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An Interactive Virtual Reality Approach to Understanding Cultural Heritage Through Storyliving: A Case Study of Seoul City Wall (Hanyangdoseong) in South Korea

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Abstract: In this study, we developed and evaluated a nonlinear narrative virtual reality approach to enhancing the understanding of cultural heritage. The system was designed to convey the historical and cultural context of Seoul City Wall (Hanyangdoseong) while engaging users in a personalized experience. A novel "storyliving" structure was used, in which users choose the progress of the narrative. To achieve this, the methodology employed three key components: evaluating criteria to assess Hanyangdoseong's sense-of-place, clustering to create distinct scenario segments, and sticker mapping to identify spatial preferences. Our approach maximizes user immersion through selective pathways and branching stories. Initial validation results suggest that this virtual reality system can greatly deepen users' understanding of Hanyangdoseong and demonstrate the system's potential as an innovative tool for cultural heritage education. This study contributes to the digital transformation of cultural heritage and provides important direction for the development of virtual reality content with richer and more personalized educational experiences.

Keywords: cultural heritage; virtual reality; nonlinear narrative; storyliving; immersive experience

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1. Introduction

Virtual Reality (VR), a relatively dormant technology for decades, has recently made rapid gains because of increasing demand from fields such as social networking, education, medicine, and gaming [1,2]. The establishment of Oculus VR and the release in 2012 of the Oculus Rift headset accelerated the mainstream adoption of VR [3]. VR has become a global phenomenon influencing various aspects of society and business [3,4]. The VR market is projected to reach USD 22.81 billion by 2024 and USD 131.93 billion by 2029 [4].

Digital narratives greatly enhance the immersive quality of VR experiences [2]. However, although hardware advances, such as affordable headsets and high data-processing capability, are actively studied, few studies address digital narratives [1,5,6]. VR digital narratives allow users to shape their experiences, which greatly increases user engagement [7–9]. As technology advances, the study of digital narratives is becoming increasingly important.

Digital narratives use two main approaches. The first is storytelling (ST), in which the narrative follows a predetermined structure. The second is "storyliving" (SL), in which users can manipulate the narrative [10,11]. SL provides users of VR environments with a richer and more personalized experience [12,13].

Various studies utilize the SL approach. For example, a French spa town uses digitalization to provide an emotional experience that attracts younger customers [14]. A virtual tour of the Canadian Parliament allows visitors to explore at their preferred pace through a nonlinear interactive format [15]. Additionally, a nonlinear VR adaptation of Shakespeare's plays provides deep immersion through multiple paths and choices [16].

These studies demonstrate the effectiveness of SL in VR environments. However, they primarily focus on the theoretical aspects of SL and its direction rather than detailing methodologies and processes for its implementation. This study aims to address this gap through the proposal of a systematic methodology for implementing SL in spatially oriented destinations.

Hanyangdoseong, Seoul's historic city wall, represents the history and culture of the Joseon Dynasty. Located in the city's heart, it has excellent accessibility and harmonizes with the natural landscape, making it an ideal subject for the development of nonlinear SL-based VR content [17,18]. The wall preserves various landscapes, providing space for healing, leisure, and a glimpse into the past [19,20]. These characteristics provide valuable visual and experiential elements for exploration in VR research.

The objective of this study was to develop, using a nonlinear SL approach, an interactive VR system centered on Hanyangdoseong. The aim was to create a method through which users can experience narratives in a personalized manner while enhancing their understanding of cultural heritage.

2. Literature Review

2.1. Digital Narrative in Virtual Reality

Digital narrative refers to storytelling through digital media, an approach that is effective in conveying information and sharing experiences [7]. Through a combination of media types, it offers users a rich experience; in a VR environment, the narrative unfolds through user interaction, enhancing immersion [2,6]. In VR, digital narratives increase user presence, interactivity, and realism. This encourages users to engage in the story as part of the virtual space, thereby providing a deeper emotional connection and understanding [11]. The associated narratives may be classified as linear or nonlinear (Figure 1).

(**a**) (**b**)

Figure 1. Types of digital narrative structures (Adapted from Yuel [21]). (**a**) Linear structure (storytelling, ST). (**b**) Nonlinear structure (storyliving, SL).

2.2. Storytelling

Linear ST (Figure 1a) progresses in a straight line, with a clear beginning, middle, and end. Users experience the narrative along a predetermined path. Traditional films, novels, and plays are examples of this category [10,11]. For example, Age of Sail (2018) is a linear ST case that induces immersion through a clear narrative structure centered on the rescue of the isolated sailor William Avery [22]. Similarly, Doctor Who: The Runaway (2019) unfolds in a straightforward manner; users experience the story by following the given path, accompanying the Doctor on an adventure [22]. However, with only simple visual interactions and a lack of personalized experience, user engagement may be low [12].

