ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

AN INVESTIGATION INTO THE IMPACT OF VR ON EPISODIC AND SPATIAL MEMORIES

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Abstract

The recent rise in virtual reality (VR) technology has influenced architectural heritage. Since the memories that people embed in heritage spaces are crucial to their lives, this research investigates the impact of the VR medium on episodic and spatial memories. The authors used a quasi-experimental approach, where sixty participants explored actual and VR heritage environments for 15 minutes. Immediately afterward, the researchers conducted the free-recall test and, 20 minutes later, the delayed recall test with each participant individually. The research results show that the difference between actual and VR environments was significant in spatial and episodic free recall. The main difference between both was recalling more details in the VR environment compared to the actual one. Meanwhile, the participants in the actual environment were more likely to recall the building in terms of spatial relationships between different entities. Nevertheless, the delayed recall test shows no significant difference between the two environments, except for spaces with high multi-sensorial and interactive components.

INTRODUCTION

Significant architectural heritage buildings were recently demolished in Egypt, making virtual environments the only option for spatially experiencing those buildings. Hence, the question is: What is the impact of the virtual medium, more specifically virtual reality (VR) technology, on individual episodic and spatial memories? The authors used a quasi-experimental approach in two phases to answer this question. They selected sixty participants with similar architectural backgrounds. In the first phase, thirty participants navigated an actual heritage building individually, without any guidance from authors, for fifteen consecutive minutes. In the second phase, another thirty participants explored a VR replica of the previous heritage building using the HTC VIVE VR headset. After each phase, the authors used the "free recall test" and the "delayed recall test" with each participant.

This paper starts with a brief survey of definitions and a literature review. The Methods section follows, which delineates the research design. Then, the Results section reports on and discusses the quasi-experiment findings. The paper ends with a Conclusion section that exposes the research limitations and offers suggestions for future work.

Memory

This section maps out conceptual definitions of episodic and spatial memory in actual and virtual environments and the ways in which they can be measured and assessed.

Endel Tulving defined episodic memory, in connection to personal experience, as the ability to consciously recall past events, which are constituted by place, emotions, sensorial information, time, people, and idiosyncrasy (Tulving, 2002). Another definition of episodic memory is the

ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

ability to recall the spatial context of a previous event, providing a spatial context and a sense of time (Burgess et al., 2002). Moreover, the episodic memory of an event entails information about the event itself, its location, its temporality, and who was involved. It allows individuals to re-experience a personal event by recollecting it (Jebara et al., 2014). Therefore, episodic memory integrates the essential content of an event and its contextual attributes into a more cohesive memory representation (Jebara et al., 2014). This integration process is called "memory binding."

Spatial memory, on the other hand, is a type of memory responsible for guiding an individual's direction and orientation while gathering information about the surrounding environment (Shelton, 2003). It is an instrument for effectively navigating any space. It is not limited to the object's location but also the association between it and its position (Schumann-Hengsteler et al., 2004), creating a logical relationship between each scene in space (Burgess and O'Keefe, 2003).

Spatial navigation is one characteristic of spatial memory, which is the ability to create a mental map of the environment and then use it as a guide for navigation (Ekstrom et al., 2003). Encoding spatial information is another characteristic of spatial memory, which transforms sensory input about the environment into a form the human mind can store and recall (Burgess, 2006). One last characteristic of spatial memory is the representation of spatial layout, which is the ability to maintain the arrangements of spatial features in the environment (O'Keefe and Nadel, 1978).

Measuring Episodic and Spatial Memories

Two of the most used methods in this field to assess memory are the free recall test and the delayed recall test. Researchers apply the free recall test immediately after an experiment, focusing on the "what, where, and when" paradigm (Jebara et al., 2014). To test the "what" of the memory, participants elaborate on the details of each event and its associating elements. Then, they report on the location of each element and its directions (right or left). Similarly, they respond to the "when" components of the paradigm. Twenty minutes after the free recall test ends, the researchers conduct the delayed recall test, asking participants to verbally narrate the spaces, scenes, and events they recall from the experiment. The free and delayed recall tests in both actual and VR environments aim to obtain participants' verbal responses and cognitive sketches so the researchers can understand what participants recalled from their exploration phase (Jebara et al., 2014).

When experiencing a space in VR, photorealism significantly affects the performance of spatial and episodic memories. According to Stephen Lekan, a high level of realism impacts the participants' spatial memory (Lekan, 2016). Similarly, different levels of immersiveness in VR enhance episodic memory performance (Dehn et al., 2017; Gamberini, 2000; Harman et al., 2017; LaFortune and Macuga, 2018; Ruddle et al., 2011; Schöne et al., 2019; Wallet et al., 2011).

ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

METHODS

This section clarifies the methods and procedures the authors rely on to investigate episodic and spatial memories in actual and VR environments. They conducted quasi-experimental research that underwent two phases: the first in an actual environment and the second in a VR environment. The authors deliberately selected Mustawsaf al-Khalifa, located in Islamic Cairo, Egypt, an obscure heritage space, to eliminate the chance that the participants have previous experience or knowledge of it. The 19th-century building consists of two main parts, an infirmary and the shrine of Shagar al-Dur, in the center of an outdoor plaza surrounded by a fence (Figure 1).

Figure 1: The ground floor plan of Mustawsaf al-Khalifa (Image Credit: Megawra - BEC)

To acquire a 3D model of the building, the authors used the photogrammetry scanning technique through three phases. In the first phase, they captured 10145 images using a Nikon D5200 camera (18mm, f/8, 1/250 sec, ISO 200, EXP 0, no flash) after conducting a color calibration to ensure the accuracy of colors compared to the actual building. Then, they processed the images using the RealityCapture software to generate the 3D model. After that, they imported the 3D model into the Unity game engine (2019.4.34f1) to enable users to navigate the building using a VR headset (HTC VIVE). Before the experiment, the authors optimized and tested the 3D model (Figures 2 and 3) to eliminate any significant differences between the model and the actual environment.

A total of sixty college students (34 females and 26 males) participated in the experiment, thirty in each phase of the study. They were young adults (18-35) years old. The authors aimed for a homogenous sample of participants within a close age group from the same architecture department at a university in Cairo, Egypt. The inclusion criterion was for the participants not to have any actual or virtual experience with the heritage building under study. Participants were allowed to participate in the research's actual or VR phases, but not both.

In each phase (the actual building and the VR environment), thirty participants explored the selected heritage building individually for 15 minutes without any guidance from the authors. After the exploration phase, the authors used the free recall test method to interview each participant. They moved gradually from asking participants for general verbal descriptions to asking them to recall each space, covering the "what", "where," and "when" questions gradually. The participants recalled details involved in the spaces, including locations and viewpoints (right or left directions). The free recall tests usually lasted for an average of 30-40 minutes for each participant. Twenty minutes after the end of the free recall test, the authors performed the delayed recall test when they asked each participant to verbally recall what they still remembered from their navigation in the environment.

The authors divided the building into ten spaces: outdoor context and external façade, entrance, main hall, staircase, main hall, main hall storage, rooftop, service zone (including the bathroom), storage area, and closed storage area (Figure 3). Then, the authors created sub-architectural categories for each space. For example, in the main hall, the subcategories were four columns, arches connected to the columns, an extended wooden rooftop, storage area, mihrab, windows, and details of each one of these items. The authors collected the data from both environments using Microsoft Excel sheets and analyzed them statistically using IBM SPSS.

RESULTS

As discussed in the Methods section above, the authors analyzed ten spaces within the building under study. However, due to space limitations, in this section, they discuss only the main hall, the main entrance, and the rooftop, which are the most representative spaces of the paper's results and argument.

Main Entrance

The authors used the t-test to measure the statistical significance ($p<0.05$) of the difference in memory recall between the two experimental phases. The mean number of participants recalling the different details of the entrance hall is the same between actual and VR recall. However, the mean values of VR recall ($M=0.79$) of the three steps at the entrance were higher than the actual recall ($M=0.45$). The difference is significant ($p=0.006$), meaning that participants in the VR environment recalled those details. Regarding the canvas hanging on the

ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

entrance wall, the difference between the mean value of the actual recall (M=0.17) and the VR recall (M=0.48) is significant (p=0.011). While the canvas on the wall had low resolution in VR, the participants tended to recall it without recalling its writing details.

Figure 2: The canvas hung on the entrance hall's wall (right: the actual environment, left: VR)

Table 1: The t-test values of the free recall between the actual environment and VR for the entrance hall using SPSS. The colored rows refer to the values of significant difference

		Independent Samples Test		
		t-test for Equality of Means		
		t	df	Sig. (2-tailed)
Entrance Recall	Equal variances assumed	0.000	56	1.000
Entrance Door	Equal variances assumed	-0.752	56	0.455
Entrance Double Height	Equal variances assumed	-0.786	56	0.435
Entrance Ceiling Shape	Equal variances assumed	0.000	56	1.000
Entrance Three Steps (Stairs)	Equal variances assumed	-2.845	56	0.006
Entrance Doors on the Both Sides.	Equal variances assumed	-0.605	56	0.548
Entrance Canvas on the Wall	Equal variances assumed	-2.622	56	0.011
Entrance Marquette on the Walls	Equal variances assumed	-0.935	56	0.354
Entrance Materials (Ceiling, Floors, Walls)	Equal variances assumed	-0.579	56	0.565
Entrance Wooden Sofa	Equal variances assumed	-1.780	56	0.080

However, applying the delayed recall test to the actual and VR environments showed no significant difference (p>0.05) in recalling the entrance itself, entrance door, entrance double height, entrance ceiling shape, maquettes hung on the entrance wall, and entrance materials.

