Exploring Gamification

Playing and learning through war-time architecture

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This paper explores wartime architecture, exemplified by Hong Kong's Shing Mun Redoubt, as a testament to humanity's complex history, advocating for its preservation through gamification and phygital (physical-digital) technologies. Existing studies on heritage conservation highlight the potential of integrating sensors with Virtual Reality (VR) in educational contexts. This research introduces a framework (VUA)—combining VR, Unity software, and Arduino-based sensors—that merges ludic narrativity (playful storytelling) with gamified architectural elements to create multi-sensory interactive experiences. A literature review informed the framework's development, enabling bidirectional interaction between virtual environments and physical sensors, which participants used to engage with and learn about architectural history through immersive experimentation. An experiment assessed participants' engagement within the VUA framework, focusing on three factors: the degree of immersion, the ease of knowledge acquisition, and the impact of multi-sensory feedback across physical and virtual environments. Results demonstrate that the VUA framework, when applied to the architectural history of the Shing Mun Redoubt, simplifies complex historical concepts and enhances experiential learning. The study highlights the potential value of gamification in deepening educational and historical appreciation of wartime architecture, while identifying opportunities to optimise the VUA framework for interdisciplinary applications and more effective learning outcomes.

Keywords: *Gamification, Virtual Reality, Sensors, WWII Architecture, Gamified learning*

INTRODUCTION

War-time architecture, despite its often-unpleasant aspects, serves as a significant testament to humanity's complex history, embodying narratives that require confrontation and understanding. McKinnon (2015) pointed out that conflict-associated architecture attracts substantial tourist interest and provides economic benefits. While these structures face risks of neglect and deterioration due to their remote locations and lack of maintenance (Wang et al., 2021). They vary in size, complexity, and environmental impact, creating economic challenges for both management and preservation. For instance, the Shing Mun Redoubt in Hong Kong exemplifies such challenges. Whereas Wang et al (2021) suggested that some wartime defensive architectures were designed for a short lifespan and may lack aesthetic, or social value, preserving their heritage is nonetheless crucial for education and historical awareness. Zheng et al (2024) and recent studies demonstrate the potential of VR in digitally restoring ancient architecture without altering the original structures, providing a foundation for innovative preservation. Traditional preservation methods are limited by various factors, but emerging technologies such as virtual reality (VR) offer alternatives.

This paper has proposed a system integrating virtual reality, unity, and arduino (VUA) that connects virtual wartime architecture with physical sensors for bi-directional interaction and feedback. Through an experimental setup, participants engage with wartime architecture by using interactive sensors, enabling the investigation of 3 aspects: (1) degree of immersion, (2) ease of knowledge acquisition and effects of multi-sensory feedback. This study advances the use of VR and sensor technology in heritage preservation and encourages interactive learning experiences through innovative design.

The next section provides a literature review that provides a clear understanding of the historical context of the site and relevant technologies, the methodology outlines the research methods, and findings will be discussed in the results. This paper will present a new perspective on using VR and sensor technology for educational purposes, enhancing experiences and understanding of architectural history through immersive engagement.

BACKGROUND

This section discusses the definition and related work of mixed reality technology, bi-directional framework, gamification, and ludic narrativity in architecture, as well as the architectural history of the Shing Mun Redoubt.

Phygitalization and human computer interaction

The term "phygitalization" is a neologism derived from the combination of "physical" and "digital". Andrade et al (2020) suggested that Mixed Reality (MR) plays a crucial role in advancing phygitalization by providing immersive experiences that seamlessly blend these two spaces. Various industries are exploring the adoption of MR technologies, which heavily rely on human-computer interaction (HCI). According to Zeng (2024), HCI focuses on the interaction between humans and computers, emphasizing mutual understanding between users and the systems they engage with.

VR technologies, as part of HCI, provide users with immersive interactive experiences, allowing them to inhabit virtual or augmented environments and interact with virtual objects. Research shows that applying VR within HCI scenarios yields significant results. However, the predominant focus remains on virtual visual aids, including eye tracking, haptic feedback devices, and gesture tracking, often overlooking the importance of real physical and haptic feedback. In architectural contexts, there is often excessive emphasis on visual impact, which can lead to a neglect of tactile or haptic engagement and the overall sensory experience. By incorporating tactile interfaces and responsive materials, phygitalization has the potential to significantly enhance users' physical engagement with architectural spaces, fostering richer interactive sensory experiences and architectural learning progress.

