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Research Article

Evaluating HCI Strategies to Improve UX within XR Representations of High Voltage Equipment in Professional Training Contexts

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Abstract

This paper explores the design and evaluation of user experience (UX) strategies in extended reality (XR) environments for high-voltage safety training. Drawing from industrial XR literature, digital twin frameworks, and gamification theory, key findings suggest that interaction fidelity and feedback clarity contribute significantly to user performance and immersion, offering valuable insights for the development of adaptive training systems in digital infrastructure.

Following the investigation, this paper outlines multiple design strategies, input methods and complementary feedback systems for human-computer interaction (HCI) within XR environments. This research is then considered in the context of our case study: the Faraday Nexus, a virtual training environment (VTE) built in Unreal Engine.

Potential implementations of research-informed interaction methods are are analysed for their potential to reinforce learner engagement and training effectiveness: various spatial tracking methods, motion controller inputs, auditory cues, visual effects, and supporting gamification strategies. The modular architecture of the VTE allows for customisation of UX features, making it a flexible platform for future evaluation and comparative testing.

Keywords: Virtual Reality; Unreal Engine; Safety Training; Electrical Engineering; Data-Driven Content; Human-Computer Interaction; User Experience in XR.

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Highlights

- Provide three key highlights that capture the essence of the article and the lessons learned from the findings; each highlight should be one sentence not exceeding 100 characters.
- Provide three key highlights that capture the article's essence, and the lessons learned from findings.
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1 Introduction

Virtual reality (VR) and broader extended reality (XR) technologies are reshaping the landscape of professional training by offering safe, immersive, and adaptive environments for complex operational procedures. In high-risk fields such as construction and electrical infrastructure, traditional methods, including classroom-based instruction or supervised practical exposure, are positioned to benefit from the scalability, adaptability and sense of presence that digital alternatives can provide. Recent developments in digital twins, serious games, and human-computer interaction (HCI) frameworks have enabled the creation of training systems that attaining to realistic representations of professional tasks while offering measurable performance feedback.

This paper addresses how HCI strategies can be designed and evaluated to improve user experience (UX) in XR environments developed for high-voltage safety training. The study builds upon current understandings of digital twin frameworks, serious game applications in safety contexts, and immersive interface design, positioning the Faraday Nexus—a virtual training environment for high-voltage switchgear operation—as a case study.

The primary research question guiding this work is: How can UX design strategies and feedback mechanisms be tailored to enhance user engagement, accuracy, and procedural clarity in XR-based high-voltage safety training? In answering this, the paper proposes and evaluates input methods and feedback systems implemented within Unreal Engine 5, assessing their alignment with real-world tasks and user expectations.

2 Background

Extended Reality (XR) encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR) systems. In the context of training, XR enables immersive simulations that enhance learning retention and engagement (Muzata, Singh, Stepanov, & Musonda, 2024). Human-Computer Interaction (HCI) refers to the design and evaluation of interactive systems focused on optimizing user interaction, with an increasing emphasis on cognitive and emotional user experience (Pushpakumar et al., 2023).

Serious Games refer to interactive digital experiences designed for purposes beyond entertainment, such as education and training (Schrader, 2023). Digital Twins represent real-world systems through real-time or simulated digital models, offering adaptive and data-driven training environments (Sharma, Kosasih, Zhang, Brintrup, & Calinescu, 2022).

Digital twin training frameworks such as DTCS (Digital Twin for Construction Safety) integrate Building Information Modelling (BIM), scheduling data, and hazard models to deliver tailored safety training scenarios (Speiser & Teizer, 2024). Complementary HCI frameworks within XR—including those related to immersion, feedback fidelity, and cognitive load—have been explored in the field of cognitive infocommunications (Katona, 2021) and UX research in healthcare education (Mäkinen, Haavisto, Havola, & Koivisto, 2022).