2.3. Storyliving

Nonlinear SL (Figure 1b) allows for multiple narrative directions based on user choices, with an emphasis on participation and interactivity. This structure is common in games, interactive media, and VR content, especially in open-world and sandbox games [12]. SL's user-driven narrative offers deep immersion and personalized experiences [10,11]. SL also plays an important role in cultural tourism. Cinematic VR can provide users with SL experiences in cultural tourism, enhancing cultural understanding and tourism satisfaction [23]. SL can also be used to enhance historical understanding and provide educational value [15]. SL-driven immersive tourism experiences contribute to greater tourist satisfaction and engagement in the tourism industry [14]. Interactive narratives that provide nonlinear SL experiences based on the user's viewpoint also offer personalized experiences [5].

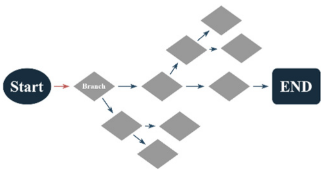
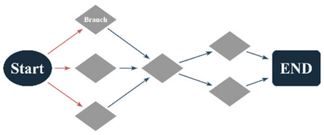
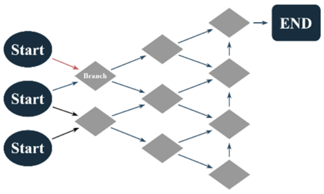
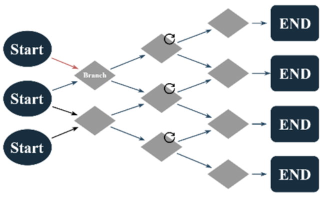
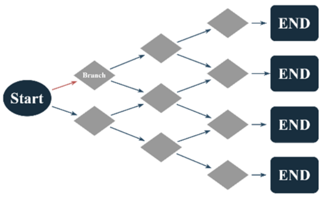
However, SL faces several technical challenges, especially in HMD (head-mounted display) VR environments. As user interaction increases, more resources may be required for development. Further, VR sickness is a major drawback, affecting user experience as a function of visual stimuli, user movement, and duration. This can limit the feasibility of long-term experiences [24,25].

Nonetheless, SL remains a powerful tool for increasing immersion and personalized experiences, with great potential for cultural tourism content. This study has applied SL to cultural tourism content, focusing on reducing user burden and ensuring effective immersion in short time frames.

2.4. Storyliving Scenario Structure

The SL scenario structure is designed based on interactions between the user and the narrative flow [26,27]. Five types of structure are considered here: String of Pearls, Parallel, Interpolated, Dynamic, and Branching (Table 1).

Table 1. Types of storyliving scenario structures (Adapted from [26,28]).

Type	Structural Diagram	Description	Advantages	Disadvantages
String of Pearls		Each episode within the narrative is independent, similar to pearls on a string.	Narrative is easy to understand.	Weak connections and poor consistency between episodes.
Parallel		Each episode is independent yet related.	Maintains interest through a complex narrative.	Can be confusing because of simultaneous progress.
Interpolated		Composes a larger narrative from smaller stories.	Offers various choices and paths.	Difficult to maintain narrative length and consistency.
Dynamic		Narrative evolves with real-time interaction and feedback.	Provides a tailored experience based on audience choices and actions.	High technical requirements.
Branching		Leads to multiple endings based on choices.	Provides high immersion and engagement through diverse choices.	Complex to design and manage.

The String of Pearls structure is easy to understand but has weak connectivity and consistency between episodes [26,29]. The Parallel structure can lead to confusion as multiple episodes progress simultaneously [26,30]. The Interpolated structure struggles to maintain length and consistency in the narrative [26,31]. The Dynamic structure, although based on real-time interaction and feedback, has high technical demands [26,31]. These requirements can be challenging to implement in HMD VR environments because of problems such as VR sickness.

Of these options, the Branching structure was selected for this study. This structure enables the narrative to develop in different directions based on user choices, which enhances immersion and engagement. It also offers new experiences in repeated playthroughs because of its multiple possible endings [32]. Although the Branching structure can be complex to design and manage, it serves this study's focus on the creation of diverse and personalized user experiences. Through the development of a nonlinear SL VR scenario using the Branching structure, this study seeks to provide an immersive experience that maximizes users' control over the progression of the story.

