Wayfinding in Museums: A Cross-sectional Comparison Between 3D Serious Games and 2D Drawings as Tools for Participatory Design

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***Abstract*—This paper investigated the impact of 3D serious games on wayfinding in public buildings. Optimal wayfinding is essential for security, economy and architectural design of public buildings. A comparative study is performed between two groups that used 2D drawings and virtual reality on the specific use-case of a museum. Following the model of Weisman, a particular questionnaire is developed. The results show "figuring out" the building was easier for the 2D group while wayfinding was easier for the VR group. The outcome demonstrates 3D games can be used as an effective tool in architecture for participatory and evidence-based design. Furthermore, the results show that virtual reality may be an effective tool for students to assess their designs.**

***Index Terms*—Wayfinding, Museums, Participatory Design, Evidence-based Design, 3D Serious Games, Design Education**

I. Introduction

While wayfinding plays a key role in different architectural projects and facilities, architects often see wayfinding as an afterthought and overlay to their buildings [1], [2]. This causes plenty of problems; a famous example is Emory University Hospital that its problems in wayfinding cost the institution $220,000 annually [3]. Wayfinding offers various benefits, such as the sense of direction or understanding one's position in the building, to visitors of any building type [4]. Museums would benefit the most from wayfinding since dwell time and engagement play two key roles in museums. Wayfinding in museums covers functional needs such as refreshments along with ensuring visitors get the most out of their visits [5]. A positive experience boosts the reputation of museums and results in positive recommendations, reviews, and repeat visits. Furthermore, while the reduction in operating costs has turned into a major concern for museums, wayfinding systems that foster independent wayfinding will reduce costs significantly [6]. While the use of virtual applications in museums has been investigated previously [7], wayfinding as an Evidence-based Design (EBD) practice has not been investigated thoroughly. Therefore, this study aims to compare users' perception of wayfinding in a museum among 23 participants through a 3D serious game and 2D drawings, including plans and sections, as tools for participatory design. The outcome of this research will illustrate whether 3D games can be used as an effective tool for participatory design and as an effective perceptual tool for students.

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II. Research Method

A. Related Work and Designing the Questionnaire

Architects benefit from evidence-based design (EBD) in designing museums. EBD refers to designing based on scientific research (evidence) that is usually resulted from post-occupancy evaluations as a building evaluation technique in the case of museums [8], [9]. Pre-Occupancy Evaluation is an emerging term in architecture that tries to evaluate buildings during the design process by improving client-designer communication [10]. Virtual reality and games as emerging technologies might be able to help museums achieve an improved wayfinding design since it can provide real-time evidence to designers. As a result, according to Kaplan's model of environmental cognition [11], information regarding specific locations and the spatial relationship between these locations are stored in one's mind. This provides an understanding of locations that are perceived as "different" from others by users. Accordingly, the layout configuration (plan) along with location cues, depth cues, and motion cues may impact wayfinding [12]. Accordingly, this study uses a questionnaire which was adopted and developed from an earlier study based on Kaplan's environmental cognition [11]. This study defines 3 constructs of Perceived Spatial Complexity (Describability), Anticipated Wayfinding Difficulty (Simplicity), and Remembrance (Memorability) based on the view of wayfinding as a cognitive task.

1) Describability: Describability or perceived spatial complexity refers to the students' general understanding of the spatial layout of the building.

2) Simplicity: Similar to describability, students in this part are asked to think about addressing a specific location in the building. This part measures students' perception of the visitors' path in the building instead of the general layout.

3) Memorability: This part of the questionnaire assesses whether architectural precedents are stored in episodic memory when they are experienced according to Lawson's research [13]. In this regard, another preliminary study on architecture students showed promising results [14]. The building in this study is completely designed for fulfilling the goal of this study and students have never experienced it before since familiarity with a building affects users' responses [12]. Questions were based on a five-point Likert Scale (except Question 18 (Q18)).

The questions for Perceived Spatial Complexity (Describability) were 1) How complex was the layout of this building? 2) Do you believe you can draw a sketch of the sequence of the major spaces outlining the arrangement of the corridors and galleries inside? (You do not have to draw the actual sketch) 3) Would doing such a diagram of this building be difficult or easy? (Don't worry about your own degree of 'artistic' ability) 4) How confident would you be of the building sketch you'd have drawn? 5) My sketch would represent the arrangement of the building .... The questions for Anticipated Wayfinding Difficulty (Simplicity) were 6) How easy would it be to find one's way around a building with this layout? 7) Can you address a stranger how to circulate inside the building to find a specific part of the building 8) How accurate do you believe your address would be? 9) How easy do you believe it would be for the stranger to find the addressed part of the building? 10) How lost can a visitor become in this building in your opinion?. Finally, the questions for Remembrance (Memorability) were 11) Roughly what percentage of the total building would you say you can remember? 12) A drawn sequence of spaces by you can represent the arrangement of spaces .... 13) Do you think you'd be able to direct a stranger to galleries inside the building? 14) How confident would you be of the directions you'd give to such a stranger? 15) All things considered, do you find this building a relatively easy or a relatively difficult place to "figure out"? 16) Do you find this building a relatively easy or relatively difficult place to find your way? 17) Finding way inside the building is .... 18) includes a set of diagrams that participants should indicate which one of the diagrams best represents the order of spaces in the building based on their opinion.