Bi-directional framework

The concept of a bi-directional framework has been explored extensively to facilitate interactions between physical and virtual environments. Chursin et al (2020) have proposed a framework that bridges the computer, particularly the software unity, arduino firmware and sensors together, enabling bi-directional signal transfer between physical and virtual environments. The components such as the microcontroller, data port, and unity script are transferred inside the virtual platform. Kucera et al (2022) have worked on the integration of VR, arduino, and. Their research results highlight the potential of virtual tours to enhance the experience of mixed reality spaces by constructing virtual environments using various input and output methods. Thus, this paper establishes a foundation for experiments that incorporate VR, sensors, and arduino firmware, while also integrating the site's history and its ludic narrativity.

Ludic narrativity

For many years, the debate between ludology and narratology has centered on whether games are primarily a medium for pure enjoyment or visually immersive storytelling. Chen et al (2023) have worked on game research, introducing the term ludic narrativity, which refers to how gameplay mechanics (ludology) and narrative elements (narratology) mutually interact and enhance each other, rather than being mutually exclusive in games. Scholars believe that storytelling in games is shaped by players' choices and actions, allowing for meaningful communication with the audience. Consequently, creators can design themes that guide players through specific journeys, imparting knowledge related to the game. As players engage with the game, they passively internalize the story.

Gamification of architecture

Interestingly, games can serve as tools for conserving architecture and history. A notable example given by Politopoulos et al (2019) is the Assassin's Creed series, where development teams invest years in gathering data and historical context to translate historical scenarios into engaging gameplay experiences and convey

Figure 1
Current interior and floor plan of the wartime building.

historical knowledge. Some architects argue that conservation should focus solely on architectural elements like texture and materials, suggesting that gamification distracts from the essence of architecture, but this focus can become a barrier to public engagement. Current conservation approaches for wartime architecture face significant challenges and limitations. Furthermore, Van et al (2021) suggested the feasibility of reconstruction of digital heritage objects for XR applications by the use of computer graphics such as 3D scanning and UV mapping, but they only capture visual aspects. This can apply to the reconstruction of war-time architecture, due to the damage to its original appearance in World War II.

Site history

The Shing Mun Redoubt, a wartime structure in Hong Kong built almost a century ago, features historically significant defensive elements such as trenches and pillboxes. However, the site has deteriorated over time, characterized by eroded concrete and exposed steel reinforcements. Individuals, communities, and non-profit organizations are dedicated to preserving this heritage as a cultural legacy. Their efforts involve raising public awareness, advocating for preservation, and undertaking conservation projects, despite the continued neglect and obscurity of these architectural sites. Wang et al (2021) pointed out that the preservation of Hong Kong's wartime heritage is hindered by insufficient government intervention, which affects conservation efforts and the maintenance of historical sites. Lai et al (2021) have emphasised the role of war-time architectures as both a material archive of military history and learning resources, considering that their preservation is indispensable for understanding these defence strategies and their socio-historical ramifications.

Constructed in 1937 on a strategically elevated ridge below Smugglers' Ridge in Hong

Kong, the Shing Mun Redoubt stands as a stronghold of British colonial military engineering, designed to counter a potential land invasion from the north before WWII. The redoubt consisted of five reinforced concrete pillboxes, an artillery observation post (AOP) in figure 1, and a network of underground tunnels and open-air firing trenches. Its geographic positioning, nestled between key topographic features near Jubilee Dam, rendered it a critical defensive node during the Pacific Theater of World War II, intended to obstruct enemy advances from Kowloon toward the Hong Kong-China border.

The tactical importance of the redoubt has been highlighted in December 1941 when the Second World War in the Pacific broke out and the Japanese invaded, prompting British forces to target the area to secure Smugglers' Ridge. However, Japanese forces overwhelmed the site, first capturing the AOP before seizing adjacent pillboxes. As defenses collapsed, Allied artillery units bombarded Japanese positions in a failed attempt to reclaim the Redoubt, marking a pivotal moment in Hong Kong's wartime history.

Virtual reality, unity, and Arduino framework

This paper presents the Virtual Reality, Unity, and Arduino (VUA) Framework, which connects virtual wartime architecture with physical sensors for bi-directional interaction and feedback.

This framework integrates design elements, electronic sensors, and user interfaces to create interactive experiences in virtual reality and narrative play. The interaction flow between inputs and outputs is illustrated in figure 2, demonstrating how data transfers between physical and virtual spaces across various media and tools.