3. Materials and Methods

This study followed four stages to develop an effective SL VR system (Figure 2).

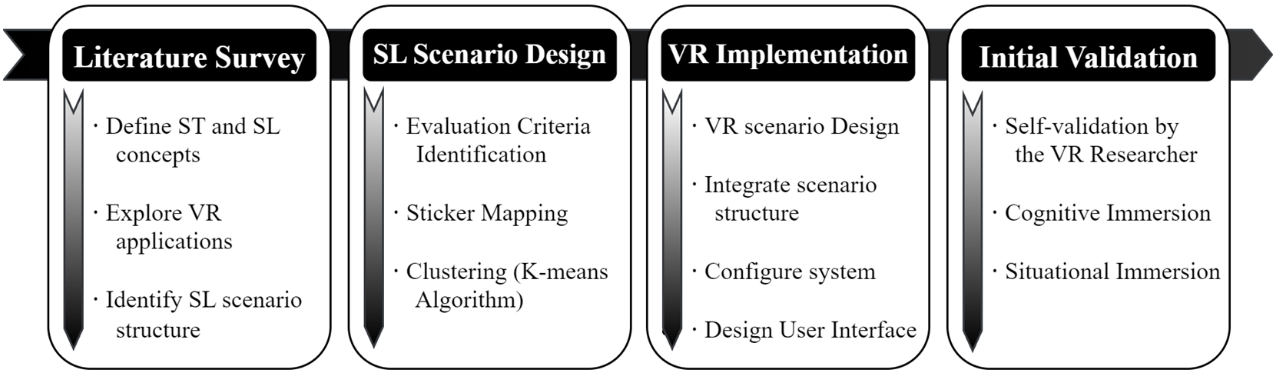


Figure 2. Research flow.

First, a literature survey of digital narratives was conducted to define the ST and SL concepts and explore their application in VR environments. The literature survey identified the scenario structure for SL, which was then tailored for implementation in relation to Hanyangdoseong.

Second, three core methodologies were used to design the scenario: identification of evaluation criteria, sticker mapping, and clustering. The evaluation criteria assessed six aspects of the city wall's sense-of-place on a five-point Likert scale; this supported the segmentation of the VR scenario [33–35]. In sticker mapping, participants provided survey responses at specific map locations using stickers; this facilitated the analysis of spatial preferences and determined the scenario's branch nodes [36,37]. Clustering grouped the data into clusters with similar characteristics; the k-means algorithm was then used to segment the data for the evaluation criteria [33,38,39].

Third, in the implementation phase, the designed scenarios were translated into a functional VR environment. This required the integration of the scenario structure into the VR system, the configuration of the system to support user interaction, and the design of an intuitive user interface.

Fourth, the VR researcher conducted an initial self-validation of the SL VR system, focusing on cognitive and situational immersion factors. The results from this analysis served as preliminary data for the refinement of the system [40–42].

This approach allowed the establishment and systematization of the SL VR scenario structure, enabling a rich and personalized experience for users.

3.1. Storyliving Scenario Construction Methodology

The SL scenario was constructed in a series of steps involving quantitative analysis (Figure 3). First, preliminary data were collected, including spatial, experiential, and geographic characteristics. Clustering was then performed on these data to analyze spatial patterns and design events using trekking and geospatial routes. A sticker-mapping survey identified the spaces most frequently interacted with, and this informed the establishment of branch nodes. All quantitative analyses in this study, including clustering, correlation analysis, and descriptive statistics, were performed using MATLAB. This systematic process allowed the quantitative design of the main routes and the nonlinear scenario.

