Hybrid User Interfaces for Multiple Views: why designer intuition is not enough

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ABSTRACT

How to arrange multiple views (MVs) in immersive environments to present information is a common problem addressed by human-computer interaction (HCI) and user experience (UX) studies. Specifically, for hybrid user interfaces (UIs) that use multiple interactive devices in an immersive environment, the MV layouts are often based on expert opinion instead of empirically validated guidelines. Thus this paper makes the case that design guidelines for multi-view layouts in hybrid user interfaces are needed as existing guidelines for MV layouts in Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MX) environments often are focused on a single interactive device instead of hybrid user interfaces. Moreover, often current guidelines tend to lack empirical support and are not cohesive. Our work further argues that such guidelines need to be based on empirical evidence. In addition, it summarizes existing related work on MVs for hybrid user interfaces and discusses the basics for running controlled experiments and establishing evidence-based design guidelines for the layout of MVs in hybrid UIs.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction techniques; —Interaction paradigms—Mixed / augmented reality; —Virtual reality

1 INTRODUCTION

Hybrid user interfaces (UIs) often have information displayed across multiple complementary screens which can be interacted with through a variety of different devices [19]. Despite significant advancements in Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) as well as multi-surface technologies in these realities, there has been a lack of studies on designing optimal, engaging user experiences (UX) within these technologies [12]. One aspect of UX design guidelines is the placement of multiple views (MVs) in the user's surrounding space.

During the past few years, expanding use of immersive technologies has led to an increasing number of studies in the field of MVs [2, 14, 18], and various layouts for MVs have been proposed [22, 23]. For the presentation of several views in immersive environments, it is common to arrange them in a grid or curved arrangements within a three-dimensional (3D) space [6, 7]. However, these layouts depend on the type of immersive environment (AR, VR and MR) and the devices that were used for each of the realities. For instance, in VR, users prefer curved layouts [6] and in AR, furniture-based layouts are preferred [9]. The variety of options to arrange MVs requires an investigation of user preferences and task performance potentially leading to empirically validated UX design guidelines on how to lay out MVs in hybrid UIs.

The motivation for our research is that although there are existing guidelines from experts, developers, and designers in the literature for VR, AR and MR environments, to the best of our knowledge there are no evidence-based guidelines on MV layouts for hybrid user interfaces. Developing evidence-based guidelines can enhance the design of multiple-view layouts, leading to an improved user experience and better information synthesis [22]. To address this gap, it is essential to develop studies to conduct user research and evaluated MV layouts to provide evidence-based guidelines.

The objective of this paper is to highlight the overlooked practical aspects of UX design for hybrid UIs. Specifically, it makes the case for evidence-based UX design guidelines for how to lay out MVs in MR, drawing attention to the area of hybrid user interfaces, that have not been adequately explored or taken into consideration. Our work discusses the basics for running controlled experiments and for establishing evidence-based design guidelines for the layout of MVs in hybrid UIs. By addressing these overlooked aspects and conducting empirical research, future design and development teams can enhance the design of hybrid UIs and provide users with more intuitive, enjoyable, and meaningful interactions. This will contribute to the overall advancement of engaging user experience design in mixed-reality applications.

In the following section, we will summarize existing related work on MVs in two main sections of MV layouts and the significance of utilizing MVs in immersive spaces. The first category involves articles that provide guidelines and explore the design space for organizing multiple views to support comparative layouts and facilitate decision-making. The second category emphasizes the use of multiple views in immersive spaces. These two topics allow us to highlight the limited research on evidence-based guidelines for MVs for hybrid user interfaces.

2 RELATED WORK

Arranging MVs in immersive environments is a frequently discussed problem in HCI and UX research. Our study investigates evidence-based UX design guidelines for MVs layouts. To begin, we will discuss the existing related work in the field.

2.1 Multiple Views

Numerous studies have focused on utilizing MVs in general. Roberts et al. [16] conducted an in-depth corpus linguistic analysis of the MVs and word collocation. They highlighted the significance of these terms in the visualization literature. Furthermore, Roberts [15] carried out a comprehensive review of the current research on coordinated MVs in exploratory visualization.

