Evaluating Navigation Techniques for Virtual Reality Museums

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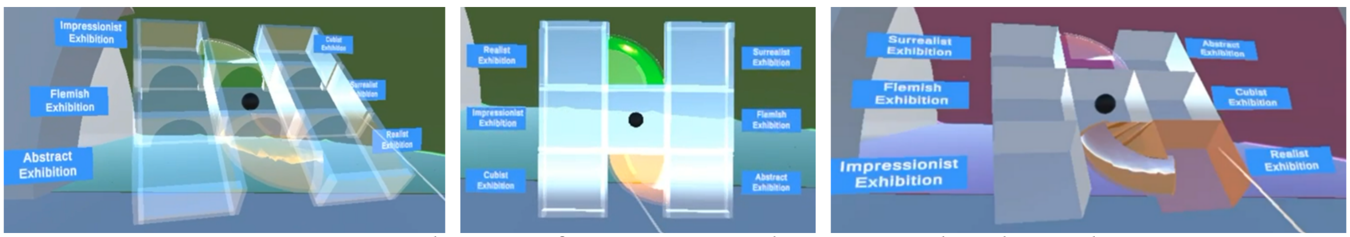

Figure 1: Visualization of Navigation Techniques Used in the Study.

Abstract

Navigating virtual environments effectively is crucial to improving user experience in VR applications, particularly in contexts such as virtual museums. Virtual Reality (VR) introduces innovative navigation methods that surpass the limitations of physical museum spaces, yet these techniques remain underexplored in virtual museum settings.

This study evaluates three navigation methods in a virtual museum environment: a 2D Non-Interactive Map, a 3D Non-Interactive Map, and a 3D Interactive Map. Through user testing, we analyzed task completion times, usability, user preferences, and perceived motion sickness. The 3D Interactive Map system significantly outperformed the other methods in efficiency and user preference as well for usability. These findings aim to guide the design of efficient and user-friendly navigation systems for VR applications, providing valuable insights for enhancing user experience in virtual museum environments and similar indoor VR settings.

Keywords

Virtual Reality - Navigation Techniques - User Study - World-in-Miniature (WiM) - 2D Map - 3D Map - Interactivity - Usability

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1 Introduction

Navigation is a fundamental activity in both real and virtual environments. Within Virtual Reality (VR), navigation encompasses locomotion and wayfinding, both essential components for creating engaging and intuitive user experiences. While navigation in open areas and outdoor settings has been widely studied, navigating complex indoor environments, such as museums, remains less explored. This study focuses on improving navigation methods in VR museum contexts, aiming to understand their impact on user performance, spatial awareness, and preferences.

Building upon previous research on navigation techniques and VR museum studies, this project evaluates the effectiveness of three distinct navigation methods: a 2D non-interactive map, a 3D non-interactive map, and an interactive 3D map (World-in-Miniature). The study was carried out within a virtual reconstruction of a museum, where participants were tasked with navigating between rooms to achieve specific objectives. Each participant tested all three sequentially randomized navigation methods, and their experiences were evaluated through objective metrics, such as task completion time, and subjective feedback collected via post-task questionnaires.

Our **research question (RQ)** investigates: *How do 2D maps, non-interactive 3D maps and interactive*

3D maps impact navigation effectiveness, spatial awareness, and user preferences in VR museums?

To address this, 35 participants completed navigation tasks using each method, with key aspects such as ease of use, perceived complexity, and user preferences evaluated.

The initial findings indicate that the interactive 3D map demonstrated superior performance compared to the other methods in terms of navigation efficiency, user preference, and perceived usability. Although the 2D map was the most familiar to users, it was identified as the least effective navigation method. In contrast, the interactive 3D map was preferred by the majority of participants due to its simplicity and enhanced rate of movement. These results emphasize the inherent trade-offs in designing navigation systems for VR environments and provide valuable insights for optimizing user experiences within virtual museum contexts.

This study contributes to the design of effective virtual reality navigation systems by empirically comparing widely used techniques in a controlled setting. Our findings inform best practices for balancing efficiency, simplicity, and user comfort in VR museum navigation, with broader implications for complex indoor navigation scenarios.

2 Related Work

Virtual Reality (VR) has increasingly been utilized to enhance museum experiences, transforming how heritage is accessed and understood.

This section reviews previous research on VR navigation methods, particularly in museum contexts, to provide a foundation for evaluating the three navigation techniques used in this study.