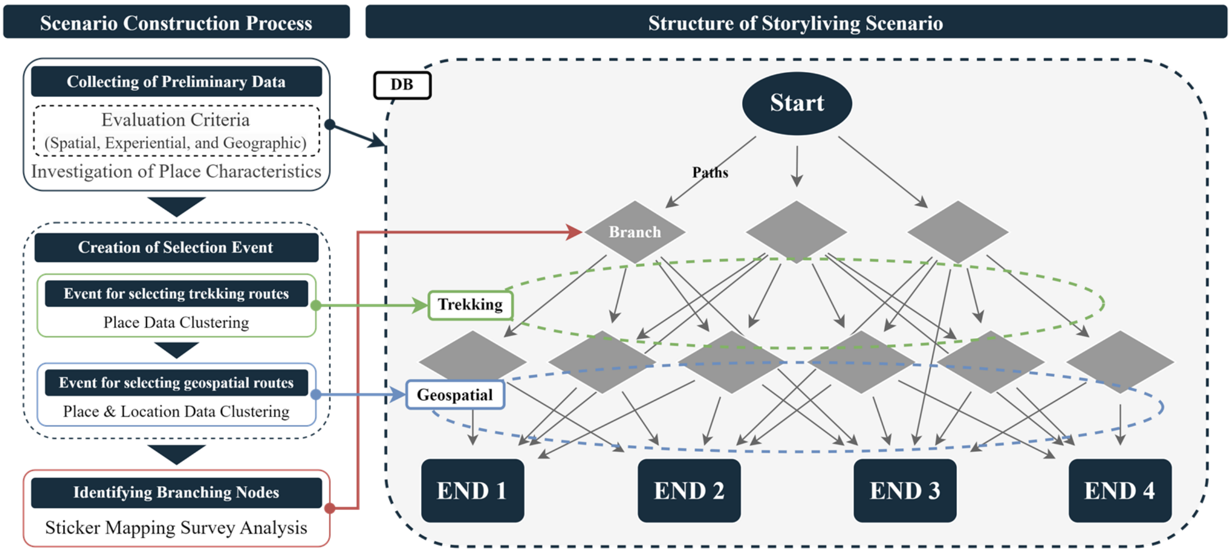


Figure 3. Storyliving scenario design process.

3.1.1. Collection of Preliminary Data Using Evaluation Criteria

To investigate the sense-of-place characteristics of 79 locations along Hanyangdoseong, we used six evaluation criteria, categorized into three types that reflect different dimensions of spatial perception: spatial (historical value [43,44] and accessibility [43,45]), experiential (convenience [45,46] and diversity [45,47,48]), and geographic (natural harmony [44,45,48] and population density [46,47]) (Table 2).

Table 2. Criteria for zoning of Hanyangdoseong.

Characteristic	Very Low Score (1)	Low Score (2)	Medium Score (3)	High Score (4)	Very High Score (5)
Historical value	No fortress	Fortress damaged	Fortress and commerce present	Fortress well-preserved	Fortress fully preserved
Accessibility	Very hard to access	Accessible by road	Car access	Bus access	Bus and subway access
Convenience	No facilities	Some rest areas	Basic sanitation facilities	Fully equipped facilities	Well-equipped with additional facilities
Diversity	Limited activities	Basic sightseeing	Guided sightseeing	Cultural events	Various experiential activities
Natural harmony	No natural elements	Minimal natural elements	Nature and fortress in harmony	Nature in an important role	Full harmony of nature and fortress
Population density	Very few visitors	Some visitors	Moderate number of visitors	Some areas crowded	Overcrowded

"Historical value" relates to the preservation state of the space, and "accessibility" relates to the ease of access. "Convenience" reflects the availability and quality of amenities, whereas "diversity" is a measure of the variety of activities offered. "Natural harmony" reports the degree to which the space blends with the natural environment, and "population density" gives the number of visitors during specified periods.

The selection of locations was based on the Hanyangdoseong map provided on the Seoul City website, with 66 locations surveyed at approximately 280 m intervals along the

18.6 km wall length [49]. These 66 locations were selected using systematic sampling [50] to ensure uniform representation. The use of a sufficiently large sample size can minimize data variability, enhancing statistical reliability, and data can also be collected in a manageable range [51,52]. Thirteen further locations on the inner and outer sections of the city wall were also included, resulting in 79 locations evaluated for the six characteristics.

The characteristics of each location were evaluated using a five-point Likert scale. The evaluation was conducted by three researchers who majored in architecture and are currently engaged in research on cultural heritage and VR. Each researcher performed evaluations three times: once through on-site visits, once using 360 photo-based assessments, and finally, through collaborative discussions. This approach allowed for the cross-verification of data and ensured a comprehensive coverage of each location's characteristics.

To derive a unified dataset, the researchers discussed and refined their individual assessments. This iterative evaluation ensured both data consistency and reliability. To quantitatively assess the degree of agreement between the researchers' evaluations, an intraclass correlation coefficient (ICC) analysis was conducted for each location, confirming the reliability of the collected data.

ICC is a statistical measure used to evaluate the consistency or reproducibility of quantitative measurements by different raters. Higher ICC values indicate strong agreement among the raters, suggesting that the evaluations were consistently aligned [53].

Table 3 presents the sense-of-place characteristics, average scores by each researcher, final aggregated scores for each location, and corresponding ICC values. The ICC values represent the degree of agreement between the three researchers' evaluations for each location. These results confirm the reliability of the dataset used for constructing the SL VR system, demonstrating its robustness and supporting the development of a nonlinear scenario for the SL VR system.