The development of the framework involved a thorough analysis of architectural structures and narratives, focusing on the Shing Mun Redoubt as a key component. Grounded in the theory of ludic narrativity, which emphasises the integration of space and narrative in gameplay, as mentioned previously, exploring the Shing Mun Redoubt

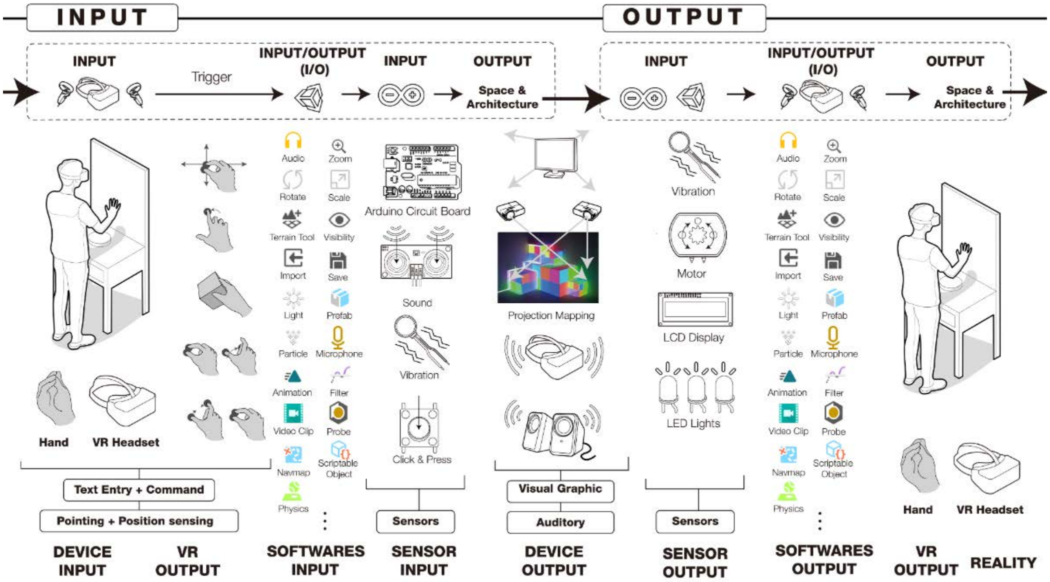

Figure 2
Interaction flow between (input and output) and (physical and virtual space).

through site drawings, historical reviews, and photo archiving. It highlights the importance of storytelling and clear objectives in enhancing users' understanding and examines how narrative elements and users' goals contribute to the gaming experience in the virtual environment.

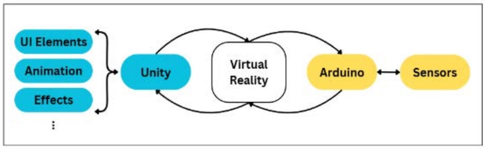

Figure 3
Virtual reality, unity, and arduino (VUA) framework.

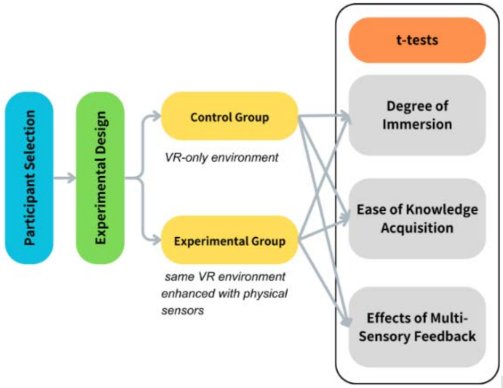

Figure 4
Experiment setup.

Figure 5
Participants' physical and virtual Interaction in reality and virtual space.

The virtual reality, unity, and arduino (VUA) framework is a vital component of this system. It comprises three main elements. Firstly, unity serves to facilitate data conversion from arduino and also creates interactions within the virtual wartime architecture.

In figure 3, the virtual reality aspect enables users to visually experience this architecture while engaging in physical haptic interactions through the arduino sensor, which provides feedback to trigger interactions in unity, including buttons and animations. While arduino connects to sensors that receive feedback from these physical interactions and transmit data to unity. The VUA framework employs modified Ardicity, an online open-source plugin, along with C++ and C# for data conversion and transfer, ensuring seamless data exchange between the virtual and physical realms.

METHOLOGY

An experimental study was conducted from February 28 to March 28, 2025, to test hypotheses related to user experiences in VR environments. The study took place in a controlled physical space measuring 10 meters in length, 10 meters in width, and 3 meters in height, with a maintained temperature of 23–25°C. A diverse group of participants under the age of 18, with varying levels of familiarity with VR and wartime history, was invited to take part.

