as well as students from Unibz, as described in (Berni et al., 2023).

2.3 Procedure

Participants booked an appointment among the available dates at the laboratory where the experiment was planned. After being welcomed in the lab and introduced to the experiment setting, participants were informed about the procedure of the experiment itself, i.e. a VR tour and subsequent evaluation of what has been displayed. Before the virtual tour phase, each participant was asked if they preferred to sit or stand (they could reverse their choice at any instance). An experimenter helped them to wear the VR headset and adjust it until they felt comfortable. After the eye-tracking calibration process, the virtual visit started. Participants had unlimited time to observe and explore the VR-supported 360° representation in each of the three points of views. Participants were asked to say "next" to move to the next stage. A short black screen transition was added between the three images to facilitate the visual transition between each point of view to minimize cybersickness. The virtual tour ended once the participant observed all the three points of view. Participants were helped to take the headset off, while the experimenter introduced the next phase, i.e., evaluating the tiny house. The Excel spreadsheet file was available on a laptop. In Section 2.1.3, the questionnaire layout and how to fill it are described.
Once the participant answered the last question, the experiment ended, and she/he was thanked and discharged. Figure 4 shows graphically the experimental procedure described above.
In the real prototype evaluation, participants were asked to wear eye-tracking glasses and freely observe the tiny house. They were also asked to fill out the same product evaluation questionnaire after the visit (Berni et al., 2022; Nezzi et al., 2022; Berni et al., 2023).

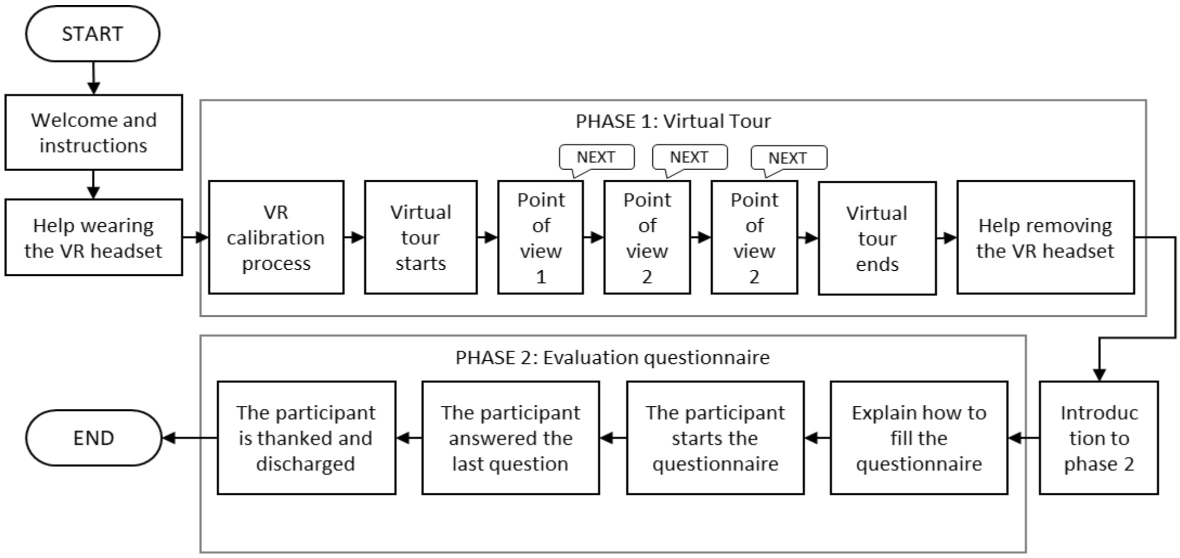


Figure 4: Experimental procedure

3 DATA COLLECTION AND ANALYSIS

Data collection concerning the physical prototype can be found in (Berni et al., 2022; Nezzi et al., 2022; Berni et al., 2023), while the next subsection describes in detail the collection and processing of visual behaviour data (3.1) and evaluations (3.2) referred to the experiment with the virtual prototype.