3.1.2. Event for Selecting Trekking Routes

In this study, "event" refers to an action initiated by user selection and triggering associated functions. Immersion is enhanced by providing actions and responses based on user choices.

To generate events focused on selecting trekking-based routes, we performed k-means clustering on the sense-of-place data for Hanyangdoseong using the Statistics and Machine Learning Toolbox. This algorithmic approach aims to allow users to experience the characteristics of various locations along Hanyangdoseong to enhance immersion. Using the elbow method [54,55], we determined the optimal number of clusters to be three. From the analysis, 79 locations were grouped into three clusters (Table 4). Trekking-1 had high scores for historical value and natural harmony but low scores for accessibility and convenience. Trekking-2 had medium scores for accessibility and convenience, with most characteristics falling around the median. Trekking-3 had high scores for accessibility, convenience, and population density, with a wide range of activities available.

The box plot in Figure 4 shows each characteristic's median, range, and outliers, revealing the differing patterns of the six characteristics across the clusters [38]. The clustering results reflect the relationships between sense-of-place characteristics in the SL scenario, which will provide users with criteria for making informed choices. The data aid in the establishment of precise trekking route events in the scenario.

However, because the clustering is based solely on sense-of-place data without consideration of geographic factors, it may not match well with the exploration routes. Further, the distribution of points within the clusters may be unbalanced. The inclusion of geospatial data in the clustering process can enhance the realism of the exploration experience and allow users to feel that they are truly navigating the environment.

Table 3. Sense-of-place Characteristics and ICC Evaluation of Hanyangdoseong.