B. Validity and Reliability

The questionnaire was given to a panel of experts, including 8 panelists, with 3 to 17 years of experience in architecture for content validity based on a 4-point scale. Content Validity Index at item-level (I-CVI) was 0.945 (minimum for new instruments = 0.8 [15]). Content Validity Index at scale level using Universal Agreement among panelists was 0.555 for the questionnaire (S-CVI/UA = 0.555) which is considered excellent [16]. The Content Validity Ratio (CVR) was 0.888 which is above 0.75 and acceptable [17]. Since the nature of this study relied entirely on a project that has been developed for its aim (measuring memorability), the reliability of the questionnaire was assessed using Cronbach's Alpha [18] among 31 senior students of bachelor's program (Excluding Q18 because of its special assessment type) and test-retest was not conducted. Table I shows Cronbach's Alpha, I-CVI and S-CVI/UA and CVR for the questionnaire.

TABLE I
VALIDITY AND RELIABALITY

	Statistical Analysis			
	I-CVI	***S-CVI/UA***	***CVR***	***Cronbach's Alpha***
Value	0.945^{a}	0.555^{b}	0.888^{c}	0.777^{d}

Scale: $^{a} \geqslant 0.80$ $^{b} \geqslant 0.51$ $^{c} \geqslant 0.75$ $^{d} \geqslant 0.7$

C. Participants

For conducting this research, architecture students in the third semester of undergraduate studies were chosen since they passed major courses that were related to technical drawings, interpretation of technical drawings, and geometry. This gave them the skills of understanding technical drawings and matching drawings with 3D perspectives. There were 23 students in the third semester.

D. Prototype Development

1) Applying theories of experiencing cities to buildings: Kevin Lynch's theory indicates that there are five qualities including Paths, Edges, Districts, Nodes, and Landmarks for any given city [19]. In this study, we tried to create similar qualities in a museum (path=vistors' path, edges=physical boundaries, districts=galleries, nodes=spaces between galleries, landmarks=uncommon memorable spaces). The museum represents a simple geometry in the plan but has a winding visitors' path. Galleries are clearly having showcases with objects in them to avoid any misinterpretation about their location (Fig. 1). The path galleries include single showcases on the walls. The red path in Fig. 2 shows the visitors' path from the entrance (where the game starts) to the exit (where the game ends by showing "Thank you for your visit" as a pop-up text).

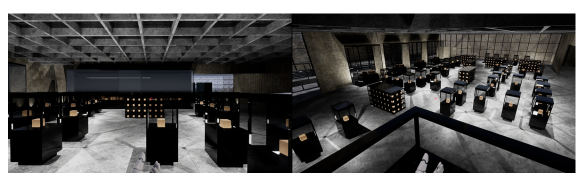

Fig. 1. Screenshots of the virtual environment

2) Time and Gaming Components: The primary gaming component in this prototype was users' ability to experience the environment as a first-person player within a specific time limit. Using a point-and-click cube-collecting game with a scoreboard distracted the users' attention from the important spatial qualities of Lynch. Therefore, we deliberately avoided to use conspicuous game elements and created an explorative non-game as a research application. Moreover, the hands of the player character in the game were shown to give the players a sense of orientation and scale.

3) Settings and Hardware: The prototype was developed in Unreal Engine version 4.24 for implementation on personal computers along with interactions.

E. Procedure

Researchers divided 23 participants into two groups. A group with 11 members played the 3D game for 20 minutes and the other studied technical plans for 35 minutes. The two groups were invited on different dates. After completing the game, students were given a 5-minute break while the authors were giving them directions on the questionnaire. After the briefing, the authors handed out the questionnaire. The timing of the game came from authors' playtime plus 40% extra time while more time was allocated to the 2D group for matching the plans and sections.