Serious games have demonstrated success in eliciting authentic behavioural responses in training contexts by combining immersive visualization with task-oriented feedback (Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018; Golovina, Kazanci, Teizer, & König, 2019). Key principles include contextual realism, real-time feedback, and dynamic scenario branching that adapts to user decisions. These environments simulate high-stakes conditions under controlled parameters, allowing learners to rehearse decision-making and procedural accuracy without real-world consequences. Feedback systems must be timely, context-aware, and intuitively mapped to in-world actions to support learning and hazard awareness (Wijewickrema, Ma, Bailey, Kennedy, & O'Leary, 2017).

3 Methodology

This research adopts a qualitative methodology to evaluate how different input methods and feedback strategies influence HCI within XR-based training environments. The study synthesises insights from academic literature and expert observations to inform implementation decisions within a real-world case study: the Faraday Nexus. Developed in collaboration with The Faraday Centre Ltd. this VTE focuses on the simulation of high-voltage switchgear operation and the insights aim to improve clarity, usability, and engagement in simulated tasks.

Literature was sourced through keyword searches in academic databases such as Scopus, IEEE Xplore, and ScienceDirect. To collect core extended reality literature, search terms used included “extended reality training,” “XR training interface design,” “human computer interaction in virtual reality,” “VR user input methods” and “spatial interaction design in XR.” To broaden the search to include other studies into gamification and UX design, additional search terms were employed: “gamification in industrial training,” “UX strategies in simulation,” “gamified learning environments,” “feedback systems in serious games,” and “interactive feedback and user engagement.” Key papers were selected based on relevance to safety training, interaction design, and simulation fidelity. Exclusion criteria included entertainment-focused XR, studies lacking implementation detail, and non-English publications. EndNote has been used to organise sources.

Recurring patterns in input types (e.g. motion control, gaze) and feedback modalities (e.g. audio cues, scoring systems) have been distilled into a summary of HCI elements that link three components: (1) input methods, (2) multimodal feedback, and (3) the impact on user experience (UX). Interaction variants are implemented into a prototype and their suitability is discussed based on alignment with real-world equipment in the high-voltage training context. Unreal Engine 5 was used as the development platform, with prototypes built using Blueprints and animation curves to simulate various user actions and system responses.

As user testing is planned but not yet complete, no personal data has been collected, and no ethical concerns have been raised to date. Future testing phases will comply with ethical guidelines, including informed consent and participant anonymity. Limitations include the current absence of live user feedback, reliance on design-based evaluation, and the specificity of the Faraday Nexus context. However, the findings provide a foundation for broader testing, with plans to extend the work into user trials for comparison and assessment of training impact.

4 Results- Key Findings

4.1 User Navigation and Immersion

Themes of multimodal feedback and interface responsiveness emerged as pivotal to the effectiveness of XR-based training systems. Vieira et al. (Vieira et al., 2024) identify synethesic strategies to significantly improve several asect of the XR experiences. Allowing users to interact using a combination of gestures, commands and touch inputs enhances accessibility, realism and situational awareness. Employing haptic cues (like vibrations) alongside visual aids to guide users through XR environments effectively improves UX and accelerates user adaptation. Haptic feedback can be used to intuitively signal points of interest or indicate virtual resistance with simulated objects. Combined with visual elements to highlight critical areas, like markers, pop-up descriptions or overlays, "creates a dual-sensory approach which tends to enrich the exploration experience." This study also reports that synergising auditory guidance and visual perception reduces errors in task performance and caters to different learning styles. These strategies improve task clarity and guide learners through sequences without reliance on textual instruction. When successfully implemented, such strategies reduce the user's cognitive load and reinforces engagement by allowing users to focus on essential content.

Comparative studies of VR input schemes, such as gaze-controlled cursor systems, further emphasise the importance of feedback alignment. Selection accuracy and task completion metrics were significantly influenced by cursor visibility and response behaviour (Choe, Yeongcheol, Jaehyun, & and Kim, 2019), highlighting the crucial role of feedback clarity in task execution.