Location	Historical Value				Accessibility				Convenience				Diversity				Natural Harmony				Population Density				ICC
	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	
1	4.333	4	4	4	1.333	1	1	1	1	1.667	1.333	1	3.333	3.333	3	3	4	4.667	4	4	2.333	2	2	2	0.941
2	4	4.333	4.333	4	2.333	2	2	2	2.333	2	2.333	2	3	3.667	3	3	3.333	3.333	3.333	3	2	2.333	2.667	2	0.824
3	3	3.333	3	3	2	2	2.333	2	2	2.333	2	2	2	2.333	2	2	2.333	2	2	2	2	2.333	2	2	0.66
4	1.333	1	1	1	3	3.667	3.333	3	1	1.333	1	1	1.333	1	1.333	1	1	1	1.333	1	1	1.333	1.333	1	0.87
5	1	1.667	1	1	3.333	3.333	3	3	1	1.333	1.667	1	1.333	1	1	1	1	1	1.333	1	1	1	1.333	1	0.856
6	5	5	5	5	5	5	5	5	1.333	1.333	1.333	1	4	4.333	4	4	3.333	3	3.333	3	3.333	3	3.333	3	0.955
7	3.333	3.333	3.333	3	2	2.333	2	2	4.333	4	4	4	3.333	3.333	3.333	3	2.333	2.333	2	2	3.667	3	3	3	0.808
8	3.333	3.333	3.333	3	2	2.333	2.333	2	2	2	2.667	2	3.333	3.333	3	3	3	3.667	3	3	3.333	3	3.333	3	0.642
9	4.667	4	4	4	2.333	2.333	2	2	2	2.667	2.333	2	3	3.333	3	3	4.333	4	4	4	4.333	4.333	4.333	4	0.874
10	4.333	4.333	4	4	1	1	2	1	1.333	1.333	1	1	3.333	3.333	3.333	3	3	3.667	3.333	3	3.333	3	3	3	0.907
11	4	4.333	4.667	4	4.333	4.333	4.333	4	4	4.667	4	4	5	5	5	5	4.333	4	4	4	5	5	5	5	0.596
12	4.333	4	4	4	4	4	4.333	4	1.667	1.333	1	1	3	3	3.333	3	3.333	3.667	3	3	3.333	3	3.667	3	0.888
13	3	3.667	3	3	2.333	2.667	2	2	5	5	5	5	5	5	5	5	1	1.333	1	1	3.333	3	3	3	0.967
14	4.333	4	4.667	4	3	3	3.333	3	1.333	1.333	1.333	1	3.333	3	3	3	3.333	3	3	3	2	2.333	2	2	0.902
15	3	3.333	3.333	3	2	2.333	2	2	5	5	5	5	5	5	5	5	1.333	1.667	1	1	3.333	3.333	3.333	3	0.958
16	4	4.333	4	4	3.333	3.667	3	3	2	2.333	2	2	3.333	3	3.333	3	3.333	3	3.333	3	2.333	2	2.333	2	0.813
17	3.333	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	4.333	4.333	4.333	4	4	4	4.333	4	0.908
18	4	4.333	4.333	4	2.333	2.333	2	2	2	2	2.333	2	3	3.333	3.333	3	3	3	3.333	3	3	3.333	3.333	3	0.83
19	5	5	5	5	5	5	5	5	2.667	2.333	2	2	4.333	4	4	4	2.333	2.667	2	2	4	4.333	4.333	4	0.939
20	3.333	3	3.333	3	5	5	5	5	5	5	5	5	5	5	5	5	2.333	2.333	2.333	2	5	5	5	5	0.963
21	3.333	3.333	3	3	5	5	5	5	5	5	5	5	3	3	3.333	3	3.667	3	3.333	3	4.333	4.333	4.333	4	0.89
22	5	5	5	5	5	5	5	5	5	5	5	5	3	3.333	3.333	3	3.333	3	3	3	3.333	3	3	3	0.954
23	1	1.333	1.333	1	3.333	3.333	3.333	3	1.333	1.333	1	1	1	1.333	1	1	1.333	1	1.667	1	1.667	1.333	1	1	0.827
24	1.333	1.333	1.333	1	3.333	3.333	3.333	3	1.667	1.333	1	1	1	1.333	1.333	1	1.333	1	1	1	1.667	1.333	1	1	0.818
25	4.333	4.667	4	4	1.333	1.333	1.333	1	1.333	1	1.333	1	3	3	3.333	3	4.333	4	4	4	3.333	3	3.333	3	0.931
26	3	3.333	3.667	3	5	5	5	5	2	2.333	2.333	2	3	3.333	3.333	3	3.333	3.667	3	3	2.333	2.667	2	2	0.878
27	4.333	4.333	4.333	4	1.333	1.333	1	1	1.667	1.333	1	1	3.333	3.333	3.333	3	4.333	4.333	4.333	4	3.333	3.667	3	3	0.918
28	3	3.333	3	3	3.333	3	3	3	2.333	2.667	2	2	3.333	3.333	3	3	3	3.333	3	3	2	2.333	2.333	2	0.612
29	4	4.333	4	4	1	1.667	1.333	1	1.333	1.333	1.333	1	3	3.333	3	3	4	4.333	4	4	3.333	3	3.667	3	0.925
30	3.333	3.333	3.333	3	3	3	3.333	3	2.333	2	2.333	2	3	3.333	3	3	3.333	3	3	3	2.333	2	2	2	0.71
31	4.667	4.333	4	4	1	1.333	1	1	1.333	1	1	1	3.333	3	3.667	3	4.333	4	4	4	3.333	3	3.333	3	0.943
32	3	3.333	3.333	3	3.667	3.333	3	3	3	3.333	3.667	3	3.333	3.667	3	3	3.667	3.333	3	3	2	2	2.333	2	0.583
33	4.333	4	4.333	4	1	1.333	1	1	2	2	2.667	2	3.667	3	3.333	3	4.333	4	4.333	4	2	2.333	2.333	2	0.919
34	1	1.667	1.333	1	1	1.333	1.333	1	1	1	1.333	1	1	1	1.333	1	3	3.333	3.333	3	1.333	1	1	1	0.856
35	1	1.333	1	1	4.333	4.333	4.333	4	1.333	1.333	1	1	1.333	1	1.333	1	1	1.667	1.333	1	1.333	1	1.333	1	0.918
36	5	5	5	5	1.333	1.333	1	1	1.333	1	1.667	1	3.667	3	3.333	3	5	5	5	5	3.333	3	3	3	0.967
37	4.333	4	4	4	3.667	3	3	3	1.333	1.333	1.333	1	3.333	3.333	3.333	3	4	4.333	4.333	4	3	3	3.333	3	0.889
38	5	5	5	5	1	1.667	1.333	1	1	1.667	1	1	3	3	3.333	3	5	5	5	5	3	3.667	3	3	0.969
39	4.667	4	4	4	3.333	3.333	3	3	4	4.333	4	4	5	5	5	5	4	4.333	4	4	5	5	5	5	0.856
40	5	5	5	5	1.333	1.333	1	1	1.333	1.667	1	1	3.333	3.333	3	3	5	5	5	5	3	3	3.333	3	0.969
41	4.333	4	4.333	4	2.333	2	2	2	5	5	5	5	3	3.333	3.667	3	4.333	4	4	4	4.667	4.333	4	4	0.901
42	2.333	2.333	2.333	2	1.667	1	1	1	1	1	1.667	1	2	2.333	2	2	5	5	5	5	2.333	2	2.333	2	0.945
43	2.333	2.333	2	2	3.667	3	3.333	3	3.333	3	3.333	3	3.333	3	3.667	3	2.333	2.333	2	2	3	3	3.333	3	0.652
44	2.333	2	2.333	2	2.667	2.333	2	2	3.333	3.333	3	3	3.333	3.333	3.333	3	3	3	3.333	3	2	2	2.333	2	0.686
45	3.333	3	3	3	4	4.333	4.333	4	2	2	2.333	2	2.333	2	2.333	2	2.333	2	2	2	4.333	4.333	4	4	0.904