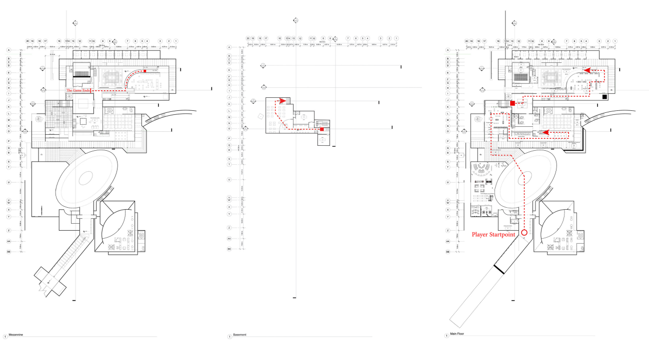

Fig. 2. Red dashed lines illustrates visitors' path in the building

III. Results and Discussion

A. Describability

The t-test of the two groups (Fig. 3) shows that there is a statistically significant difference between questions except for question 5 (Q5), Q11, and Q14. The t-test results illustrate Q1 has the biggest difference between the two groups in the first part. The 2D group with an average of 3.64 perceived the building as less complex. Although the 2D drawings may appear like a complex building to experts, novice students assume that the building won't be complex for users. This shows that not only students can use VR to learn about the effect of their designs but also VR is a good tool for evaluating users' experience. Similarly, the members of the 2D believed they can draw more precise sketches according to Q2 and Q3. This issue might be due to the fact that diagrams are abstract conceptual drawings that are illustrated mostly as 2D drawings. Likewise, Q4 and Q5 show they were more confident with their sequence drawings and considered them more precise although the difference between the two groups in Q5 was not statistically significant. Overall, we can see that students perceive 2D drawings as more simple and less complex in comparison to what drawings may actually be. This shows that using VR technologies in designing museums can be an efficient and effective tool for architects and designers to examine their concepts and designs which would result in inclusive design and realtime evidence for the design process.

Independent Samples Test

		t-test for Equality of Means								
		Mean	Std. Deviation	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Q1	2D	3.64	0.809	4.336	21	0.000	1.553	0.358	0.808	2.298
	VR	2.08	0.900	4.357	20.995	0.000	1.553	0.356	0.812	2.294
Q2	2D	3.82	0.751	2.942	21	0.008	1.068	0.363	0.313	1.823
	VR	2.75	0.965	2.975	20.492	0.007	1.068	0.359	0.320	1.816
Q3	2D	3.27	0.647	2.841	21	0.010	0.689	0.243	0.185	1.194
	VR	2.58	0.515	2.812	19.128	0.011	0.689	0.245	0.176	1.202
Q4	2D	3.45	0.820	2.828	21	0.010	0.955	0.337	0.253	1.656
	VR	2.50	0.798	2.825	20.707	0.010	0.955	0.338	0.251	1.658
Q5	2D	3.18	0.603	1.963	21	0.063	0.515	0.262	-0.031	1.061
	VR	2.67	0.651	1.970	20.996	0.062	0.515	0.262	-0.029	1.059
Q6	2D	2.64	0.924	-3.178	21	0.005	-1.114	0.350	-1.842	-0.385
	VR	3.75	0.754	-3.149	19.365	0.005	-1.114	0.354	-1.853	-0.374
Q7	2D	2.45	0.522	-3.306	21	0.003	-0.795	0.241	-1.296	-0.295
	VR	3.25	0.622	-3.332	20.858	0.003	-0.795	0.239	-1.292	-0.299
Q8	2D	2.64	0.674	-3.452	21	0.002	-0.864	0.250	-1.384	-0.343
	VR	3.50	0.522	-3.413	18.843	0.003	-0.864	0.253	-1.394	-0.334
Q9	2D	2.55	0.522	-3.459	21	0.002	-0.871	0.252	-1.395	-0.347
	VR	3.42	0.669	-3.498	20.518	0.002	-0.871	0.249	-1.390	-0.352
Q10	2D	3.64	0.674	2.892	21	0.009	0.720	0.249	0.202	1.237
	VR	2.92	0.515	2.858	18.694	0.010	0.720	0.252	0.192	1.247
Q11	2D	3.36	0.924	-1.891	21	0.073	-0.720	0.381	-1.511	0.072
	VR	4.08	0.900	-1.888	20.714	0.073	-0.720	0.381	-1.513	0.074
Q12	2D	4.00	0.775	4.113	21	0.000	1.333	0.324	0.659	2.008
	VR	2.67	0.778	4.114	20.845	0.001	1.333	0.324	0.659	2.008
Q13	2D	3.09	0.539	-2.704	21	0.013	-0.659	0.244	-1.166	-0.152
	VR	3.75	0.622	-2.722	20.947	0.013	-0.659	0.242	-1.163	-0.155
Q14	2D	3.00	0.632	-0.306	21	0.762	-0.083	0.272	-0.649	0.482
	VR	3.08	0.669	-0.307	20.973	0.762	-0.083	0.271	-0.648	0.481
Q15	2D	4.00	0.632	4.482	21	0.000	1.333	0.297	0.715	1.952
	VR	2.67	0.778	4.524	20.724	0.000	1.333	0.295	0.720	1.947
Q16	2D	3.09	0.539	-2.296	21	0.032	-0.576	0.251	-1.097	-0.054
	VR	3.67	0.651	-2.316	20.806	0.031	-0.576	0.249	-1.093	-0.058
Q17	2D	2.91	0.539	-3.067	21	0.006	-0.674	0.220	-1.131	-0.217
	VR	3.58	0.515	-3.060	20.611	0.006	-0.674	0.220	-1.133	-0.216