In figure 4, the experiment compared two groups: a control group interacting with wartime architecture in a VR-only environment and an experimental group using VR enhanced with physical sensors. The study aimed to measure differences in immersion, ease of knowledge acquisition, and the effects of multi-sensory feedback on user engagement and understanding. Participants were required to complete a parental declaration form and a post-experiment questionnaire. The procedural steps for each component are outlined below.

Participants

The experiment involved ten participants, all secondary school students under the age of 18. There were five participants in each experiment.

Setting

The experiment was conducted in a controlled physical space measuring 10 meters in width, 10 meters in length, and 3 meters in height. In figure 5, participants began in a virtual redoubt environment, offering an enclosed interiority, and were provided with instructions and a declaration form.

Upon pressing a virtual button, participants experienced several gaming scenarios focused on the site's history and its historical figures, guided by AI-generated voice instructions. Two types of scenarios were included: God-view mode, allowing participants to gain an overview of the site. Interior scenario, providing a first-person perspective of individuals who used the site historically. The setup included an Arduino UNO and sensors, enabling participants to interact with the virtual scene. Unity version 2021.1.4f1 was used, with all scripts written in C#. The Oculus Quest 2 VR headset was connected to a computer via type-C cables using the Meta Link application.

Procedures

The privacy, confidentiality, and anonymity of all participants were meticulously safeguarded. Before the experiment, participants completed a declaration form and a questionnaire, followed by verbal instructions and process reminders.

Each experiment lasted 10 minutes per participant, with participants randomly assigned to one of three experiment components without duplication.

Sampling and data collection

In figure 6, participants will be randomly assigned to either experiment 1 (the control group) or experiment 2 (the experimental group). In experiment 1, participants will experience virtual wartime architecture solely through VR. In experiment 2, the spatial experience will be enhanced using arduino and sensors. Before the test, participants will be instructed to familiarise themselves with the VR devices and engage in a brief 30-second walking exercise. During the experiment, participants' actions and responses will be recorded using a single camera for later analysis. After the gameplay experience, participants will complete a survey, assessing three aspects: degree of immersion, ease of knowledge acquisition, and effects of multi-sensory feedback.

Question 1 : Degree of Immersion
The virtual war-time architecture is (0-10).
0 …… 1 …… 2 …… 3 …… 4 ……5 ……6 ……7 ……8 ……9 ……10
Fake ……………………Neutral ……………………Real

Question 2: Ease of Gaining Knowledge
It is (0-10) to gain knowledge in the virtual war-time architecture.
0 …… 1 …… 2 …… 3 …… 4 ……5 ……6 ……7 ……8 ……9 ……10
Difficult …………………… Normal…………………… Easy

Question 3: Effects of Multi-Sensory Feedback
How would you rate the overall experience of playing inside the virtual war-time architecture? (0-10)
0 …… 1 …… 2 …… 3 …… 4 ……5 ……6 ……7 ……8 ……9 ……10
Very Poor …………………… Average…………………… Excellent

Table 1
Survey form: measurements of experiment rate a score from 0 to 10.

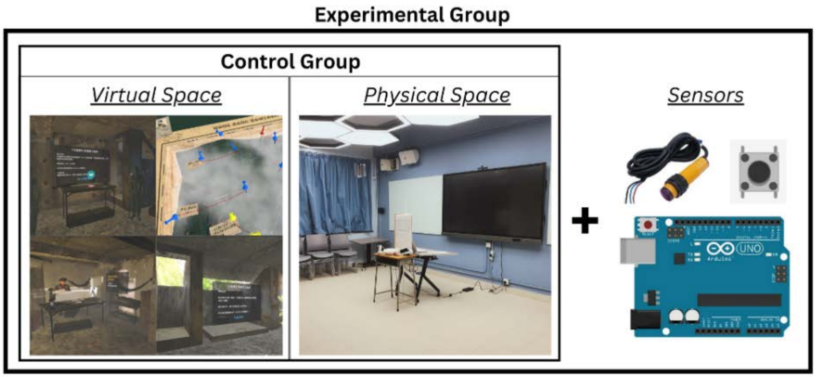

Figure 6
Development environment and tools.