Table 3. *Cont.*

Location	Historical Value				Accessibility				Convenience				Diversity				Natural Harmony				Population Density				ICC
	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	A	B	C	Final	
46	5	5	5	5	2.333	2	2.333	2	2.333	2	2.333	2	2.333	2.333	2	2	4	4.333	4	4	2	2	2.333	2	0.942
47	3	3.333	3	3	3.333	3.333	3.333	3	2.333	2.333	2	2	2.333	2.333	2.333	2	3.333	3.333	3.333	3	2	2	2.333	2	0.692
48	2	2.667	2	2	3.333	3	3.667	3	2.333	2	2	2	2.333	2.333	2	2	3.333	3.333	3.333	3	3	3.667	3.333	3	0.715
49	3.333	3.333	3.333	3	5	5	5	5	4.333	4.333	4.333	4	3.333	3	3	3	3.333	3	3.333	3	5	5	5	5	0.89
50	3.333	3.333	3.333	3	5	5	5	5	4.333	4.333	4.333	4	2.333	2	2.333	2	3	3	3.333	3	4.333	4	4	4	0.899
51	1.333	1.333	1.333	1	5	5	5	5	4.333	4.333	4	4	4	4.333	4.333	4	1	1.333	1.333	1	4	4	4.333	4	0.96
52	4.667	4	4.333	4	3	3.333	3	3	3.333	3	3.333	3	5	5	5	5	3.333	3.333	3.333	3	3	3.333	3	3	0.849
53	1	1.333	1	1	3	3.333	3.667	3	1.333	1	1	1	1	1.333	1.333	1	1	1.333	1.333	1	3	3.333	3.667	3	0.903
54	1.333	1.333	1.333	1	5	5	5	5	5	5	5	5	4.333	4	4.667	4	1.333	1	1.333	1	4.667	4	4.333	4	0.966
55	2	2.333	2.333	2	5	5	5	5	4.667	4	4	4	4.333	4	4	4	1.333	1	1	1	3.333	3	3.667	3	0.953
56	4	4.333	4	4	2.333	2	2	2	3.333	3.333	3	3	2	2.333	2	2	3	3	3.333	3	2	2.333	2.667	2	0.853
57	1.333	1.333	1.333	1	3.333	3	3.667	3	4	4.333	4	4	2.333	2.333	2	2	1	1.333	1.333	1	1	1	1.333	1	0.921
58	3	3	3.333	3	1.667	1	1.333	1	1.333	1.333	1.333	1	2	2.333	2	2	4.333	4.333	4.333	4	3	3.333	3	3	0.914
59	3	3.333	3.333	3	2.333	2.333	2	2	2	2.333	2.333	2	2.333	2	2.333	2	4	4.333	4	4	3	3.333	3.333	3	0.821
60	4.333	4	4.333	4	1.667	1	1.333	1	1	1.333	1	1	2	2.333	2.333	2	5	5	5	5	2.333	2	2.667	2	0.954
61	4	4.333	4	4	1.333	1.333	1.333	1	1.333	1.333	1.333	1	2.333	2.333	2	2	5	5	5	5	3.333	3.333	3.333	3	0.948
62	4	4.333	4.667	4	1	1.333	1.333	1	1	1.333	1.333	1	2	2	2.667	2	5	5	5	5	2	2.333	2.333	2	0.954
63	4.667	4	4.333	4	1.333	1.333	1.333	1	1.333	1	1.333	1	2.667	2	2.333	2	5	5	5	5	3.333	3	3	3	0.95
64	3	3.333	3	3	1	1.333	1	1	1.333	1.333	1.333	1	2.667	2.333	2	2	5	5	5	5	2.333	2	2	2	0.953
65	1	1.667	1.333	1	3.333	3	3.667	3	1	1.333	1	1	2.333	2.333	2.333	2	5	5	5	5	1.333	1.333	1.333	1	0.946
66	2.333	2	2	2	2	2.667	2.333	2	2	2	2.667	2	2	2	2.333	2	5	5	5	5	1	1.667	1	1	0.941
67	5	5	5	5	4.333	4	4.333	4	1.333	1.333	1.333	1	3.333	3.333	3.333	3	3	3	3.333	3	3	3.333	3.667	3	0.923
68	4	4	4.333	4	1.333	1.333	1.333	1	3.333	3.667	3	3	3.667	3	3	3	5	5	5	5	2.667	2.333	2	2	0.929
69	5	5	5	5	1.333	1.333	1	1	2.667	2.333	2	2	2	2.333	2	2	5	5	5	5	2.667	2	2	2	0.967
70	5	5	5	5	1	1	1.333	1	2.667	2	2.333	2	3.333	3.333	3	3	5	5	5	5	2.333	2	2	2	0.97
71	5	5	5	5	1	1.333	1	1	2.333	2.333	2	2	2.333	2	2.333	2	5	5	5	5	2.333	2.667	2	2	0.967
72	5	5	5	5	1	1.333	1	1	3	3.333	3	3	2	2	2.667	2	5	5	5	5	2.333	2.333	2	2	0.972
73	5	5	5	5	1.333	1	1	1	2.333	2	2	2	2.333	2.333	2	2	5	5	5	5	2.333	2.333	2.333	2	0.971
74	5	5	5	5	1.333	1	1.333	1	2	2.333	2.333	2	2	2.333	2	2	5	5	5	5	1	1.333	1	1	0.978
75	5	5	5	5	1	1.333	1.333	1	2	2	2.667	2	3	3.333	3	3	5	5	5	5	2	2	2.333	2	0.972
76	5	5	5	5	1.333	1.333	1	1	2	2	2.667	2	2.667	2.333	2	2	5	5	5	5	2	2.667	2.333	2	0.96
77	5	5	5	5	1.667	1	1	1	1	1.333	1	1	3	3.333	3	3	5	5	5	5	1.333	1.333	1	1	0.98
78	5	5	5	5	1.667	1	1	1	3	3.333	3	3	3.667	3	3	3	5	5	5	5	1.333	1.333	1	1	0.972
79	4	4	4.333	4	3	3.667	3.333	3	3.333	3	3	3	4.333	4	4.333	4	4.333	4.333	4	4	3	3.333	3.667	3	0.649