Only for the three steps (p=0.003), entrance doors (p=0.031), the canvas on the wall (p=0.006), and the sofa (p=0.001), there was a significant difference in favor of the actual space.

All the later space features afforded active haptic interaction in the actual environment but not in VR. For example, participants could sit on the sofa at the actual entrance but not in VR.

ISSN 1533-9211

DOI: 10.5281/zenodo.10559250

Table 2: The t-test for the delayed recall of the main entrance in both actual and VR environments. The colored rows refer to the values of significant difference

	Independent Samples Test			
		t	df	Sig. (2-tailed)
Entrance Recall	Equal variances assumed	-1.028	56	0.308
Entrance Door	Equal variances assumed	-1.058	56	0.294
Entrance Double Height	Equal variances assumed	1.977	56	0.053
Entrance Ceiling Shape	Equal variances assumed	-1.390	56	0.170
Entrance Three Steps (Stairs)	Equal variances assumed	-3.076	56	0.003
Entrance Doors on the Both Sides.	Equal variances assumed	-2.219	56	0.031
Entrance Canvas on the Wall	Equal variances assumed	-2.836	56	0.006
Entrance Maquette on the Walls	Equal variances assumed	-1.740	56	0.087
Entrance Materials (Ceiling, Floors, Walls)	Equal variances assumed	-0.853	56	0.397
Entrance Wooden Sofa	Equal variances assumed	-4.137	56	0.000

Main Hall

The different architectural components of the main hall were its shape (configuration), columns, materials, details on the walls, furniture, windows (location, number, details, and shape), opening on the left side (number and position), storage inside the main hall (door, location, and details), curtain (location and details), arches (number, materials, and shape), and mezzanine (location and details).

Figure 1: The Main Hall (right: actual environment, left: VR)

The mean values of the actual and VR recall differ for some architectural components of the main hall. The difference between the mean values of the main hall shape's actual recall (M=0.9) and VR (M=0.52) is significant (p=0.001). Participants in the actual environment tended to recall the shape of the main hall more accurately than their peers in VR recall. Moreover, the difference between the mean values of the number of columns in actual recall (M=0.72) and VR recall (M=0.45) is significant (p=0.033). The participants tended to have more sensorial interaction with columns in the actual environment than in VR, helping their recall. The main hall floor material analysis shows a significant (p=0.045) difference between memory recall in actual (M=0.21) and VR (M=0,.03) environments. The actual environment

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ISSN 1533-9211

DOI: 10.5281/zenodo.10559250

triggered more floor materials recall than VR due to participants' interaction with the physicality of the floor, touching and counting its tiles as they walked. Regarding the details of the canvas on the wall, Table 3 shows that the difference between the mean value of actual recall (M=0.48) and VR recall (M=0.76) is significant (p=0.031). According to the participants' verbal recall, most remembered the canvas in VR better as it triggered their attention to read the text on the board, perhaps due to their focus on the details in VR as scenes rather than a holistic recall of the spatial configuration. For the windows on the left side of the main hall, Table 3 shows that the difference between the mean value of actual recall (M=0.90) and VR recall (M=0.62) is significant (p=0.014). The participants in the actual environment better recalled the windows than their peers in VR. Similarly, the difference between the mean value of actual recall (M=0.41) and VR recall (M=0.10) for the number of windows is significant (p=0.006).