RESULT

Participants from both the control group and the experimental group completed a questionnaire and a brief task to evaluate their learning degree of immersion, ease of knowledge acquisition, and effects of multi-sensory feedback experience in the virtual architecture environment. The questionnaire, detailed in table 1, included three questions focused on the degree of immersion, ease of knowledge acquisition, and the effects of multi-sensory feedback in phygital environments.

In question 1, scores of 5 or lower indicated a "non-realistic virtual environment," a score of 5 represented "in-between realistic and virtual," and scores of 6 or higher suggested a "realistic virtual environment." For question 2, scores of 5 or lower indicated "difficult" knowledge acquisition, a score of 5 represented "normal" ease, and scores of 6 or higher indicated "easy" knowledge acquisition. In question 3, scores of 5 or lower reflected a "very poor" experience, a score of 5 signified an "average" experience, and scores of 6 or higher indicated an "excellent" overall experience. This scale provided insight into participants' perceptions of virtual architecture in VR, both with and without the aid of sensors.

Table 2
Comparison of mean scores and statistical analysis between control and experimental groups across questions.

Question	Q1	Q2	Q3
C (M ± SD)	8.4 ± 1.33	8.6 ± 0.75	8.6 ± 1.33
E (M ± SD)	7.6 ± 0.84	6.8 ± 1.29	8.2 ± 0.45
t-statistic	1.21	2.50	0.65
p-value	0.12	0.025	0.53

The experiments conducted offer valuable insights into the educational questions outlined in the paper, comparing the control group with the experimental group regarding immersion in virtual wartime architecture, ease of knowledge acquisition, and the effects of multi-sensory feedback on spatial experience. The primary findings from these experiments are summarised in table 2.

In Q1, the control group performed a higher average score compared to the experimental group, with a mean score of C (8.4 ± 1.30) and E (7.6 ± 0.84). The t-test results showed a t-statistic of 1.21 and a p-value of 0.12, indicating that the difference between the control group and the experimental group was not statistically significant. This indicates that the control group found the level of immersion in the virtual wartime architecture to be more realistic compared to the experimental group, which did not utilise Arduino sensors within the VUA framework.

In Q2, the gap between the control group and the experimental group widened, with a mean score of C (8.6 ± 0.75) and E (6.8 ± 1.29). The t-test results revealed a t-statistic of 2.50 and a p-value of 0.025, indicating that knowledge acquisition without sensors was easier for the control group. Conversely, the experimental group felt that gaining knowledge about architectural history with the use of sensors within the VUA framework was a bit easier.

In Q3, the control group achieved a mean score of C (8.6 ± 1.30), compared to the experimental group's mean score of E (8.2 ± 0.45). The t-statistic for this comparison was 0.65, with a p-value of 0.53, indicating no significant difference in overall experience. Participants in the control group rated their experience as excellent, while the experimental group’s ratings were slightly lower. This suggests that the haptic sensory feedback integrated into the experimental group may not have been more impactful than the visual and auditory effects present in the game.

Overall, the results presented in table 2 indicate that the t-tests across the three questions show the control group had an easier time acquiring knowledge compared to the experimental group, especially in Q2. However, the absence of significant differences in Q1 and

Q3 suggests that the experimental group's perceptions of immersive and overall experience in the war-time architecture did not differ from those of the control group.

The table 3 illustrates the results of a study on war-time architecture, comparing correct response percentages between the control and experimental groups across four questions. In MC1 (the name of the architecture), both groups scored 40%. However, in MC2 (a brief architectural history), the experimental group significantly outperformed the control group, scoring 60% compared to just 20%. This suggests that immersive and interactive learning methods can enhance participants' understanding of architectural history. In MC3 (the current player location in the game), the control group scored 80%, indicating effective spatial awareness, while in MC4 (the person with whom the player interacts), the experimental group excelled at 80%, reflecting their engagement with interactive elements.

These findings highlight that experiential learning environments can foster better retention of historical content, particularly in understanding context and engaging with architectural narratives, enhancing their overall learning experience within the VUA framework.

DISCUSSION

The results presented in tables 2 and 3 provide valuable insights into enhancing participants' learning experiences and retention of architectural history within the VUA Framework. The comparative analysis of the control and experimental groups demonstrates how immersive environments can facilitate engagement and support knowledge acquisition. Yet, a limitation of this study must be acknowledged, with a sample size of only 10 participants. The finite sample size limits the potential statistical results, making it difficult to draw affirmative conclusions about the additive effects of multisensory devices.

