Echoes in the Gallery: A Collaborative Immersive Analytics System for Analyzing Audience Reactions in Virtual Reality Exhibitions

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ABSTRACT

Virtual reality (VR) has enriched the exhibition experience, yet curators and artists often face challenges in curation due to disagreements in the spatial arrangement of exhibits. Although VR applications permit audiences to express their reactions, these multimodal and semantically rich data remain underutilized in spatial arrangement deliberations. Based on insights from semi-structured interviews with curators and artists, we outline design requirements to enhance collaboration in analyzing visitors' reactions, focusing on traffic flow analysis, angle-induced reactions, what-if analysis, and cross-view annotations. To meet these requirements, we propose a novel collaborative immersive analytic system that visualizes audience flow and individual reactions within VR spaces, facilitating more effective communication and decision-making between artists and curators. Future research will explore advanced visual design techniques to address scalability issues and in-place spatial comparison. We will also finish the development and conduct usability studies.

Index Terms: Human-centered computing—Visualization—Visualization application domains—Information visualization

1 INTRODUCTION AND RELATED WORK

Virtual reality (VR) has transformed the modern exhibition landscape by offering audiences profound and immersive experiences [5, 9]. Nonetheless, the curation process has long posed challenges for both curators and artists, as they frequently encounter disagreements regarding the spatial arrangement of exhibits and the ways of placing them. Many VR applications (e.g., Spatial and VRChat) allow the audience to express their reactions and emotions within virtual gallery spaces in multimodal ways, including text, emojis, and predefined sets of poses. Visualizing and analyzing the data empowers curators and artists to gain valuable insights into audience engagement, facilitating informed discussions and coordination based on this newfound understanding.

However, no existing collaborative immersive visual analytic systems can assist curators and artists in effectively analyzing the vast amount of audience data collected, ultimately expediting the process of bridging differences and reaching a consensus. Existing tools like MRAT [6], ReLive [3], ARCHIE++ [4], and AvatAR [7] primarily focus on individual analysis and fall short when considering the collaborative nature of the design and evaluation process of VR spaces. For instance, artists frequently engage in debates with curators regarding the exhibition space they occupy within the environment to attract a wider audience to their artworks. Collaborative systems like MIRIA [1] and Embodiment Provenance [8] mainly focus on numerical data and lack specialized design to handle reaction data, which is semantically rich with poses, text, and emojis. For example, these systems fail to address issues stemming from the misinterpretation of an artist's intention due to improper exhibit placement angles.

In essence, the existing visualization tools fail to meet the design requirements for spatially visualizing and analyzing audience reactions in VR space based on their personal attributes. Therefore, our first step is to gather key insights for the analytic system design through semi-structured interviews with curators, artists, and visitors. The insights inform the subsequent design requirements for supporting collaboration: (R1) Enabling traffic flow analysis in a narrative style is crucial for providing a comprehensive understanding of spatial factors that influence audience behavior over time; (R2) Integrating angle-induced reactions in 3D space allows for precise positioning and contextual understanding of visitor responses, aiding in optimizing exhibit placements; (R3) Supporting collaborative what-if analysis facilitates exploring alternative scenarios and evaluating their impact on the visitor experience, addressing differing opinions; (R4) Supporting cross-view annotations promotes effective communication and discussion between curators and artists when focusing on different data tasks. These design requirements collectively enhance collaboration, decision-making processes, and the creation of engaging visitor experiences.

To meet the design requirements, we introduce a collaborative analytic system featuring two coordinated views to enhance analysis and collaboration between artists and curators. The Timeline View visualizes audience flow and enables the comparison of visitor reactions to different spatial layouts, aiding in assessing the alignment between artwork narratives and spatial arrangements. The Detailed Immersion View provides a first-person, close-up examination of individual user reactions, allowing analysts to explore detailed poses, orientations, and associated emojis within the original spatial context. Interactions support collaborative what-if analysis and object manipulation, while synchronized annotations can be added in both views for enhanced communication and reference across layouts.

For future work, we will continue the development of a fully functional prototype, conduct a summative user study to evaluate the usability, and contribute to the design of immersive analytic tools for multi-party collaboration. Additionally, sharing our findings and contributing to the broader field will support the advancement of collaborative immersive analytics.

2 DESIGN REQUIREMENTS

To gather insights into the requirements for the analytic system design, we conducted semi-structured interviews with key stakeholders, including two curators (C1 and C2) and two VR artists (A1 and A2). We also interviewed four frequent visitors (V1-V4) experienced in

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VR-based exhibitions, aiming to gain a deeper understanding of the visitor data that curators and artists can analyze. In this study, we focus on VR exhibitions that are fully virtual, allowing visitors to enjoy exhibits from anywhere with VR devices. Visitors can walk around the virtual spaces freely and observe exhibits from various perspectives.

