

Designing Form-Based Interaction in Virtual Reality: A Multidimensional Usability Evaluation Using Eye-Tracking and MCDA

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Abstract. The increasing use of virtual reality (VR) beyond entertainment raises questions about the evaluation of task-oriented immersive applications. This paper presents form-based interaction in VR as a multi-criteria decision-making problem. An experimental study was conducted in a three-dimensional virtual travel agency, where users performed a trip reservation task using interactive forms. The analysis focused on eye-tracking-based criteria related to visual attention allocation, exploration dynamics, and selected indicators of cognitive load, integrated within a multi-criteria framework to support a structured and interpretable evaluation of interaction quality. The results indicate that the proposed approach helps identify key factors influencing VR form usability and provides a systematic basis for evaluating immersive applications.

Keywords: Multi-Criteria Decision Analysis · Forms · VR · UX/UI

1 Introduction

Virtual reality is increasingly used in education, healthcare, e-commerce, and professional training, making the design and evaluation of immersive user interfaces an important research challenge [15]. However, classical usability and user experience approaches, including Nielsen’s heuristics [9], Norman’s interaction design principles [10], and ISO human-centred design standards [5], were developed primarily for two-dimensional interfaces and do not fully reflect the spatial, perceptual, and motor characteristics of VR. This limitation is especially relevant to form-based interactions, which remain essential in transactional systems but require different design assumptions in immersive environments.

VR interface evaluation often relies on isolated metrics or subjective opinions, limiting comparability and practical usefulness. This paper proposes a structured framework for evaluating form-based interaction in immersive environments, focusing on eye-tracking-derived measures interpreted through multi-criteria decision analysis. The framework was applied in an experimental study conducted

in a three-dimensional virtual travel agency, where participants completed a trip reservation task using interactive forms. The collected eye-tracking data were analysed with PROMETHEE II to compare weighting scenarios and identify the criteria most influential for interaction quality.

2 Literature Review

Literature increasingly describes VR as a platform supporting task-oriented activities rather than entertainment alone, with applications spanning domains such as education, e-commerce, healthcare, and professional settings [3, 8]. As VR adoption expands, immersive interfaces are expected to meet requirements similar to those of conventional information systems, including efficiency, clarity, and low error rates. However, established usability and UX approaches [9, 10, 5] were developed primarily for two-dimensional interfaces and do not fully capture key characteristics of immersive interaction, such as depth perception, viewpoint variability, physical effort, and increased cognitive load [2]. This limitation becomes especially relevant in the case of form-based interaction, where users must process textual information, identify labels, and select interface elements within a three-dimensional space.

A particularly important issue in this context concerns the perceptual and ergonomic constraints affecting form-based interaction in VR. Recent studies indicate that interaction quality in immersive environments is shaped not only by layout and information structure, but also by perceptual constraints, pointing accuracy, visual stability, and muscular fatigue [1, 7]. Unlike two-dimensional interfaces, where forms rely on relatively stable visual conventions and predictable layouts, VR introduces additional variability resulting from user movement, changing viewpoints, and field-of-view limitations. Consequently, forms in immersive environments cannot be treated as direct counterparts of their 2D equivalents and require dedicated evaluation approaches.

Against this background, the contribution of the present study lies in proposing a structured evaluation framework for form-based interaction in VR that integrates eye-tracking and interaction-based evidence within a multi-criteria analytical perspective. Rather than introducing a standalone formal model, the study develops an integrated evaluation approach that treats form interaction as a complex process involving information processing, spatial presentation, and interaction ergonomics. Unlike prior studies that often rely on isolated indicators such as task completion time or error rate, the proposed perspective supports the joint interpretation of heterogeneous criteria relevant to immersive interaction.

This approach is further motivated by the fact that eye-tracking metrics may provide indirect evidence of visual attention allocation, search efficiency, and processing effort, while interaction-based indicators complement them in the assessment of usability-related aspects associated with cognitive load and interaction quality [2, 1]. However, the literature still lacks coherent approaches that combine such heterogeneous indicators within a structured evaluation framework specifically for VR forms. Existing work on text entry and interaction in immer-

sive environments has largely focused on individual techniques, such as virtual keyboards, raycasting, gaze-based input, or controller-based interaction, rather than on forms as complete interaction processes [4, 14].