Diegetic user interfaces emerged as a key design theme in both user experience studies and design frameworks. For instance, a VR fitness study reported that wrist-mounted UIs used to display exertion and task progress allowed users to remain immersed without the distraction of traditional HUD elements (CHENG, YOO, & PARKER). Similarly, Miranto et al. (Miranto, Rante, & Sukaridhoto, 2021) found that control panels embedded into the environment improved interaction clarity and procedural focus. These findings suggest that diegetic UI can preserve spatial coherence and reduce cognitive separation between user interface and task, contributing to stronger immersion and a more intuitive user experience.

4.2 Gamification, Scoring Logic and Adaptive Modelling

Gamified logic has also been shown to support learning in both immersive and non-immersive systems. Within the domain of smart buildings, gamified feedback—such as scoreboards and performance streaks—has improved engagement and retention by encouraging behavioural repetition (Konstantakopoulos et al., 2019; Ubachukwu et al., 2025). While these systems are predominantly 2D, the scoring mechanisms they employ provide transferable structures for immersive training platforms where task compliance and procedural mastery are crucial.

A stronger link between immersive gamification and training outcomes is made in Teizer's work on serious games in VR. These studies used immersive environments to simulate close-call scenarios in high-risk construction settings. By embedding feedback systems such as near-miss detection and automated behavioural logging, the serious gaming techniques could also positively reinforce safe behaviour while unsafe behaviour triggered alerts (Golovina et al., 2019).

These approaches echo findings in healthcare and design research, where score-based or milestone-driven systems have been shown to scaffold early user learning, promote confidence through positive reinforcement, and structure user engagement across multi-step procedures. In VR healthcare training, such mechanisms are frequently employed to reduce performance anxiety, sustain motivation, and support incremental mastery by providing timely feedback at each stage of a complex task. Visual progress indicators and gamified rewards have been linked to better task adherence and retention, especially for novice users navigating unfamiliar environments.

4.3 Adopting BIM to Enhance Simulation Realism and Training Relevance

Beyond individual feedback mechanisms, XR systems are increasingly integrating adaptive models to enable situationally responsive training. Foundational work by Teizer and colleagues (Golovina et al., 2019) introduced VR safety simulations in which users could explore hazardous construction scenarios. These systems monitored the proximity of avatars to danger zones, recording "near-miss" events that triggered immediate, instructive feedback—helping users learn to avoid risks through experiential exposure. Jacobsen et al. (Jacobsen, Solberg, Golovina, & Teizer, 2022) extended this by implementing behavioural tracking and quantifiable performance metrics, such as time spent in hazard zones, number of close calls, correctness of navigated paths, consistency in safe behaviour, and scenario completion time. These additions allowed for more precise evaluation of trainee performance and scenario effectiveness. This foundation enabled more advanced applications, such as the Digital Twin for Construction Safety (DTCS) framework by Speiser and Teizer (Speiser & Teizer, 2024), which automatically generates VR training environments from BIM and 4D scheduling data, allowing for dynamic and personalised scenario construction. Similarly, Johansen et al. (Johansen, Hong, Schultz, & Teizer, 2024) applied real-time location tracking to assess worker exposure to falling object hazards, combining planned layouts with live movement data to generate quantitive feedback based on user behaviour.

4.4 Summary of VTE-Applicable Key Findings

The relevant key findings from literature can be summarised as follows

Table I. Summary of relevant VR input and feedback methods from literature.