Fig. 3. The comparison of two groups

B. Simplicity

Q6 shows that students in the VR group were able to find their way easier. Similarly, Q7 shows that students in the VR group could provide addresses easier. Likewise, Q8 shows that the VR group with an average of 3.5 was more confident about their ability to provide accurate addresses but students' feedback on Q9 shows that wayfinding is harder for the 2D group. The VR group believed it is more likely for a visitor to become lost in the buildings (Q10).

Although these evaluations are subjective and highly relies on the ability of the 2D group to interpret 2D drawings, it shows wayfinding was easier for the VR group. However, Q10 shows that students may have struggled during wayfinding and relied on exploration but they eventually were able to find their way. On the other hand, the 2D group believed it is less likely for someone to be lost in the building according to the Q10. This might due to their ability to interpret the 2D drawings and lack of experience or the psychological effect of an easy-to-understand 2D drawing.

C. Memorability

Although Q11 was of significant importance to this study, students' feedback cannot confirm that remembering a building is easier for those who experience it in VR since the t-test did not show any significant difference between the two groups. The 2D group indicated that their drawn sequences of spaces may represent the arrangement of spaces more precisely (Q12). Q13 and Q14 ask about the ability of the respondents to guide someone inside the building. Although there was not a statistically significant difference between the two groups in being confident about their provided guidance based on their feedbacks (Q14), Q13 shows that the 2D group was less confident about their ability to direct a stranger to the galleries inside the building. Q15 shows that the 2D group perceived the building as an easy-to-understand building while the VR group perceived it as hard to figure out. Q16 and Q17 ask almost the same question and show wayfinding was considered easier in the VR group.

Q18 was not included in the independent t-test analysis since it measures the ability of students to find the correct diagram of spaces. In this question, the correct answer is the second one while the first choice has an error of 25%, the third and fourth choice have an error of 50%, and the fifth choice has an error of 75%. These percentages represent the number of wrong sequences. According to the results in Fig. 4, the 2D group had the highest percentage of correct answers (54.5%). The 2D group also had a higher percentage of the answer with a 25% error. Although none of the groups checked the answer with a 75% error, the cumulative percentage of those who checked the answers with 50% error (options 3 and 4) was higher in the VR group (33.3%).

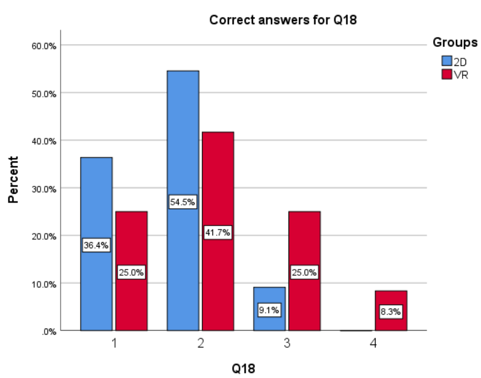

Fig. 4. Correct answers (%)

These results show that the VR group was able to guide someone inside the building better than the 2D group and believed that wayfinding was easy in this building while the 2D group believed the building was easy to figure out. On the other hand, it is obvious that the 2D group figured the building out better since they provided more correct answers in Q18. This issue might be due to the fact that 2D drawings were more similar to the construct of the abstract spatial diagrams while the VR group had to think and come up with a 2D diagram for answering questions. On the other hand, the VR group may have found the wayfinding easy because it was a single straight path to follow while it was meandrous 2D drawings.

IV. Conclusion

This paper investigated the impact of 3D serious games on wayfinding in a museum among architecture students through three constructs of Describability, Simplicity, and Memorability. The results showed that those who experience spatial configuration in VR may not be able to draw conceptual 2D diagrams but they can assess wayfinding easily in buildings through experiencing it. This is a valuable effect of VR since it can provide realtime evidence for architects and designers for implementation in their buildings. Furthermore, the tool can be used for novice architecture students to assess their 2D drawings or sketches. This preliminary study illustrates virtual environments can be an effective tool for participatory design and evidence-based design.

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