The results showed that visitors are inclined to express their reactions, emotions, and thoughts within VR spaces, particularly when they discover intriguing angles to appreciate 3D artworks. For example, V1 said, *"Some artworks viewed from unusual angles offer a refreshing surprise and I am eager to share this."* By utilizing VRChat's poses and emojis, V1 could expressively invite their accompaniers to reevaluate the artwork from a fresh perspective. Furthermore, the visitors emphasized that the placement of an exhibit significantly influenced their perception of it. According to V3, *"I would express my displeasure with an angry or disgusted pose and emoji if an unattractive exhibit is placed in the center."* However, if the same exhibit is placed in a disregarded corner, V3 would express a milder reaction and use less emotionally charged emojis, such as a question mark, when sharing their opinion.

We also found that curators and artists might have conflicting opinions on the spatial arrangement of the exhibits. For example, artist A2 expressed a desire to position her sculpture in an unconventional and elevated location, stating, *"I wish to immediately capture the visitor's attention and make them truly appreciate the subtle details of my design."* However, curator C1 shared, *"My job is to create a coherent narrative and ensure a smooth visitor journey through artworks from various artists. However, artists often desire prominent placements for their pieces to get greater visibility. It is part of my job to guide them in understanding that central placement does not necessarily equate to the best exposure and audience feedback. However, without visible evidence, persuading them can prove challenging."*

All curators and artists were interested in leveraging audience reactions as a means of communicating and validating the spatial layout and placement of the exhibits. A1 expressed, *"The reactions visitors leave in VR spaces are direct communication with me. I am happy to read their reactions and to examine whether the current placement enhances or hinders the message I want to convey."*

Based on the findings, we distill the following design requirements to support collaboration between curators and artists.

R1: Enabling Traffic Flow Analysis in Narrative Style. As we learned from the interviews, curators care more about providing a smooth and coherent narrative in an exhibition, the system should provide the flexibility to select specific miniatures based on patterns of traffic flows, allowing them to delve deeper into the corresponding spatial context at a narrative granularity. Overall, this design requirement seeks to enable spatial analysis and comparison of traffic flows, providing a comprehensive understanding of the spatial factors influencing audience behavior over time.

R2: Integrating Angle-Induced Reactions in 3D Space. We strive to combine and visually display the positive or negative reactions triggered by different angles of observation within the 3D space. The system is designed to deliver precise positioning and a contextual understanding of these reactions, assisting curators and artists in discerning if and why visitor responses vary across different viewing perspectives. This data-driven approach will empower artists and curators to optimize the positioning of their exhibits, such as putting exhibits in a way that allows visitors to easily find the angle with the most positive reactions.

R3: Supporting Collaborative What-if Analysis. Collaborative what-if analysis can be useful in addressing the different opinions of curators and artists on the spatial arrangement of exhibits. After getting insights from the historical data, both parties can explore different scenarios and assess the potential impact of each option on the visitor experience. For example, they can simulate the effect of placing an artist's sculpture in an unconventional and elevated location and evaluate its impact on the overall narrative and visitor flow. Similarly, they can assess the effect of placing the sculpture in a more traditional location and compare the feedback from visitors in both scenarios. This approach allows curators and artists to work together to find a solution that satisfies both parties and creates an engaging and memorable visitor experience.

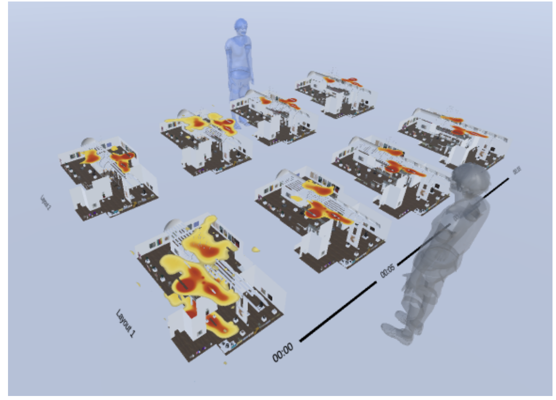

Figure 1: The timeline view visualizes changes in visitors' flow over time for different layouts. The x-axis displays exhibitions' normalized timestamps in five-minute intervals, and the y-axis shows data for each layout.

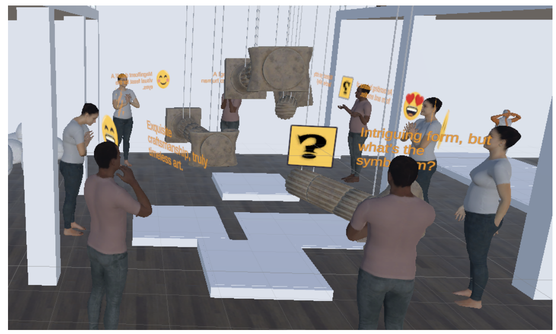

Figure 2: The detailed immersion view shows visitors' reactions in a clustered view based on density, highlighting the most common poses, text, and emojis while avoiding visual clutter.

R4: Supporting Cross-view Annotations. The system should support the ability for users to annotate or add comments to items or content from different views. Annotation across different views helps curators and artists be aware of each of their design thoughts and facilitates discussion when they are focusing on different data tasks from different views.

3 Collaborative Immersive Analytics System

We propose a collaborative immersive analytic system comprising two coordinated views designed to facilitate seamless analysis and synchronous collaboration between artists and curators, who can work in the same or different locations.