2.1 Navigation in Virtual Museums

Navigation is a fundamental activity in VR, encompassing locomotion and wayfinding.

Lepouras et al. [4] highlighted the potential of VR to address spatial and accessibility constraints in physical museums, enabling users to explore virtual reconstructions of heritage sites.

Building on this, Caputo et al. [2] compared various navigation methods in virtual museum settings, demonstrating that interactive methods, such as point-and-teleport, improved efficiency over joystick-based controls.

Marín-Morales et al. [6] explored the differences in navigation behavior between physical and virtual museum settings using immersive HMDs. Their findings revealed significant differences in initial exploration patterns but close similarities over extended navigation, supporting the validity of VR simulations for navigation tasks.

Zhang et al. [3] investigated game-based strategies to enhance spatial awareness, emphasizing the benefits of integrating interactive navigation aids like World-in-Miniature (WiM) systems to support effective wayfinding.

Similarly, MagicMap by Wang et al. [1] introduced hierarchical navigation interfaces, showcasing improved usability and prolonged engagement in VR museums.

2.2 World-in-Miniature (WiM) and 3D Mapping

WiM systems are increasingly recognized for their ability to enhance navigation by providing users with a scaled-down, interactive representation of virtual environments.

In the context of VR museums, Wang et al. [1] evaluated the effectiveness of combining WiM with traditional 2D maps, leading to the development of MagicMap. Their findings revealed that interactive WiM systems reduce cognitive load and motion sickness while enhancing spatial awareness.

2.3 Usability and Motion Sickness in VR

Bekele and Champion [5] analyzed the impact of immersive interaction methods on user experience in VR heritage settings, emphasizing the importance of usability and minimizing motion sickness to ensure prolonged engagement.

Continuous locomotion methods, while supporting spatial awareness, often induce motion sickness, presenting a design challenge in VR navigation systems.

Discrete methods, like teleportation, address this issue but may disrupt spatial understanding, highlighting the need for balanced approaches.

2.4 Application to This Study

Drawing from these works, this study explores the impact of 2D maps, non-interactive 3D maps, and interactive WiM systems on navigation effectiveness, spatial awareness, and user preferences in a VR museum.

While previous research provides a robust foundation, our study extends this knowledge by comparing these methods in a controlled VR environment with a focus on user-centered metrics, such as task performance, perceived usability, and motion sickness.

3 Methods

The VR museum was developed to serve as a controlled environment for evaluating navigation methods. The museum layout as shown in Figure 3 is fairly simple, consisting of a central hub, two corridors connecting each side, and six exhibition rooms. Several iterations of the architecture were made to ensure that tasks would be neither too easy nor too difficult. We chose several artistic movements as themes for each exhibition room in order to make the museum more realistic, as well as to help the user navigate the building, and in each room there were two paintings of that theme.

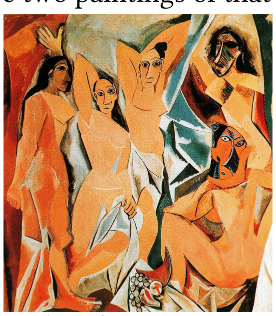

Figure 2: Example of painting: "*Les demoiselles d'Avignon*" by Pablo Picasso

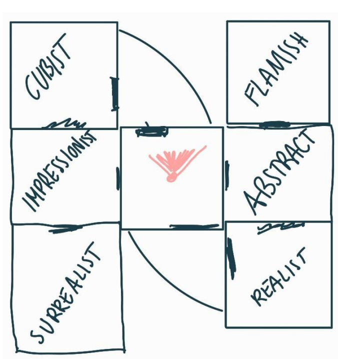

Figure 3: Museum Architecture

For all navigation techniques two things were the same: how the user can open the map and how to move around the museum. By pressing the 'A' button on the right-hand controller the map can be opened and closed. By using both joysticks the user can move around, rotating with the joystick on the left-hand controller and actually moving with the one on the right.

The three navigation methods were implemented in our VR museum using Unity and Meta Quest 2:

(1) **2D Map:**
- A simplified and non-interactive map that displays the user's position and room labels. Designed for simplicity and familiarity and does not require interaction with the map beyond visualization.
- Movement is controlled manually using VR controllers to simulate "walking."