More recent literature also highlights the need for evaluation approaches that are not only methodologically rigorous but also practically applicable in domains where VR supports structured user processes rather than exploratory experiences alone [8, 13, 11]. In this context, the framework proposed in this paper aims to provide a systematic basis for comparing alternative analytical perspectives and identifying the criteria that matter most for form usability in immersive environments. This gap motivates the conceptual framework introduced in the following section.

3 Conceptual Framework and Methods

The study was designed as a multidimensional evaluation of form-based interaction in a proprietary VR travel agency prototype. The choice of participants, task scenarios, and evaluation metrics was guided by the aim of reproducing a realistic booking process as a representative stress-test for spatial user interfaces. Following prior work indicating that form-based interaction in VR cannot be reliably assessed using isolated measures alone [12], the study focused primarily on eye-tracking-derived indicators related to visual attention, exploration dynamics, and selected aspects of cognitive load [6]. In this perspective, usability was examined through the joint interpretation of these heterogeneous measures under controlled laboratory conditions, while MCDA supported a structured analysis of trade-offs between different interaction dimensions. Although the study used a single application scenario, the selected participants, task sequence, and evaluation dimensions were intended to reflect common challenges of form-based interaction in immersive environments, thereby supporting cautious transferability of the findings to other task-oriented VR systems.

As illustrated in Fig. 1, the user was positioned at the center of a 360° environment, with the form located in the central visual field to support precise data entry and peripheral regions (45–60°) supporting exploration. Behavioral data, derived primarily from eye-tracking, were analysed in relation to visual attention, exploration dynamics, and cognitive load, allowing the effects of locomotion and spatial layout on psychophysical comfort to be examined in an integrated manner.

The experiment used an HTC Vive Pro 2 headset to ensure sufficient text legibility and visual clarity in a task requiring participants to read hotel descriptions and price lists. Its resolution (4896 × 2448) reduced the screen-door effect known from earlier head-mounted displays, while the 120 Hz refresh rate helped minimize motion-to-photon latency and reduce the risk of motion sickness. To improve ecological validity and eliminate movement constraints, the setup also included the VIVE Wireless Adapter based on WiGig technology, enabling unrestricted 360° exploration. The software environment integrated SteamVR with

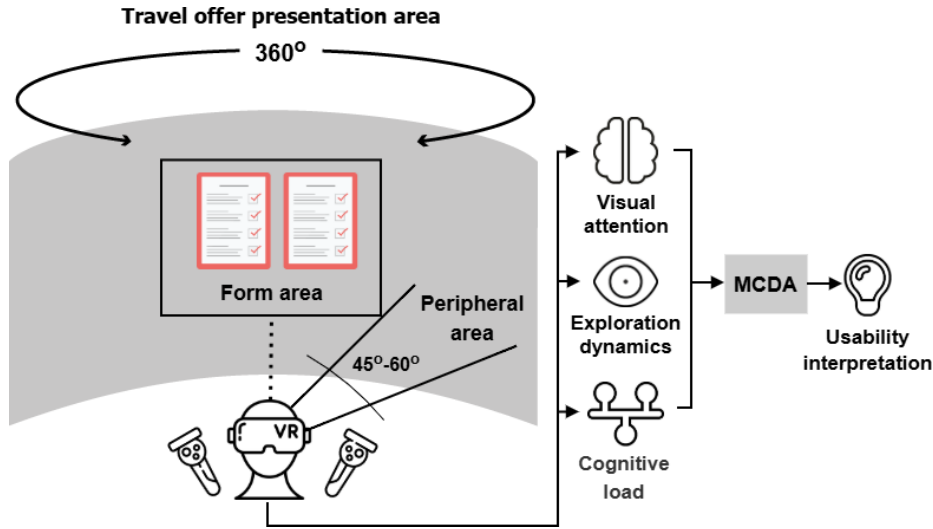


Fig. 1. Conceptual diagram of form-based interaction in a virtual travel agency, illustrating the central form area, peripheral exploration regions, and the integration of interaction data across visual attention, exploration dynamics, and cognitive load using MCDA.

the Cognitive3D analytics platform, which enabled unobtrusive collection of gaze paths and heatmaps.