3.1 Collection and processing of visual behaviour

The authors categorized the elements of the tiny house in five Areas of Interest (AOIs): "Ceiling", "Floor", "Lighting", "Walls", "Door/Window frames", see Figure 1b. In the physical prototype, there

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was a larger number of identified AOIs because of the project's requirements, see Figure 1; the authors will consider hereinafter the shared five AOIs only for the sake of comparability. Prior to the conduction of the experiment, the AOIs had been set manually in the Tobii Pro Lab software, where all the three 360° images were uploaded to run the virtual tour in VR, see Figure 2 b. Dwell times for each AOI were used as a proxy for observation behaviour and duration. The authors summed all participants' dwell times for each AOIs to obtain total dwell times per AOI/participant.

3.2 Collection and processing of evaluations

As mentioned, the evaluation variables (in next sentence in quotation marks) used in the analysis match the assessment terms of the questionnaire fully presented in (Nezzi et al., 2022). The tiny house was therefore evaluated in terms of its perceived "Good quality", "Preference", "Convenience", (absence of) "Disadvantages", "Originality", "Representativeness" (of the territory), appropriateness to serve as a venue for "Generic accommodation", "Permanent accommodation", "Conferences", Seminars", "Office", "Holydays", and "Sustainability".

4 RESULTS

In light of the objectives of the paper and for space reasons, questionnaire's evaluation data are not reported. Moreover, because of the different visit conditions, there were no expectations about the similarities of the total durations of the visits; the average gaze duration for all the five AOIs combined was 54.2 and 74.5 s for the physical and virtual prototype, respectively.

4.1 Answering RQ1 - visual exploration behaviour

The dwell times of the AOIs observations in the physical prototype are compared to those in the virtual prototype. The dwell times are measured in seconds (continuous variable) and they indicate the time each participant spent gazing a certain AOI. Total dwell times are reported in Table 1. The data suggests that the "Door + Window Frames", "Walls", and the "Lighting" system were the most, second most, and least observed AOIs in both conditions, respectively. This indicates some similarities in the visual behaviour across the two involved representation forms. Similarity is then further tested in multiple ways. A Shapiro Wilk test was performed to verify the normality of the distribution of gazes' durations to carry out further analyses. As a rule of thumb, the null hypothesis of normal distribution is rejected when the p-value is smaller than 0.05. The results show that nearly all the observations deviate from normality in both the physical and virtual environment (Table 1).

Table 1: Descriptive data of dwell times (average and standard deviation in seconds) and Shapiro-Wilk test results are shown for both prototypes

AOI	PHYSICAL PROTOTYPE (26 observations)			VIRTUAL PROTOTYPE (50 observations)		
	Average dwell time (s)	Standard Deviation (s)	p-value of the Shapiro-Wilk test	Average dwell time (s)	Standard Deviation (s)	p-value of the Shapiro-Wilk test
Ceiling	5.214	6,476	< .001	7.100	5,405	< ,001
Floor	3.855	4,194	< .001	13.759	7,493	< ,001
Lightning	2.151	1,650	0.052	3.097	2,905	< ,001
Walls	19.106	18,155	< .001	24.863	11,561	< ,001
Door + window Frames	23.846	23,214	< .001	25.473	10,994	0,007

In order to use a test of general acceptance to compare the relative attention paid to AOIs, each second overall spent on AOIs was transformed into an entry for the physical or virtual prototype, so to make the variables categorical. It was then possible to run a Chi-Square test on the distribution of these entries for the physical and the virtual prototype. To examine whether the two distributions are similar, the probability associated to the result of the test should be >0.05. The results of the tests are shown in Table 2. Based on these results, it is possible to conclude that the distributions of gaze durations across AOIs between the physical and the virtual environment differ significantly. Therefore, in this case study, the representation form affects the visual behaviour, intended as duration of observation of the elements belonging to a product.