Table 3: The t-test values of the recall between actual and VR recall of the main hall. The colored rows refer to the values of significant difference

		Independent Samples Test		
		t-test for Equality of Means		
		t	df	Sig. (2-tailed)
Main Hall Recall	Equal variances assumed	1.797	56	0.078
Main Hall Shape	Equal variances assumed	3.430	56	0.001
Main Hall Columns	Equal variances assumed	2.183	56	0.033
Main Hall Floor Materials	Equal variances assumed	2.054	56	0.045
Main Hall Chairs (other Furniture)	Equal variances assumed	-1.097	56	0.277
Main Hall Canvas on Walls	Equal variances assumed	-2.219	56	0.031
Main Hall Wall Materials	Equal variances assumed	0.295	56	0.769
Main Hall Windows Recall	Equal variances assumed	2.548	56	0.014
Main Hall Number of Windows.	Equal variances assumed	2.836	56	0.006
Main Hall Windows shape	Equal variances assumed	1.608	56	0.114
Main Hall Windows Details (items attached to the windows)	Equal variances assumed	0.310	56	0.758
Main Hall Windows Shelves	Equal variances assumed	-1.169	56	0.247
Main Hall Left Side Opening Recall	Equal variances assumed	1.864	56	0.068
Main Hall Number of Left Openings	Equal variances assumed	0.461	56	0.647

As shown in Table 4, there is no significant difference in the delayed recall in the actual space and VR regarding the main hall columns, floor material, wall materials, window shapes and details, the window shelves, and the number of openings.

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ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

Table 4: The t-test for the delayed recall of the main hall in actual and virtual environments. The colored rows refer to the values of significant difference

	Independent Samples Test			
		t	df	Sig. (2-tailed)
Main Hall Recall	Equal variances assumed	1.834	56	0.072
Main Hall Shape	Equal variances assumed	3.147	56	0.003
Main Hall Columns	Equal variances assumed	0.520	56	0.605
Main Hall Floor Materials	Equal variances assumed	1.028	56	0.308
Main Hall Chairs (other Furniture)	Equal variances assumed	-2.503	56	0.015
Main Hall Canvas on Walls	Equal variances assumed	-4.154	56	0.000
Main Hall Wall Materials	Equal variances assumed	0.853	56	0.397
Main Hall Windows Recall	Equal variances assumed	2.149	56	0.036
Main Hall Number of Windows.	Equal variances assumed	3.550	56	0.001
Main Hall Windows shape	Equal variances assumed	1.864	56	0.068
Main Hall Windows Details (items attached to the windows)	Equal variances assumed	0.605	56	0.548
Main Hall Windows Shelves	Equal variances assumed	-0.752	56	0.455
Main Hall Left Side Opening Recall	Equal variances assumed	3.225	56	0.002
Main Hall Number of Left Openings	Equal variances assumed	1.797	56	0.078

The Rooftop

The building's rooftop provides crucial information, such as the minaret (location and shape) and the roof's relationship to the ground floor, the surrounding context, and the fence.

Table 5: The t-test of the rooftop free recall between the actual environment and VR. The colored rows refer to the values of significant difference

Independent Samples Test				
		t-test for Equality of Mean		
		t	df	Sig. (2-tailed)
Roof Recall	Equal variances assumed	-1.028	56	0.308
Roof Minerate Recall	Equal variances assumed	2.766	56	0.008
Roof Minerate Shape	Equal variances assumed	4.128	56	0.000
Minerate Location	Equal variances assumed	4.523	56	0.000
Roof Relation To the Ground Floor	Equal variances assumed	2.269	56	0.027
Roof Relation To the Terras When Seen Above	Equal variances assumed	0.890	56	0.377
Roof Fence	Equal variances assumed	0.000	56	1.000
Crenelations Shape Form	Equal variances assumed	0.295	56	0.769
Broken Crenelations Sama on Roof	Equal variances assumed	-0.381	55	0.704
Crenelations Position	Equal variances assumed	1.687	56	0.097
Roof Context Building	Equal variances assumed	1.043	56	0.302
Roof Context Trees	Equal variances assumed	0.357	56	0.723

According to Table 5, the minaret recall shows a significant (p=0.008) difference between the actual environment (M=0.72) and VR (M=0.38). Moreover, the number of participants who recalled the relationship between the rooftop and the ground floor was significant (p=0.027) in the actual environment (M=0.79) compared to VR (M=0.52). In VR, the participants could not bind their memory, which made them recall only scenes of the space but not collective or

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ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

holistic spatial configurations. The delayed recall test was significant for the minaret's shape and location. For the shape, the delayed recall was significant (p=0.001) in favor of the actual environment (M=0.45) over VR (M=0.07). Similarly, the location was significant (p=0.001), favoring the actual environment (M=0.52) rather than VR (M=0.10). The participants had a higher level of interaction with the minaret in the actual environment. The participants could only see the minaret in VR without further sensorial interaction. Otherwise, the delayed recall results of the other rooftop components were insignificant.