Some studies have focused on the use of MVs in information visualization, and guidelines for multiple coordinated views (MCVs). For instance, Scherr [20] examined MCVs in information visualization and identified seven aspects that affect the usefulness of an MCV system. In addition, Baldonado et al. [23] presented guidelines for designers and developers to effectively use MVs in information visualization, which can improve the user's comprehension of data. The authors came up with these guidelines by analyzing existing systems, drawing on their expertise in system design.

Research on MVs to visualize information has explored various layouts, as reported in several surveys. One such survey, conducted by Roberts and Al-Maneea [1], involved analyzing layouts in 340 visualization tools from articles published between 2012 and 2017. The authors reported different strategies for laying out MVs in these

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tools such as side-by-side, stacked, or integrated views. Meuleman et al. [13] also conducted a study on small-multiple layouts arranged in a 2D order and conditioned by spatial distributions and location. They examined how whitespace can enhance arranged layouts better to convey the spatial distribution of the conditioning variable, but did not provide any guidelines.

Four review papers were found that provide guidelines or a design space for the layout of MVs. Brehmer et al. [3] surveyed 263 timelines to explore the design space and considerations for creating expressive storytelling timelines. The survey resulted in 14 design choices in representation, scale, and layout dimensions. L'Yi et al. [10] analyzed 127 research papers, including 15 with quantitative user studies, to enhance their comprehension of three comparative layouts (juxtaposition, superposition, and explicit encoding) for visual comparison. They provided a comprehensive analysis of the design space, guidelines, and future directions for such layouts, where MVs are used to compare different datasets. Shaikh et al. [22] used a systematic approach for organizing MVs in information visualization, with a focus on user-centred design principles. They investigated the challenges of layout design for MVs and suggested categorized, composite, hierarchical, and flexible layouts, as well as cascade, focused, split, stacked and tab layouts. Schulz et al. [21] discussed the entire design space for hierarchy visualization techniques, considering four aspects of dimensionality, edge representation, node representation, and layout. They also recommended some considerations for designing effective implicit hierarchy visualizations.

2.2 Multiple Views in Immersive Spaces

While there are several studies on the importance of using MVs, guidelines, and design spaces for MVs as well as the layout of MVs in information visualization, we found a limited number of articles about MVs in immersive environments and no studies on hybrid UIs. In addition, very limited empirical evidence exists for selecting specific designs for MVs to enhance user experiences for specific tasks. Roberts et al. [17] provided five case studies to discuss the challenges and opportunities of using MVs in immersive spaces. The study discussed the importance of displaying alternative views concurrently as it allows the user to see the same information from different viewpoints. With concurrent alternative views, it is also important to link information between these complementary views. Knudsen and Carpendale [5] explored the benefits and challenges of using MVs in immersive analytics, where users interact with data in an immersive environment, such as virtual reality. The authors addressed coordination techniques for MVs across multiple displays, task and interaction behaviour, and collaboration challenges in such environments. Two studies were carried out to enhance the multi-view immersive design. Ma and Millet [11] focused on designing immersive dashboards, interactive interfaces that display multivariate data through coordinated views. Although the authors gathered guidelines that cover potential design issues, their work clearly shows that there is no existing empirical-based research on hybrid UIs. In addition, Danyluk et al. [4] provided a design space for Worlds-in-Miniature (WiMs), which is an overview-detail interface. The design space was based on seven design dimensions. Lastly, Liu et al. [8] discussed the layout of MVs for immersive charts, diagrams, and plots, graph/network visualization, and high-dimensional and multivariate data visualization. However, their study focused on interactive extended reality techniques in information visualization and did not provide guidelines.

Although all these papers are on MVs, none collected the papers with guidelines on the layouts of MVs. Moreover, the papers do not have user studies for evaluating the layouts. We believe that there's a need for evidence-based UX design guidelines for MV Layouts as they guide designers on what choices make sense in specific situations that are based on measured data instead of a designer intuition (which takes a long time to develop).