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Table 2: AOI interaction Crosstabulation (count in seconds) and Chi square tests (on the right)

AOI	Physical	Virtual	total
Ceiling	136	355	491
Floor	100	698	798
Lightning	56	155	211
Walls	497	1243	1740
Door + window Frames	620	1274	1894
total	1409	3725	5134

Outcome	value	df	Probability (2-sided)
Pearson Chi Square	116.947a	4	<.001
Likelihood ratio	131.026	4	<.001
N of valid cases	5134		

For further scrutiny, the distribution of the relative dwell times duration of each AOI has been compared too. Markedly, data has been normalized to allow better comparability also in consideration of the strongly uneven durations of the participants' interactions with prototypes. The relative fractions of dwell times for each AOI (out of the total time spent on the five considered AOIs) per participant have been computed. In other words, the gaze time of an AOI was divided by the total duration of gaze times spent on all AOIs for both the virtual and the physical prototype. Nearly all the fractions of dwell times on AOIs turned to be non-normally distributed based on the Shapiro-Wilk test, which suggests comparing their distribution between the physical and the virtual prototype through a non-parametric test. The homogeneity of variance between the two groups was checked too through a Levene's test. The results show that the test is significant for almost all the AOIs (p-value smaller or equal to 0.05 in bold). This means that the distributions of these AOIs in the physical prototype are different from those of the virtual one. The AOI "Floor" is the only case where the Levene's test is not significant, and the two distributions are of the same nature. Since the assumption of homogeneity is refused, the authors chose a Mann-Whitney non-parametric test to compare distributions for each AOI. The results shown in Table 3 suggest that the difference of distribution is significant for two AOIs (see the p-values in bold), while for "Ceiling", "Lightning", and "Walls" there is not sufficient evidence to claim a significant difference among the two population medians (p-value greater or equal 0.05).

The outcome obtained with the sum of total observation duration is confirmed. Thus, despite some elements are similarly observed in the physical and virtual prototype (e.g., "Floor"), the observation of most AOIs is very different depending on the representation forms.

Table 3: Normality test, homogeneity of variance test, and test of the similarity of the distribution of the relative fractions of dwell times spent for each AOI for the physical and virtual prototype; significant values are in bold.

	Test of Normality (Shapiro-Wilk)			Test of Equality of Variances (Levene's)			Mann-Whitney U test	
AOIs	group	W	p	F	df	p	W	p
Ceiling	Real	0.915	**0.034***	3.974	1	**0.050****	622.000	0.763
	VR	0.946	**0.023***					
Floor	Real	0.876	**0.005***	0.426	1	0.516	160.000	**< .001*****
	VR	0.929	**0.005***					
Lightning	Real	0.793	**< .001***	10.979	1	**0.001****	700.000	0.588
	VR	0.917	**0.002***					
Walls	Real	0.920	**0.044***	10.358	1	**0.002****	675.000	0.789
	VR	0.925	**0.004***					
Door + window Frames	Real	0.975	0.975	5,083	1	**0.027****	863.000	**0.020*****
	VR	0.983	0.983					

** The distributions are not normally distributed*
*** The two variances are significantly different*
**** It is possible to claim that the difference between the populations' medians is statistically significant*

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4.2 RQ2 - correlation between visual behaviour data and evaluation variables

The dwell times for each AOI were correlated to the evaluation variables. A Spearman's correlation was chosen due to the lack of normality of the distributions. The values of the correlations for the virtual and physical prototype are shown in Table 4. In both cases, the magnitude (value of the Spearman's rho) and the significance are included. The correlation at three different p-value thresholds was highlighted: $p < .05$ (*), $p < .01$ (**). A few significant relations emerged among the AOIs and the evaluation variables. The virtual prototype shows slight significant correlations of two AOIs with several evaluation variables. In particular, "Ceiling" is negatively correlated with the evaluation variables "Good quality" (-0.319), "Preference" (-0.367), and positively correlated with "Holydays" (0.331). Observing the ceiling in the virtual prototype has a slight negative effect on the overall quality but increases the perception of the suitability of the tiny house for vacations and short permanence (Table 4). Similarly, "Lighting" affects negatively the "Good quality" (-0.306) and "Preferences" (-0.279). The lighting system has a negative impact also on the perception of the tiny house as representative product for the territory of the experiment (South Tyrol, Italy).