The study involved $N = 45$ participants (24 women and 21 men) aged 17–46 ($\bar{x} = 27.2$). The sample deliberately included both experienced VR users ($n = 33$) and novices ($n = 12$), allowing the evaluation to capture both learned and intuitive interaction patterns. In addition, 40% of participants ($n = 18$) had diagnosed vision impairments, including astigmatism, which supported an accessibility-oriented assessment of text legibility and interface sizing. The experiment was conducted in a dedicated laboratory room with a safe interaction area of $3 \text{ m} \times 3 \text{ m}$. Lighthouse base stations were positioned to minimize controller occlusion, and the researcher acted as a spotter throughout the session.

The procedure followed a structured protocol. After screening for health contraindications and completing a short introductory interview, each participant underwent headset calibration, including individual adjustment of interpupillary distance and headset position. A three-minute training session in a neutral virtual environment was then used to familiarize participants with the controls: parabolic teleportation with the left controller and interaction with interface elements using the right controller. The main experimental phase comprised four tasks with different cognitive demands: (1) a guided task verifying interface logic, (2) a free task assessing autonomous decision-making during trip selection, (3) a readability task requiring participants to locate and report specific pricing information, and (4) a time-constrained task (120 s) evaluating performance under stress. This task sequence was intended to cover a range of interaction conditions

relevant to form use in VR, from guided completion to autonomous exploration and time pressure. The procedure concluded with a post-experimental questionnaire completed immediately after immersion.

4 Experimental Results and Analysis

The eye-tracking analysis revealed consistent visual behavior typical of cognitively demanding tasks. Users spent approximately 75–85% of samples in fixations, indicating strong sustained attention, in line with prior literature.

Fixation duration varied from about 295 ms to 1380 ms, suggesting two dominant strategies: rapid scanning (300–500 ms) and deeper analytical processing (600–1400 ms). Despite this, fixation rates remained stable (0.09–0.13 fixations/s), indicating moderate interaction tempo without time pressure. This supports the conclusion that the interface promotes analytical rather than exploratory behavior.

The proportion of fixation time differed across users (3–18%), reflecting individual exploration styles. A one-way ANOVA confirmed significant differences in mean fixation duration: $F(9, 500000) = 14.23$, $p < 0.001$, which was supported by the Kruskal–Wallis test: $H = 112.8$, $p < 0.001$.

Spearman correlation analysis showed strong relationships between key metrics. Mean fixation duration correlated with fixation time proportion ($\rho = 0.82$), fixation count with recording duration ($\rho = 0.91$), and fixation rate moderately with fixation proportion ($\rho = 0.67$), indicating consistent viewing behavior.

Overall, the interface supports sustained analytical attention without excessive cognitive load, while significant inter-user differences emphasize the need for adaptive design approaches.

4.1 Multi-Criteria Decision Analysis Using PROMETHEE II

Multi-Criteria Decision Analysis (MCDA) enables evaluation of complex phenomena described by multiple criteria. In eye-tracking studies, it allows integration of heterogeneous metrics into a unified and interpretable framework, emphasizing trade-offs rather than a single optimal solution.

In this study, the PROMETHEE II method was applied. It is an outranking approach providing a complete ranking based on pairwise comparisons and preference functions, well-suited for behavioral data due to its transparency and robustness.

Five eye-tracking criteria were used: fixation ratio [%] (C_1 , max), average fixation duration [ms] (C_2 , min), exploration rate (fixations/s) (C_3 , max), fixation time proportion [%] (C_4 , max), and spatial dispersion (std. dev. in X,Y) (C_5 , min). Criteria C_1 and C_4 reflect fixation dominance, C_3 captures exploration dynamics, whereas C_2 and C_5 relate to cognitive load and stability.