Input Method	Methods of Feedback	UX Impact
Motion Controller Button	Haptic pulses, auditory clicks, visual state changes (e.g. toggle indicators)	Simple and reliable interaction; may lack realism or depth; steep learning curve for new users
Head-Mounted Display Gaze Cursor	Visual cursor enlargement, colour changes, auditory confirmation cues	Enables hands-free interaction; good for making selections; accessible but exherts less control
Hand/Motion Gestures	Real-time object response, haptics for resistance, visual alignment aids	High realism; natural interaction; suited to precision tasks
Interaction with In-Simulation UI	Diegetic cues (e.g. wrist display), animation-based feedback, auditory UI clicks	Maintains immersion; supports context-awareness;
Voice Commands	Spoken confirmation, audio feedback, visual prompts	Supports multitasking and accessibility; requires quiet environments; speech recognition limits

To demonstrate the practical implications of findings across the literature, a VTE capable of simulating interaction with realistic virtual representations of training equipment from the field of electrical engineering has been developed. For the context of this paper a single interactive training element will be considered: an Electric Circuit Breaker (ECB). This virtual ECB rotates 45° clockwise to open (de-energise) or 45° anticlockwise to close (re-energise) a circuit, and serves as a controlled unit for comparing input methods and feedback strategies. Built in Unreal Engine, the system adopts a modular architecture which enables flexible implementation of the following input and output features:

- Motion controller face button press: Maps buttons A/B (left hand) and X/Y (right hand) to select ECB state.
- Motion controller analogue stick: Uses horizontal axis value to drive ECB rotation and activation.
- Wrist rotation: Rotate motion controller to trigger ECB interaction based on angular thresholds.

- Spatial hand tracking (delta location): Detect controller movement to the left or right of the ECB to infer interaction intent.

Feedback strategies:

- VFX: Highlights selected components with glowing outlines and uses particle systems to confirm successful interactions
- SFX: Auditory cues that respond to actions (click, chime, electrical hum).
- Scoring system: Points, streaks and progress indicators to support learning
- Diegetic UI integration: A clipboard interface visible within the virtual scene.

These strategies and their implementation will be discussed in the following section.

5 Discussion

This study set out to evaluate how human-computer interaction strategies—particularly input methods and feedback systems—shape user experience and training quality within immersive XR environments used for safety-critical procedures. Key findings reinforce that intuitive input and layered feedback systems improve clarity, retention, and engagement when simulating high-risk infrastructure operations. Results reflect a broader shift in architecture and urban systems toward interface-responsive design, where the interaction itself becomes an extension of built infrastructure.

5.1 Input and Feedback for Improved UX

Across the reviewed literature and prototype implementation, one recurring insight was that interaction methods must strike a balance between realism and usability. Motion controller buttons remain the most accessible input scheme but fail to mirror the physical interaction of operating real-world switchgear. Controller rotation or location tracking offers greater fidelity but can be challenging for first-time users or inconsistent without carefully attuning input values. Implementing features like operative dead zones can manipulate the float values provided by input methods to refine XR interactions, reducing unwanted behaviour like jittering. These observations align with previous studies suggesting that the most effective input method depends not only on realism but also on user experience.

Another central theme is the role of feedback in reinforcing task comprehension and supporting learning experiences. Diegetic UI—interface elements embedded into the simulation environment—has been found to be particularly effective for preserving immersion. By situating cues like checklists or indicators within the environment, users are guided without breaking presence. This approach supports findings in manufacturing, construction and healthcare training, where spatially consistent feedback improves memory retention and reduces cognitive overload.

5.2 Input and Feedback for Improved UX

Gamification strategies were also found to enhance engagement and motivation, particularly when designed to emphasise correctness, completeness, and procedural fidelity rather than speed. Scoring structures and reward systems tailored to the training context offer a way to scaffold learning and promote active participation. The Faraday Nexus implementation intentionally avoids rewarding quick performance, instead encouraging accuracy and safe sequencing—findings that echo best practices in safety training and VR-based education.

Table 2. example frameworks for scoring systems as a strategy to gamify XR HV training.