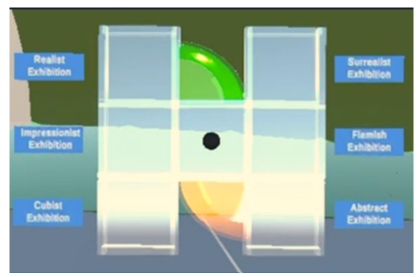

Figure 4: 2D Non-Interactive Map

(2) **3D Non-Interactive Map:**
- A scaled-down, non-interactive 3D model of the museum displayed in the VR space.
- Users move within the environment using VR controllers, with the WiM map serving as a spatial reference.

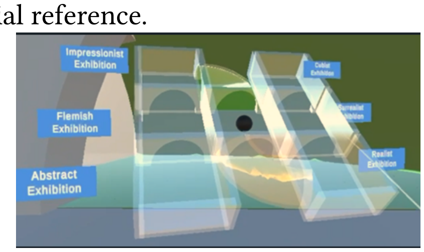

Figure 5: 3D Non-Interactive Map

(3) **3D Interactive Map:**
- An interactive 3D model of the museum that allows point-and-teleport navigation using a VR controller.
- Users can select destinations by pointing at any room in the model and pressing the trigger button, reducing physical movement requirements

by automatically transporting the user. It is also still possible to "walk" around the museum like in the two previously described methods.
- When hovering over a room in the map, that room will appear with a different color to help users see where they will be clicking and consequently where they will teleport.

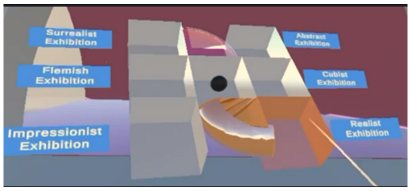

Figure 6: 3D Interactive Map

The goal to achieve, when testing each map, was to find a specific painting presented in the beginning of the test, so in order to mitigate learning effects, these three techniques were tested by each user in a random order and each method had different room layouts. Upon selecting a painting, users received immediate feedback through visual and auditory cues to confirm success or an indicative that a retry necessary.

4 User Study

4.1 Participants

The study involved 35 participants, aged 15 to 65+, representing a diverse group of VR experience levels, in total 14 women and 21 men. Approximately 14 were beginners, 12 had moderate experience, and 9 were advanced VR users. Participants were recruited from local communities and school community at IST.

4.2 Protocol

Participants were tasked with locating specific paintings that were shown at the beginning of each test using each navigation method: 2D Map, Non-Interactive 3D Map, and Interactive 3D Map. Throughout the testing process, users were asked to remain seated in the same place for consistency purposes.

The sequence of navigation methods was randomized to mitigate order effects. Each trial included identifying an assigned painting while navigating through the museum's rooms. The layout of the rooms was different for each method and so was the correct painting, but to maintain difficulty the distance from the user's initial position to the correct painting was always the same.

After completing each method, the participants provided feedback via the SUS questionnaire and motion sickness scale. A final questionnaire was answered after all methods were tested, in which users could mention which one they found the most and least effective.

4.3 Metrics

Objective metrics, such as task completion time, were used to evaluate navigation efficiency.

Subjective metrics, including SUS scores and motion sickness ratings, provided insights into user experience and comfort levels.

5 Results

5.1 Task Completion Time

The 3D Interactive Map system achieved the fastest average task completion time (mean completion time of 57.3 seconds), as shown in Figure 7, significantly outperforming both the 2D Map (mean completion time of 101.1 seconds) and the Non-Interactive 3D Map (mean completion time of 86.8 seconds).

Statistical analysis using one-way ANOVA revealed a significant difference in completion times between the navigation methods ($p < 0.05$).

Post-hoc Tukey tests highlighted the following:
- **3D Interactive Map vs. 2D Map:** Significant improvement with 3D Interactive Map ($p < 0.001$).
- **3D Interactive Map vs. Non-Interactive 3D Map:** Significant improvement with 3D Interactive Map ($p < 0.01$).
- **2D Map vs. Non-Interactive 3D Map:** No significant difference ($p > 0.05$).

These results demonstrate the superior efficiency of the 3D Interactive Map system in facilitating user navigation within the VR museum environment.