In the physical prototype, a moderate positive correlation only emerges between the AOI "Floor" and the evaluation variable "Disadvantages" (0.440). This shows that observing the floor in the real prototype had a positive impact on the perception in terms of the absence of disadvantages (Table 4). Overall, it emerged that gaze times had more impact in the VR visit than in the real prototype.

Table 4: Spearman's correlation between AOIs and evaluation variables in the virtual prototype (_VR) and Physical one (_REAL)

Variables	Ceiling_VR	Floor_VR	Lights and electrics_VR	Walls_VR	Door/Window Frames_VR	Ceiling_REAL	Floor_REAL	Lights and electrics_REAL	Walls_REAL	Door + Window Frames_REAL
Good_quality	**-0.319***	-0.126	**-0.306***	-0.020	-0.124	-0.231	-0.003	-0.084	-0.085	-0.172
Preference	**-0.367****	-0.227	**-0.279***	0.141	-0.195	0.092	0.149	-0.247	0.014	0.248
Convenience	0.076	-0.210	0.124	0.120	0.238	0.244	-0.142	-0.290	0.218	0.087
Disadvantages	-0.097	-0.156	-0.058	0.008	-0.191	0.155	**0.440***	-0.049	0.330	0.331
Originality	0.068	-0.041	-0.092	0.203	0.019	0.035	-0.100	-0.264	0.273	0.095
Representativeness	-0.208	-0.154	**-0.323***	0.085	-0.272	0.336	-0.076	-0.036	0.313	0.333
Gen_accommodation	-0.048	-0.165	-0.107	0.113	-0.016	0.276	-0.099	-0.111	-0.054	0.077
Conferences	-0.271	-0.164	-0.241	-0.116	-0.231	0.160	-0.074	-0.034	0.069	0.061
Office	-0.066	-0.143	-0.017	-0.069	0.074	0.275	0.013	-0.255	0.103	0.315
Holidays	**0.331***	0.020	0.207	0.059	0.095	0.220	0.009	0.071	0.226	0.266
Sustainability	-0.159	-0.100	-0.140	0.030	-0.042	-0.027	-0.023	-0.159	0.066	0.218

* $p < .05$, ** $p < .01$

5 DISCUSSIONS AND CONCLUSIONS

The authors conducted an experiment where participants visited a tiny wooden house in an immersive virtual environment. The eye-tracker integrated into the VR viewer allowed data on visual behaviour (dwell times) to be captured. After the virtual tour, participants evaluated the product by means of a Likert-point questionnaire. Dwell times in AOIs (established a priori) were acquired and summed. AOIs were defined as the main elements the house consists of (ceiling, floor, door and window frames, walls, and lighting system). The results of this study were compared with those achieved with the physical prototype of the same tiny house in previous studies to answer the RQs.

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- As for **RQ1,** d*ifferences emerged in the visual exploration behaviour when observing a real prototype and the same object in an (immersive) virtual setting.*
- As for **RQ2, t***he observation of certain product elements affects the product evaluation unevenly in its representation through a physical and a virtual prototype.*

Therefore, when a product or concept is presented through physical and virtual representations, potential users tend to look at their main elements differently. In other terms, the representation form turned to be a significant aspect in participants' experience — evaluation and interaction experiments should be compared only when representation forms are similar according to the outcomes of the present study.

However, the greater variation of visual behaviour in the physical prototype (as inferable from Table 1) along with a lower number of significant correlations between AOIs' observation and the evaluations could be explained by the following points, which can be considered limitations of this study, though mostly unavoidable because of various contingency factors.