PROMETHEE II was applied to compare weighting scenarios as preference profiles, where Φ denotes net dominance. Four scenarios were defined to reflect

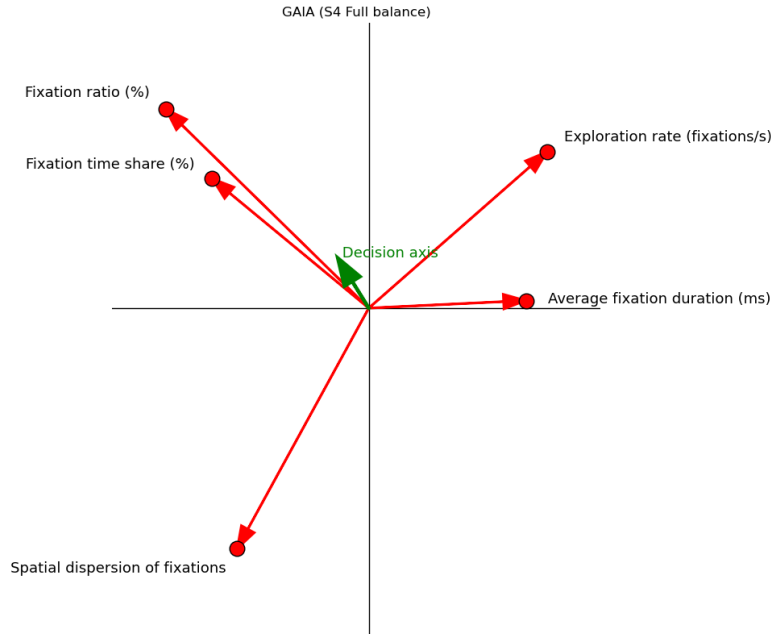
Table 1. Weighting scenarios and PROMETHEE II results

Scenario	C_1	C_2	C_3	C_4	C_5	Scenario	Φ^+	Φ^-	Φ	Rank
S1	0.35	0.10	0.10	0.35	0.10	S3	0.320	0.180	0.140	1
S2	0.20	0.10	0.40	0.20	0.10	S1	0.295	0.205	0.090	2
S3	0.10	0.50	0.10	0.20	0.10	S2	0.270	0.230	0.040	3
S4	0.20	0.20	0.20	0.20	0.20	S4	0.200	0.300	-0.100	4

different analytical priorities: fixation stability (S1), exploration (S2), cognitive load minimization (S3), and balanced weighting (S4).

Scenario S3 achieved the highest dominance, whereas S4 served as a neutral baseline. Using average weights, the criteria were ranked as follows: C_4 ($\Phi = 0.090$), C_2 ($\Phi = 0.070$), C_1 ($\Phi = 0.050$), C_3 ($\Phi = 0.020$), and C_5 ($\Phi = -0.100$). Thus, temporal fixation measures (C_4 , C_2) were the most influential, whereas spatial dispersion (C_5) played a minor role.

GAIA plane (Fig. 2) provides a geometric interpretation of criteria relationships. While criteria positions remain stable, the decision axis varies with weighting. S1 emphasizes fixation dominance, S2 favors exploration (C_3), and S3 highlights fixation duration (C_2) as a proxy for cognitive load. S4 represents a balanced configuration without strong alignment.

**Fig. 2.** S4: Full balance

The GAIA analysis for the full balance scenario illustrates the trade-off between stability and exploration criteria within a single, representative configuration. This example demonstrates how the balanced weighting scheme captures a compromise between competing objectives, providing an interpretable and holistic view of the decision space.

The PROMETHEE II results indicate that S3 (cognitive load minimization) is the dominant preference profile, followed by S1 and S2, while S4 acts as a neutral reference. Among criteria, fixation time proportion (C_4) and duration (C_2) are most influential, while C_1 and C_3 are moderate, and C_5 remains least significant. The consistency of rankings confirms the robustness of the MCDA framework for eye-tracking analysis.

5 Conclusions

This paper presented a multidimensional evaluation of form-based interaction in virtual reality using a proprietary virtual travel agency prototype as a case study. The findings indicate that the usability of VR forms cannot be captured by isolated performance measures alone, as interaction quality emerges from the interplay of perceptual, cognitive, and behavioral factors.

Eye-tracking results suggest that form completion in VR is associated with an analytical visual processing strategy, reflected in longer fixations and structured allocation of attention. This implies that VR form interfaces should prioritise visual stability, clear information hierarchy, limited numbers of simultaneously displayed elements, and high typographic legibility. At the same time, the observed inter-user variability indicates that effective solutions should also accommodate differences in prior experience and individual interaction strategies through guidance, feedback, and error-prevention mechanisms.