Action Type	Example Tasks	"Base Score" Value	"Hero Score" Value	Notes
Visual checks	Visual inspection, confirm cable type	2	50	Encourages attention to detail
Repetitive Steps	Apply locks, attach danger tags	5	100	Enforces compliance
Key Procedural Step	Operate circuit breaker, applying circuit main earth	10	250	Rewards correct actions made towards simulation goal
Minor Error	Skipping a tag, reversing sequence	-10	-250	Penalised to discourage procedural errors
Major Error	Failing to prove the circuit dead before applying circuit main earth	Score is reduced to zero		Safety-critical errors are caused for failure, and highly penalised
Prove Dead Bonus	Use proving unit, insert test probes to prove a successful isolation	30	500	A large bonus to indicate critical safety step
Completion Bonus	Full procedure completion	30	1000	Cumulative success incentive; includes all steps and correct sequencing
No-help bonus	Completing the training scenario without triggering a hint, prompt or guide	—	500	Encourages independent mastery.
No-mistake bonus	Perform actions in required order without error	10	600	Rewards high levels of procedural accuracy

To support variable training needs, two scoring structures are proposed: one "Base Score" scheme for formal training assessments, and a more game-like "Hero Score" scheme for appropriate motivational settings. Both highlight critical moments in the training but differ in scale and emphasis. Table 6 (see above) demonstrates how identical actions can be framed to support either assessment rigour or player engagement

5.3 Limitations and Directions for Future Study

Reviewed studies focus on proof-of-concept environments rather than long-established, field-validated outcomes. Input accessibility for users with differing abilities is not yet well understood, and the practical scaling of feedback systems in operational contexts remains a challenge. Additionally, the effect of combining input types (e.g. gaze and motion) or adaptive feedback mechanisms has yet to be rigorously tested.

Looking ahead, future studies should focus on mixed interaction designs and test feedback frameworks across broader user demographics. The Faraday Nexus offers a platform to explore these questions systematically. Comparative testing—e.g. between wrist-based vs. analogue stick input, or between floating UI and diegetic interfaces—could yield insights into optimal configurations for different training contexts.

As XR technologies increasingly intersect with urban infrastructure, architecture, and energy systems, the ability to model human interaction becomes a critical competency. The use of digital twins, procedural feedback, and gamified task logic bridges design, safety, and education. XR systems like the Faraday Nexus offer new ways to test infrastructure understanding and procedural compliance, potentially informing how future smart systems are not only controlled but experienced and learned.

6 Conclusions

This study addresses the intersection of XR design, simulation of infrastructure, and safety training by analysing verified interaction and feedback methods across industrial domains. The findings demonstrate that immersive models which integrate multimodal feedback, task-aligned input, and gamified structures, can improve user clarity, engagement, and procedural accuracy. The modular design of the Faraday Nexus enables input and feedback systems to be customised or disabled, allowing for future flexible testing and comparisons to be made across combinations of HCI strategies. This adaptability reflects broader demands for training systems that accommodate user variation, technical limits, and evolving pedagogical goals. Overall, the study reinforces XR's value as a responsive medium for simulating critical operations, with UX design emerging as key to instructional effectiveness.

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Data Availability Statement
Further detail about The Faraday Centre LTD can be found at https://www.faradaycentre.co.uk/

Conflicts of Interest
Caolán Plumb is a Knowledge Transfer Associate tasked with incorporating VR technology into the delivery of vocational safety training by The Faraday Centre LTD.

References

CHENG, X., YOO, S., & PARKER, C. Staying Fit in the Metaverse: Evaluating Diegetic GUIs for Representing Exertion Data in a VR Exergame.

Choe, M., Yeongcheol, C., Jaehyun, P., & and Kim, H. K. (2019). Comparison of Gaze Cursor Input Methods for Virtual Reality Devices. International Journal of Human–Computer Interaction, 35(7), 620-629. doi:10.1080/10447318.2018.1484054

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. Computers & Education, 127, 252-266.

Golovina, O., Kazanci, C., Teizer, J., & König, M. (2019). Using Serious Games in Virtual Reality for Automated Close Call and Contact Collision Analysis in Construction Safety.