Question	Q1	Q2	Q3
C (M ± SD)	8.4 ± 1.33	8.6 ± 0.75	8.6 ± 1.33
E (M ± SD)	7.6 ± 0.84	6.8 ± 1.29	8.2 ± 0.45
t-statistic	1.21	2.50	0.65
p-value	0.12	0.025	0.53

Table 3
Multiple choices regarding the history in the game.

Lampropoulos et al (2024) in their work suggested that integrating VR and gamification in education enhances students' learning outcomes, motivation, engagement, and self-efficacy, particularly in the context of video games and historical architecture. This suggests a promising opportunity to enrich the educational experience with gamified and interactive elements in wartime architecture, as well as to aid in the conservation of these structures through VR. Similarly, Marougkas et al (2023) noted that the use of constructivist learning theory in VR technology allows students to showcase their creativity and ideas within a safe virtual environment. However, it is crucial to design VR experiences, a framework that fosters learner autonomy and facilitates opportunities for independent exploration.

One question arising from these findings is whether the degree of immersion within the VR framework effectively enhanced the learning experience. While the control group reported a greater sense of realism (table 2, question 1) compared to the experimental group, this discrepancy may stem from a mismatch between the materials used for haptic effects and the virtual props, which could detract from the overall realism. Additionally, technical challenges encountered in aligning virtual and physical objects in games may also have an impact on it. For example, the participant's position will be reset when taking off the VR headset, causing delays and mismatches in game triggers.

Another finding indicates that knowledge acquisition may be easier in the virtual environment, as the control group reported that it was simpler to learn without using the sensors (table 2, question 1). This implies that, without the sensors, participants could better focus on the visual and sound effects related to wartime architecture. They paid greater attention to the spatial interiority (table 3, MC 3) and the architecture itself, rather than the overall narrative of the structure. Nonetheless, the positive results suggest that participants gained a better understanding of the neglected wartime architecture, Shing Mun Redoubt. The experimental group's success in knowledge acquisition indicates that incorporating interactive elements can simplify complex architectural concepts, making them more accessible (table 3, MC 2 and 4).

Marougkas et al (2023) also stated that immersive experiences enable students to interact with virtual objects and scenes in a hands-on and experiential way, which means that when combined with interaction with physical objects, it has the potential to enhance students' immersion and enable them to learn more effectively. In this connection, this paper suggests that multi-sensory feedback can further improve knowledge retention, particularly for short-term memories. The mean scores of the control and experimental groups (table 2, question 3) are very similar, with all questions in table 2 scoring above or equal to 50%. Therefore, it appears that the interactive and multi-sensory elements of the VR experience may have played a pivotal role in enhancing participants' ability to internalise historical information during the short phygital experience, thereby improving engagement and facilitating knowledge acquisition.

Architecture associated with war, such as Shing Mun Redoubt, serves as a medium for conveying historical memory. Far from being neutral, wartime architecture embodies narrativity of conflict, resilience, and loss, evoking emotional resonance and prompting critical discussion about historical context. While it is critical that students do not carry the burden of past trauma, the concept of “playing” with history is central to this exploration and involves engaging with historical narratives through interactive methods such as role play, simulations, and creative storytelling under the framework of ludic narrativity.

Within the VUA framework, students have diverse perspectives, can build deeper emotional connections, and gain architectural knowledge related to war. However, the method proposed in this paper must be approached with caution to ensure that the gravity of historical events is respected and historical correctness is achieved while allowing for meaningful exploration and reflection.

CONCLUSION

In summary, this study reveals the intricate relationship between sensory feedback and learning outcomes in this VUA framework, suggesting the use of sensors and VR within a gamified framework has the potential to enhance the virtual experience through multi-sensory interactions. This paper identifies a potential area for further exploration regarding knowledge retention and gamified wartime architecture, particularly in the educational field, in spite of the lack of statistical significance, the initial insights from this paper highlight the need for further research.

While this study introduces the preliminary phygital VUA framework, its iterative refinement can enhance its applicability in schools by developing educational tools with purposeful sensory interactions that boost engagement. These tools should balance the gaming experience without compromising educational values, ultimately deepening students’ understanding of architectural heritage and preservation. Provides a vision for the confluence of interdisciplinary, architectural, educational, and technological approaches to create more effective learning experiences. Future research can critically examine the effectiveness of physical elements in the VUA framework, examining whether they enhance learning outcomes or introduce unnecessary complexity under the educational theory.

ACKNOWLEDGEMENTS

The work described in this paper was partially supported by a grant from the Hong Kong Polytechnic University (Project No. P0047199).

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