- The use of 360° images could reduce the variability of visual behaviour. Participants had a limited freedom of movement. They could just turn their head 360° while remaining in a fixed position. This clearly contrasts with the condition of the visitors of the physical tiny house. It has to be noted that the modelling of a virtual environment to enable maximum freedom of movement would have required more time and substantial differences of texture between the physical and virtual prototype would have inevitably emerged.
- Even though the variability of visual behaviour in the virtual prototype is lower than in the physical one, such variability is still remarkable. This could be partially explained by people's different reactions to the VR technology. Some could have enjoyed the VR tour and could have spent more time than required to observe the tiny house.
- The physical prototype had more elements to be observed than the virtual prototype (Berni et al., 2023). Only AOIs common to both representations were chosen for analysis. The greater variety of visual behaviour in the physical prototype could be due to the greater number of elements combined with the greater freedom of movement.
- The cohorts of participants differed substantially. The people who participated in the interaction with the physical prototype while wearing the eye-tracking tool were supposed to be highly motivated by the product they were going to experience (Nezzi et al., 2022). This could have represented a bias in the evaluations and contributed to the scarce role of the visual behaviour in this setting.

Despite these limitations, the paper contributes to research aimed to compare different representation forms. An alternative method of virtualizing a product using 360° images is proposed. Such representation is suitable to virtually recreate existing environments with photographic quality rapidly and effortlessly. Such virtual acquisitions could help evaluate existing (large-scale) physical prototypes that cannot be easily moved from a place to another to acquire users' evaluation data; this paper represents a first step to assess their utility in this ambit.

REFERENCES

Artacho-Ramírez, M.A., Diego-Mas, J.A. and Alcaide-Marzal, J. (2008), “Influence of the mode of graphical representation on the perception of product aesthetic and emotional features: An exploratory study”, International Journal of Industrial Ergonomics, Vol. 38 No. 11, pp. 942–952.

Berni, A., Altavilla, S., Ruiz-Pastor, L., Nezzi, C. and Borgianni, Y. (2022), “An Eye-Tracking Study to Identify the Most Observed Features in a Physical Prototype of a Tiny House”, Proceedings of the Design Society, Cambridge University Press, Vol. 2, pp. 841–850.

Berni, A. and Borgianni, Y. (2020), “Applications of Virtual Reality in Engineering and Product Design: Why, What, How, When and Where”, Electronics, Vol. 9 No. 7, p. 1064.

Berni, A., Maccioni, L. and Borgianni, Y. (2020), “Observing Pictures and Videos of Creative Products: An Eye Tracking Study”, Applied Sciences, Vol. 10 No. 4, p. 1480.

Berni, A., Nezzi, C., Ruiz-Pastor, L., Altavilla, S., Kofler, I. and Borgianni, Y. (2023), “Exploring People’s Visual Perception and Its Impact on Evaluation of a Tiny House Prototype Using Eye Tracking Technology”, in Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C. and Roucoules, L. (Eds.), Advances on Mechanics, Design Engineering and Manufacturing IV, Springer International Publishing, Cham, pp. 1471–1482.

https://doi.org/10.1017/pds.2023.383 Published online by Cambridge University Press