3 Conclusion and Future Directions

In conclusion, this article emphasizes the critical imperative for establishing evidence-based design guidelines about multiple view (MV) layouts within hybrid user interfaces (UIs) in immersive environments. While prevailing guidelines for MV layouts in Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) environments exist, they are hampered by a lack of empirical validation and a predominant focus on single interactive devices. By strategically addressing these gaps and embarking on empirical research endeavours, the trajectory of future work holds the potential to significantly elevate the design of hybrid UIs, thereby affording users more natural, gratifying, and purposeful interactions.

In the trajectory of future research within the domain of MV layouts in hybrid UIs, a paramount emphasis should be placed on the systematic execution of controlled experiments designed to collate empirical insights into user preferences and task performance. This empirical evidence will form the basis for establishing evidence-based design guidelines that offer informed choices to designers and developers, optimizing the arrangement of MVs in hybrid UIs for an enhanced user experience.

A **comparative layout study** is one example of controlled experiments that could be conducted within the domain of MV layouts in hybrid user interfaces (UIs) to gather empirical insights into user preferences and task performance. In a comparative layout study, the researcher designs and implements several variations of MV layouts in a hybrid UI. These layouts could differ in terms of the arrangement, size, and interaction mechanisms of the multiple views. Participants would be tasked with completing specific tasks that require interaction with the UI. By measuring completion times, accuracy, and user preferences, researchers can quantitatively analyze which layout configuration facilitates optimal task performance and user satisfaction. Another example of controlled experiments in this domain could be **device integration assessment** where participants interact with a hybrid UI that integrates different devices, such as a VR headset and a handheld controller. Then researcher will evaluate various configurations for device integration, including device placement and interaction mapping. Finally, data will be collected on user comfort, efficiency, and overall usability to determine which setups yield the best results in terms of user experience.

Future research in the field of MV layouts in hybrid UIs should also prioritize conducting controlled experiments for **cross-device interaction** to explore how users interact with hybrid UIs across different devices, such as transitioning between a VR headset and a tablet and designing experiments that simulate these transitions. This could involve tasks requiring seamless content handover from one device to another. Another future direction is to design tasks that involve context switching between different MVs to evaluate how the layout impacts multitasking and context retention (**Contextual task analysis**). Participants could be asked to switch between a navigation map and a communication panel, for example. Measure the speed and accuracy of context switching and gather feedback on the perceived seamlessness of transitions.

By systematically conducting these controlled experiments, researchers can amass robust empirical evidence that not only informs the development of evidence-based design guidelines but also guides designers and developers toward optimal choices for arranging MVs in hybrid UIs, ultimately enhancing the overall user experience.

Additionally, investigating the unique challenges and opportunities presented by hybrid UIs, such as integrating multiple interactive devices, considering spatial layout, and exploring innovative interaction techniques, is crucial. Evaluating the impact of MV layouts on user satisfaction, efficiency, and engagement through qualitative feedback and quantitative measurements will provide valuable insights. Applying and testing the developed guidelines in real-world immersive applications across various domains will validate their effectiveness and applicability.

Addressing these research directions will contribute to the advancement of engaging user experience design in immersive applications. The resulting evidence-based guidelines will empower designers and developers to create more intuitive interactions, improve information synthesis, and ultimately enhance the overall user experience within immersive environments.

References

[1] H. M. Al-maneea and J. C. Roberts. Study of multiple view layout strategies in visualisation. In *Posters presented at the IEEE Conference on Visualization (IEEE VIS 2018), Berlin, Germany (Oct. 2018). URL: http://ieeevis. org/year/2018/welcome*, vol. 1, 2018.

[2] L. Bavoil, S. P. Callahan, P. J. Crossno, J. Freire, C. E. Scheidegger, C. T. Silva, and H. T. Vo. Vistrails: Enabling interactive multiple-view visualizations. In *VIS 05. IEEE Visualization, 2005.*, pp. 135–142. IEEE, 2005.

[3] M. Brehmer, B. Lee, B. Bach, N. H. Riche, and T. Munzner. Timelines revisited: A design space and considerations for expressive storytelling. *IEEE transactions on visualization and computer graphics*, 23(9):2151–2164, 2016.

[4] K. Danyluk, B. Ens, B. Jenny, and W. Willett. A design space exploration of worlds in miniature. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, pp. 1–15, 2021.