Timeline View. We designed the timeline view (Fig. 1) to visualize the visitors' flow during their visit. Visualizing the flow of people helps artists and curators understand whether the narrative flow of the artworks matches the spatial layout of the exhibition (R1). It consists of several arrays of miniature replicas of the full-scale 3D environment of each layout at different timestamps, each encapsulating user reactions occurring within its corresponding spatial layout. Reactions are visualized with heatmaps whose color encodes the density of reactions in a specific place. When an artist and a curator debate on which space layout to choose for the artist's artwork, they

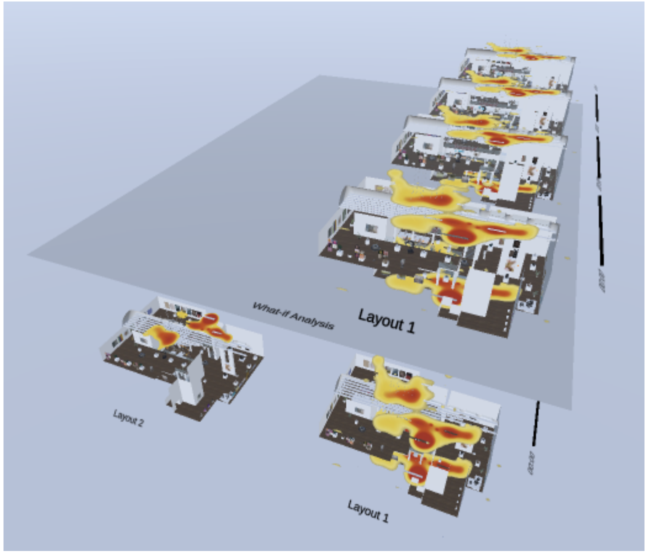

Figure 3: This figure illustrates what-if analysis. The timeline view is updated after objects are manipulated. Each manipulation causes the creation of a new floor of layouts.

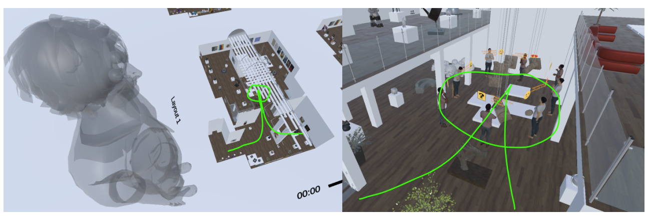

Figure 4: This figure illustrates the same annotation in both the timeline and detailed immersion views.

can select the spatial layout they prefer and compare how visitors react to each spatial layout. They can notice the variations in reactions based on the location or orientation of exhibits, changes in reactions due to the proximities to specific exhibits, and responses influenced by spatial factors such as accessibility conditions. Analysts can select any miniature based on apparent patterns or their research interests to delve deeper into the corresponding spatial context at a fine granularity with a detailed immersion view later.

Detailed Immersion View. The detailed immersion view (Fig. 2) provides a deep dive into individual user reactions from different angles (R2). Curators and artists can walk in the virtual space and observe the reaction data in a close-up, first-person perspective. The detailed immersion view provides a detailed depiction of the user's poses, orientation, precise reaction location, and the associated emoji and text, all set within their original spatial context. The detailed immersion view is inherently interactive, granting analysts the freedom to navigate around the expanded reaction, examine it from various angles, and closely inspect individual elements. This ability to explore reactions in such detail helps analysts understand the users' experiences within the VR environment more empathetically and intuitively. In circumstances where the density of reactions in a local zone is high and risks causing visual clutter, we cluster the reactions and only display the reaction with the most counts. Moreover, the view is equipped with functionality that allows analysts to filter reactions based on their needs, thus maintaining the clarity and readability of this immersive view.

Interactions. To enable collaborative what-if analysis, users can manipulate objects in a shared space for discussion (R3). The overall narrative and visitor flow are simulated in real-time for the new layout. A new floor of layouts is generated on the positive Z-axis instead of replacing for recall and comparison when detecting updates, similar to DataHop [2] (refer to Fig. 3).

Moreover, users can add annotations to both the timeline and detailed immersion views (R4), which are synchronized across different views for discussion and all layouts, as shown in Fig. 4. It allows users to communicate and record design goals, hypotheses, and data insights from different views.

4 Conclusion

In this work, we proposed a novel collaborative immersive analytics system for conducted curators and artists to adopt a data-driven approach in facilitating better collaboration and adjustment of their exhibitions. We conducted semi-structured interviews with eight participants to gather design requirements and understand current practices. We figured out the conflicts between curators and artists and proposed a data-driven approach to solve the conflicts and come up with a better solution, compromising the design needs of both parties. Based on the result, we identified some potential features and designed a collaborative immersive analytics system. We plan to investigate more advanced visual design and interaction techniques to address the scalability issues and in-place spatial comparison in 3D space. Then, we will complete the implementation of the system based on the design and conduct a user study to evaluate the usability of the prototype. We hope our contributions assist the future design of collaborative immersive analytic tools involving multiple parties. Since this study focuses on artists and curators and other stakeholders like exhibition supporters or venue owners are not the focus, future work is needed to understand their needs for improving VR exhibitions with data analysis.

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