Christoforakos, L. and Diefenbach, S. (2018), “Idealization Effects in UX Evaluation at Early Concept Stages: Challenges of Low-Fidelity Prototyping”, International Conference on Applied Human Factors and Ergonomics, Springer, pp. 3–14.
Crilly, N., Moultrie, J. and Clarkson, P.J. (2004), “Seeing things: consumer response to the visual domain in product design”, Design Studies, Vol. 25 No. 6, pp. 547–577.
De Crescenzio, F., Bagassi, S., Asfaux, S. and Lawson, N. (2019), “Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality”, International Journal on Interactive Design and Manufacturing (IJIDeM), Vol. 13 No. 2, pp. 761–772.
Engelbrektsson, P. and Söderman, M. (2004), “The use and perception of methods and product representations in product development: A survey of Swedish industry”, Journal of Engineering Design, Taylor & Francis, Vol. 15 No. 2, pp. 141–154.
Eroglu, S., Gebhardt, S., Schmitz, P., Rausch, D. and Kuhlen, T.W. (2018), “Fluid Sketching―Immersive Sketching Based on Fluid Flow”, 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), presented at the 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 475–482.
Felip, F., Galán, J., García-García, C. and Mulet, E. (2020), “Influence of presentation means on industrial product evaluations with potential users: a first study by comparing tangible virtual reality and presenting a product in a real setting”, Virtual Reality, Vol. 24 No. 3, pp. 439–451.
Goudswaard, M., Snider, C., Gopsill, J., Jones, D., Harvey, M. and Hicks, B. (2021), “The prototyping fungibility framework”, 31st CIRP Design Conference 2021 (CIRP Design 2021), Vol. 100, pp. 271–276.
Guo, Z., Zhou, D., Zhou, Q., Mei, S., Zeng, S., Yu, D. and Chen, J. (2020), “A hybrid method for evaluation of maintainability towards a design process using virtual reality”, Computers & Industrial Engineering, Vol. 140, p. 106227.
Häggman, A., Tsai, G., Elsen, C., Honda, T. and Yang, M.C. (2015), “Connections between the design tool, design attributes, and user preferences in early-stage design”, Journal of Mechanical Design, American Society of Mechanical Engineers, Vol. 137 No. 7, p. 071408.
Lauff, C.A., Knight, D., Kotys-Schwartz, D. and Rentschler, M.E. (2020), “The role of prototypes in communication between stakeholders”, Design Studies, Vol. 66, pp. 1–34.
Lukačević, F., Škec, S., Törlind, P. and Štorga, M. (2020), “Identifying subassemblies and understanding their functions during a design review in immersive and non-immersive virtual environments”, Frontiers of Engineering Management, available at:https://doi.org/10.1007/s42524-020-0099-z.
Nezzi, C., Ruiz-Pastor, L., Altavilla, S., Berni, A. and Borgianni, Y. (2022), “How Sustainability-Related Information Affects the Evaluation of Designs: A Case Study of a Locally Manufactured Mobile Tiny House”, Designs, Vol. 6 No. 3, available at:https://doi.org/10.3390/designs6030057.
Ozcelik, D., Quevedo-Fernandez, J., Thalen, J. and Terken, J. (2011), “Engaging users in the early phases of the design process: attitudes, concerns and challenges from industrial practice”, Proceedings of the 2011 Conference on Designing Pleasurable Products and Interfaces - DPPI ’11, presented at the the 2011 Conference, ACM Press, Milano, Italy, p. 1.
Pei, E., Campbell, I. and Evans, M. (2011), “A taxonomic classification of visual design representations used by industrial designers and engineering designers”, The Design Journal, Taylor & Francis, Vol. 14 No. 1, pp. 64–91.
Reid, T.N., MacDonald, E.F. and Du, P. (2013), “Impact of Product Design Representation on Customer Judgment”, Journal of Mechanical Design, Vol. 135 No. 9, available at:https://doi.org/10.1115/1.4024724.
Rieuf, V., Bouchard, C., Meyrueis, V. and Omhover, J.-F. (2017), “Emotional activity in early immersive design: Sketches and moodboards in virtual reality”, Design Studies, Vol. 48, pp. 43–75.
Samantak, R. and Choi, Y.M. (2017), “Employing design representations for user-feedback in the product design lifecycle”, DS 87-4 Proceedings of the 21st International Conference on Engineering Design (ICED 17), Vol. 4, presented at the International Conference on Engineering Design (ICED 17), Vancouver, Canada, pp. 563–572.
Song, H., Chen, F., Peng, Q., Zhang, J. and Gu, P. (2018), “Improvement of user experience using virtual reality in open-architecture product design”, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 232 No. 13, pp. 2264–2275.
Verhagen, T., Vonkeman, C. and van Dolen, W. (2016), “Making Online Products More Tangible: The Effect of Product Presentation Formats on Product Evaluations”, Cyberpsychology, Behavior, and Social Networking, Mary Ann Liebert, Inc., publishers, Vol. 19 No. 7, pp. 460–464.
Violante, M.G., Vezzetti, E. and Piazzolla, P. (2019), “How to design a virtual reality experience that impacts the consumer engagement: the case of the virtual supermarket”, International Journal on Interactive Design and Manufacturing (IJIDeM), Vol. 13 No. 1, pp. 243–262.

https://doi.org/10.1017/pds.2023.383 Published online by Cambridge University Press