Table 6: The t-test of the difference between the actual environment and VR delayed recall of the rooftop. The colored rows refer to the values of significant difference

	Independent Samples Test			
		t	df	Sig. (2-tailed)
Roof Recall	Equal variances assumed	-1.390	56	0.170
Roof Minerate Recall	Equal variances assumed	1.941	56	0.057
Roof Minerate Shape	Equal variances assumed	3.596	56	0.001
Minerate Location	Equal variances assumed	3.742	56	0.000
Roof Relation to the Ground floor	Equal variances assumed	-1.043	56	0.302
Roof Relation to the Terras when seen above	Equal variances assumed	0.329	56	0.743
Roof Fence	Equal variances assumed	-0.264	56	0.793
Crenelations Shape Form	Equal variances assumed	-0.786	56	0.435
Broken Crenelations on Roof	Equal variances assumed	-0.461	56	0.647
Crenelations Position	Equal variances assumed	-0.584	56	0.561
Roof context Building	Equal variances assumed	0.000	56	1.000
Roof Context Trees	Equal variances assumed	1.403	56	0.166

DISCUSSION

Although VR has relatively less details than the actual building due to photogrammetry technical affordance and limitations, the detailed recall of the context was better in VR during the free recall test. For example, more VR participants could recall details at the main entrance, such as the three steps and the canvas hanging on the wall. Other aspects of the entrance recall had no significant differences in the free recall. The delayed recall of the entrance hall showed no significant differences except for the three steps in VR. Alternatively, more participants could recall the windows in the main hall in the actual experience than in VR. The reason behind this is that the participants could observe more details of the context outside the windows, which were not available in the VR due to the limitation of photogrammetry. Details seem to boost memory recall regardless of the environment.

Otherwise, in the free recall of the main hall, the significant difference favored the recall in the actual space, with more participants being able to recall the main hall shape and its columns. Observation showed that more participants had active haptic interaction with the actual space, touching the different building materials, which led to recalling more spatial details. Similarly, for the mihrab, a substantial feature of the main hall, the free recall indicated that the participants could recall it better in the actual building than in VR in terms of location, shape, and columns on both sides of the mihrab. In the delayed recall test, the significant difference was in favor of the actual building only in terms of the building materials, the shape of the

DOI: 10.5281/zenodo.10559250

arches, locations, and the shape of the mihrab. These differences remained significant in the delayed recall test, suggesting that more sensorial input and interaction with the building materiality are likely to improve memory recall. Correspondingly, the free recall of the actual rooftop was significantly better than in the VR, especially in recalling the minaret, which reflects the implication of the participants' multi-level sensorial interaction with the minaret in the actual environment. They could touch the walls and ascend the stairs toward the top of the tower. In VR, the participants could not have this level of interactivity. They could only see the stairs but not touch or climb them. This interactivity also resonated with the participants' spatial memory. The recall of the relationship between the building's ground floor and its roof (spatial binding) was more significant in the actual building than in VR. The participants could recreate the relationship between the two floors more accurately. These findings also remain significant in the delayed recall test, which suggests that more meaningful interaction can trigger relatively lasting memories.

CONCLUSION

In this paper, the authors devised a two-phase quasi-experiment to test the impact of VR on episodic and spatial memory. In the first phase, the authors asked 30 participants to visit Mustawsaf al-Khalifa, an obscure heritage building in Historic Cairo, Egypt, for 15 minutes. In the second phase, they asked another 30 participants to visit a VR replica of the building. Each phase was immediately followed by a free recall test, then 20 minutes later, by a delayed recall test.

Generally, in the free recall test, the participants showed some significant differences in recalling spatial features between the actual building and its VR representation. However, in the delayed recall test, these differences became statistically insignificant. In other words, experiencing a high-fidelity photorealistic VR of a building seems to affect memory recall immediately after the event but not in the long run. However, there were some exceptions where significant differences in favor of the actual building persisted in the delayed recall test. A common feature of these exceptions is their haptic sensorial input, which the VR replica did not afford. The participants could recall spatial features they could touch and interact with in the actual building better than the ones they could only see. The above conclusion highlights a limitation of this paper's experiment. The authors did not account for multi-sensorial interactivity in their design of the VR replica. Future work can explicitly address this issue by building haptic input in VR and testing its impact on memory recall.

Acknowledgment

We are grateful to the members of the VR laboratory at Ain Shams University for their crucial support for this research. We also thank Megawra (Built Environment Collective) for hosting the experiment's first phase. Finally, we are grateful for our Research in Architectural Media (RAM) laboratory teammates, who contributed their advice and insights to this research.

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ISSN 1533-9211
DOI: 10.5281/zenodo.10559250

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