[5] S. Knudsen and S. Carpendale. Multiple views in immersive analytics. In *IEEE VIS 2017 Workshop on Immersive Analytics*, 2017.

[6] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Design and evaluation of interactive small multiples data visualisation in immersive spaces. In *2020 IEEE conference on virtual reality and 3D user interfaces (VR)*, pp. 588–597. IEEE, 2020.

[7] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Effects of display layout on spatial memory for immersive environments. *Proceedings of the ACM on Human-Computer Interaction*, 6(ISS):468–488, 2022.

[8] R. Liu, M. Gao, L. Wang, X. Wang, Y. Xiang, A. Zhang, J. Xia, Y. Chen, and S. Chen. Interactive extended reality techniques in information visualization. *IEEE Transactions on Human-Machine Systems*, 52(6):1338–1351, 2022.

[9] W. Luo, A. Lehmann, H. Widengren, and R. Dachselt. Where should we put it? layout and placement strategies of documents in augmented reality for collaborative sensemaking. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, pp. 1–16, 2022.

[10] S. LYi, J. Jo, and J. Seo. Comparative layouts revisited: Design space, guidelines, and future directions. *IEEE Transactions on Visualization and Computer Graphics*, 27(2):1525–1535, 2020.

[11] Q. Ma and B. Millet. Design guidelines for immersive dashboards. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 65, pp. 1524–1528. SAGE Publications Sage CA: Los Angeles, CA, 2021.

[12] F. Maurer, C. Anslow, J. Jorge, and M. Sousa. Enhancing cross-reality applications and user experiences. In *Proceedings of the 2022 International Conference on Advanced Visual Interfaces*, pp. 1–3, 2022.

[13] W. Meulemans, J. Dykes, A. Slingsby, C. Turkay, and J. Wood. Small multiples with gaps. *IEEE transactions on visualization and computer graphics*, 23(1):381–390, 2016.

[14] C. North and B. Shneiderman. Component-based, user-constructed, multiple-view visualization. In *CHI'01 Extended Abstracts on Human Factors in Computing Systems*, pp. 201–202, 2001.

[15] J. C. Roberts. State of the art: Coordinated & multiple views in exploratory visualization. In *Fifth international conference on coordinated and multiple views in exploratory visualization (CMV 2007)*, pp. 61–71. IEEE, 2007.

[16] J. C. Roberts, H. Al-maneea, P. W. Butcher, R. Lew, G. Rees, N. Sharma, and A. Frankenberg-Garcia. Multiple views: different meanings and collocated words. In *Computer Graphics Forum*, vol. 38, pp. 79–93. Wiley Online Library, 2019.

[17] J. C. Roberts, P. W. Butcher, and P. D. Ritsos. One view is not enough: review of and encouragement for multiple and alternative representations in 3d and immersive visualisation. *Computers*, 11(2):20, 2022.

[18] Y. S. Ryu, B. Yost, G. Convertino, J. Chen, and C. North. Exploring cognitive strategies for integrating multiple-view visualizations. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 47, pp. 591–595. SAGE Publications Sage CA: Los Angeles, CA, 2003.

[19] C. Sandor, A. Olwal, B. Bell, and S. Feiner. Immersive mixed-reality configuration of hybrid user interfaces. In *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'05)*, pp. 110–113. IEEE, 2005.

[20] M. Scherr. Multiple and coordinated views in information visualization. *Trends in information visualization*, 38:1–33, 2008.

[21] H.-J. Schulz, S. Hadlak, and H. Schumann. The design space of implicit hierarchy visualization: A survey. *IEEE transactions on visualization and computer graphics*, 17(4):393–411, 2010.

[22] A. R. Shaikh, D. Koop, H. Alhoori, and M. Sun. Toward systematic design considerations of organizing multiple views. In *2022 IEEE Visualization and Visual Analytics (VIS)*, pp. 105–109. IEEE, 2022.

[23] M. Q. Wang Baldonado, A. Woodruff, and A. Kuchinsky. Guidelines for using multiple views in information visualization. In *Proceedings of the working conference on Advanced visual interfaces*, pp. 110–119, 2000.