5.2 SUS (System Usability Scale) Scores

Participants rated the 3D Interactive Map system as the most effective in terms of usability, with a mean SUS

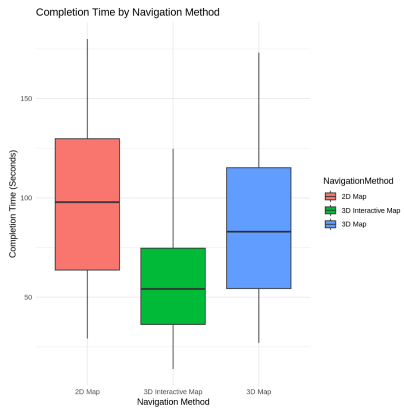

Figure 7: Completion Time By Navigation Method Plot

score of 70.4, followed by the Non-Interactive 3D Map score of 61.7 and the 2D Map score of 56.1.

Welch's t-tests revealed the following:

- **3D Interactive Map vs. 2D Map:** Significant improvement in 3D Interactive Map ($p = 9.412e - 10$).
- **3D Interactive Map vs. Non-Interactive 3D Map:** Significant improvement in 3D Interactive Map ($p = 1.002e - 06$).
- **2D Map vs. Non-Interactive 3D Map:** Significant improvement for the Non-Interactive 3D Map ($p = 0.05213$).

These findings confirm that the interactive navigation method offers the highest usability, aligning with user preferences for simplicity and efficiency. The interactive method allowed users to go directly to the rooms they intended, making it less likely to get lost.

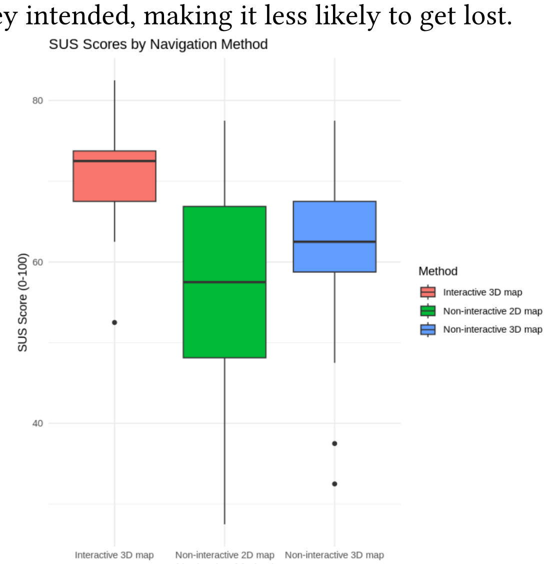

Figure 8: SUS Scores By Navigation Method Plot

5.3 Ease Of Use and Complexity

Ease of Use and Complexity were assessed via self-reported usage ratings on a 5-point scale:

- The **Non-Interactive 3D Map** was considered the least complex, with a mean rating of 1.2 and a ease of use rating of 4.5.
- The **2D Map** received a slightly higher complex rating of 1.8 and a ease of use rating of 3.8.
- The **3D Interactive Map** caused the highest complexity of 1.5, likely due to the increased movement and interaction required. Had a ease of use rating of 4.

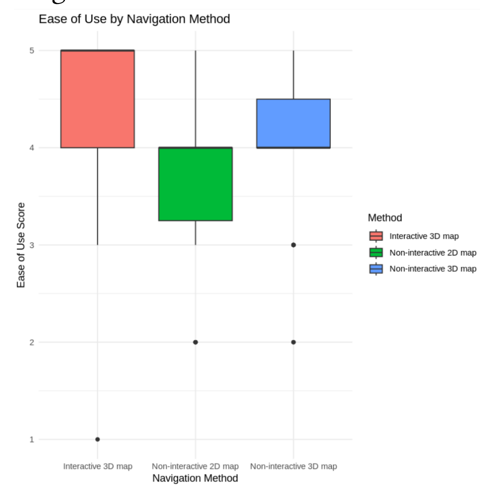

Figure 9: Ease of Use for each Navigation Method Plot

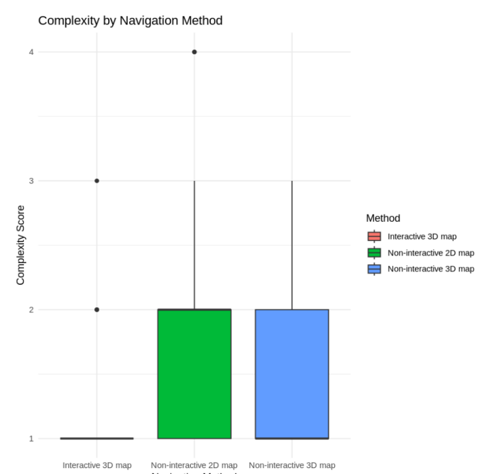

Figure 10: Complexity for each Navigation Method Plot

5.4 Motion Sickness

Statistical analysis (one-way ANOVA) revealed no significant differences in motion sickness ratings among the three navigation methods ($p > 0.05$), as only 2/35 people had motion sickness throughout the whole procedure and not just a specific navigation method itself.