The study also demonstrated the usefulness of MCDA (PROMETHEE II) as a tool for interpreting heterogeneous interaction data. The analysis showed that temporal fixation measures, such as fixation time proportion and average fixation duration, had a stronger effect on the overall preference structure than spatial dispersion measures. Rather than reducing usability to a single score, the MCDA approach made it possible to expose trade-offs between interaction stability, exploration, and cognitive efficiency, thus providing a more informative basis for design decisions in immersive environments.

The study has several limitations. It was conducted under controlled laboratory conditions, within a single application scenario, and with a limited set of form-related tasks, which constrains generalizability. Future research should therefore extend the framework to other VR form types, interaction techniques, and application domains, as well as explore adaptive solutions responsive to individual user differences.

In conclusion, the proposed approach contributes to immersive interface research by offering a structured perspective on VR form usability and by showing how MCDA can support the interpretation of complex behavioral data and more informed VR interface design.

References

1. Bhowmik, A.K.: Virtual and augmented reality: Human sensory-perceptual requirements and trends for immersive spatial computing experiences. *Journal of the Society for Information Display* **32**(8), 605–646 (2024)
2. Chen, M.X., Hu, H., Yao, R., Qiu, L., Li, D.: A survey on the design of virtual reality interaction interfaces. *Sensors* **24**(19) (2024). <https://doi.org/10.3390/s24196204>
3. Choudhery, H., Kesharwani, S.: The role of ar and vr in shaping e-commerce: A literature review. *Global Journal of Enterprise Information System* **16**(2), 83–90 (2024)
4. Dube, T.J., Arif, A.S.: Text entry in virtual reality: A comprehensive review of the literature. In: Kurosu, M. (ed.) *Human-Computer Interaction. Recognition and Interaction Technologies*. pp. 419–437. Springer International Publishing, Cham (2019)
5. ISO: Ergonomics of human-system interaction – part 9241-210: Human-centred design for interactive systems. <https://www.iso.org/standard/77520.html> (2019)
6. Makransky, G., Petersen, G.B.: The cognitive affective model of immersive learning (camil): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review* **33**(3), 937–958 (2021)
7. Mimnaugh, K.J., Center, E.G., Suomalainen, M., Becerra, I., Lozano, E., Murrieta-Cid, R., Ojala, T., LaValle, S.M., Federmeier, K.D.: Virtual reality sickness reduces attention during immersive experiences. *IEEE Transactions on Visualization and Computer Graphics* **29**(11), 4394–4404 (2023)
8. Moskala, K., Frankowski, M., Igras-Cybulska, M., Bohné, T., Witoszek-Kubicka, A., Tadeja, S.: A novel approach to enhance vr user awareness of nearby non-virtual hazards through adaptive visual alerts. In: *2024 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. pp. 252–255. IEEE (2024)
9. Nielsen, J.: *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA (1994)
10. Norman, D.A.: *The Design of Everyday Things*. The MIT Press. Cambridge, Mass.: MIT Press. (2013)
11. Olejnik-Krugły, A., Bortko, K., Jankowski, J., Bródka, J.: Towards effective visual alerts in immersive vr environments: Balancing visibility and user experience. In: *Proceedings of the 59th Hawaii International Conference on System Sciences (HICSS-59)*. p. 299 (2026), <https://hdl.handle.net/10125/111428>
12. Radianti, J., Majchrzak, T.A., Fromm, J., Wohlgenannt, I.: A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education* **147**, 103778 (2020)
13. Sharma, G., Mishra, S.: Alert modalities in connected and smart work zones to enhance workers’ safety from traffic accidents using virtual reality (vr) experiments. *Transportation Research Part C: Emerging Technologies* **174**, 105085 (2025)
14. Speicher, M., Feit, A.M., Ziegler, P., Krüger, A.: Selection-based text entry in virtual reality. In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. p. 1–13. CHI ’18, Association for Computing Machinery, New York, NY, USA (2018). <https://doi.org/10.1145/3173574.3174221>
15. Sung, H., Kim, M., Park, J., Shin, N., Han, Y.: Effectiveness of virtual reality in healthcare education: Systematic review and meta-analysis. *Sustainability* **16**(19), 8520 (2024)