Jacobsen, E. L., Solberg, A., Golovina, O., & Teizer, J. (2022). Active personalized construction safety training using run-time data collection in physical and virtual reality work environments. Construction Innovation, 22(3), 531-553. doi:10.1108/CI-06-2021-0113

Johansen, K. W., Hong, K., Schultz, C., & Teizer, J. (2024). Automated quantification of construction workers' exposure to falling object hazards. Proceedings of the Institution of Civil Engineers - Management, Procurement and Law, 177(4), 207-222. doi:https://doi.org/10.1680/jmapl.23.00103

Katona, J. (2021). A Review of Human–Computer Interaction and Virtual Reality Research Fields in Cognitive InfoCommunications. Applied Sciences, 11(6), 2646. Retrieved from https://www.mdpi.com/2076-3417/11/6/2646

Konstantakopoulos, I. C., Barkan, A. R., He, S., Veeravalli, T., Liu, H., & Spanos, C. (2019). A deep learning and gamification approach to improving human-building interaction and energy efficiency in smart infrastructure. Applied Energy, 237, 810-821. doi:https://doi.org/10.1016/j.apenergy.2018.12.065

Mäkinen, H., Haavisto, E., Havola, S., & Koivisto, J.-M. (2022). User experiences of virtual reality technologies for healthcare in learning: an integrative review. Behaviour & Information Technology, 41(1), 1-17.

Miranto, C., Rante, H., & Sukaridhoto, S. (2021). Exploring concept design of user experience with diegetic approach for cultural heritage virtual reality exhibition,‖ in. Paper presented at the Proc. 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES).

Muzata, A. R., Singh, G., Stepanov, M. S., & Musonda, I. (2024). Immersive Learning: A Systematic Literature Review on Transforming Engineering Education Through Virtual Reality. Virtual Worlds, 3(4), 480-505. Retrieved from https://www.mdpi.com/2813-2084/3/4/26

Pushpakumar, R., Sanjaya, K., Rathika, S., Alawadi, A. H., Makhzuna, K., Venkatesh, S., & Rajalakshmi, B. (2023). Human-computer interaction: Enhancing user experience in interactive systems. Paper presented at the E3S Web of Conferences.

Schrader, C. (2023). Serious Games and Game-Based Learning. In O. Zawacki-Richter & I. Jung (Eds.), Handbook of Open, Distance and Digital Education (pp. 1255-1268). Singapore: Springer Nature Singapore.

Sharma, A., Kosasih, E., Zhang, J., Brintrup, A., & Calinescu, A. (2022). Digital Twins: State of the art theory and practice, challenges, and open research questions. Journal of Industrial Information Integration, 30, 100383.

Speiser, K., & Teizer, J. (2024). Automatic creation of personalised virtual construction safety training in digital twins. Proceedings of the Institution of Civil Engineers - Management, Procurement and Law, 177(4), 173-183. doi:10.1680/jmapl.23.00104

Ubachukwu, E., Pick, J., Riebesel, L., Lieberenz, P., Althaus, P., Xhonneux, A., & Müller, D. (2025). User engagement for thermal energy-efficient behavior in office buildings using dashboards and gamification. Applied Thermal Engineering, 266, 125598. doi:https://doi.org/10.1016/j.applthermaleng.2025.125598

Vieira, V., Oliveira, E., Menin, A., Clua, E., Winckler, M., & Trevisan, D. (2024). Understanding affordances in XR interactions through a design space. Paper presented at the Proceedings of the XXIII Brazilian Symposium on Human Factors in Computing Systems. https://doi.org/10.1145/3702038.3702112

Wijewickrema, S., Ma, X., Bailey, J., Kennedy, G., & O'Leary, S. (2017). Feedback techniques in computer-based simulation training: a survey. arXiv preprint arXiv:1705.04683.