5.5 Navigation Preferences

In post-test questionnaires, the majority of participants (65.7%) preferred the 3D Interactive Map system due to its ease of use, faster movement, and intuitive interaction. The Non-Interactive 3D Map was the second most preferred method (25.7%), while the 2D Map was the least preferred (8.6%), primarily due to its simplicity but slower navigation.

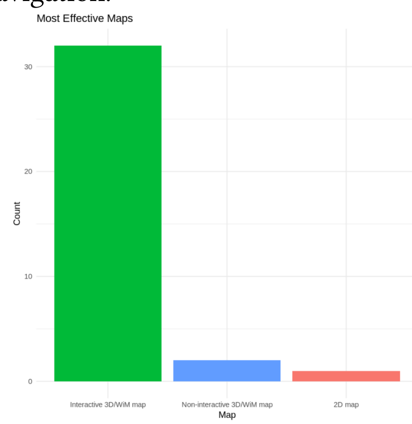

Figure 11: Effectiveness by Navigation Method Plot

5.6 Statistical Summary

- **Task Completion Time:** Significant differences found between Interactive and Non-Interactive methods.
- **SUS Scores:** Significant differences in usability across methods, Interactive 3D more enjoyed by the users.
- **Motion Sickness:** No significant differences observed.

6 Limitations and Future Work

This study has several limitations that provide avenues for future research. First, the paintings selected for the navigation tasks were not randomized, which may have introduced a degree of predictability in participant responses, since they may be more familiar with certain styles. While the randomized testing order for navigation methods mitigated learning effects to some extent, future studies could incorporate a fully randomized task design to ensure unbiased evaluations.

Second, our virtual museum environment, while carefully designed, was not a replica of a physical museum. Although the use of themes and curated rooms provided a realistic context, future research could benefit from implementing actual museum collections or more complex layouts. Comparing navigation performance in virtual replicas of physical museums would provide deeper insights into how VR navigation systems can enhance real-world applications.

Third, this study focused exclusively on single-floor environments. Many museums, shopping malls, and other complex indoor spaces include multiple floors, presenting additional navigation challenges. Extending the interactive 3D Map system to support multi-floor navigation through features such as vertical transitions or layered map representations would be a valuable direction for future work.

Additionally, while this research analyzed individual navigation experiences, it did not address the social aspects of museum visits. Museums are often social spaces, and collaborative navigation in VR could open new opportunities for user engagement. Future studies could explore multi-user interactions, such as integrating collaborative features like shared annotations or heatmaps to enhance group navigation experiences.

Future work could focus on refining the teleportation experience within interactive systems by incorporating features like teleportation previews or smoother transitions. Exploring hybrid navigation methods that combine the simplicity of 2D maps with the interactivity of WiM systems could also help address the trade-offs identified in this study.

By addressing these limitations and exploring these areas, future research could further enhance navigation systems in VR environments, making them more adaptable, scalable, and user-friendly across diverse settings.

7 Conclusion

In this study, we evaluated the effectiveness of three navigation techniques— 2D Map, Non- Interactive 3D

Map, and Interactive 3D Map — in the context of a VR museum.

Our results demonstrate that the Interactive 3D Map significantly outperformed the other methods in terms of navigation efficiency, usability, and user preference.

While the 2D Map was the most familiar to participants, it was rated the least effective due to its limited functionality and slower task completion times.

The Non-Interactive 3D Map offered improved spatial awareness compared to the 2D Map but lacked the interactivity necessary for optimal navigation.

The Interactive 3D Map, on the other hand, was widely preferred by participants for its simplicity and enhanced navigation speed. Despite causing slightly higher motion sickness, it provided the best overall user experience by balancing efficiency and ease of use. These findings highlight the trade-offs between different navigation methods and underscore the importance of interactivity in VR navigation systems.

This work contributes to the development of effective VR navigation systems by providing empirical evidence on the strengths and limitations of widely used techniques. Our findings inform design practices for VR museum environments, offering insights into optimizing navigation systems for improved usability and user satisfaction.

Project Links

- `Code Base`
- `Demo Video`

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