Table 4. Results of k-means clustering for sense-of-place data.

Cluster	Locations	Historical Value	Accessibility	Convenience	Diversity	Natural Harmony	Population Density
Trekking-1	40	4.225	1.475	1.575	2.6	4.275	2.4
Trekking-2	18	1.833	2.889	1.778	1.889	2.389	1.611
Trekking-3	21	3.238	3.952	3.905	3.857	2.524	3.762

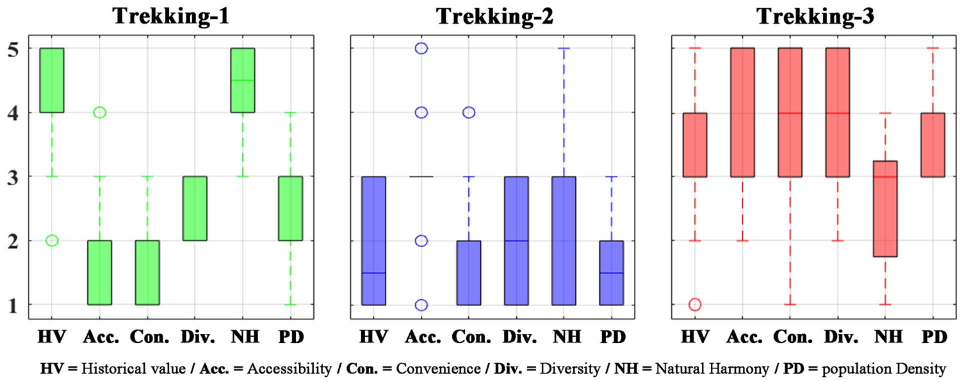


Figure 4. Sense-of-place characteristic distributions for each cluster.

3.1.3. Event for Selecting Geospatial Routes

To generate events that take into account the geographical environment, geographical data were integrated into the clustering process, with weights reflecting distances according to the sense-of-place [33,56]. Location data were extracted by adding the x- and y-coordinates to the Hanyangdoseong map. Taking account of the data complexity and the flexibility of the elbow method, we set the number of clusters to six [57]. Custom scripts utilizing statistical functions supported by the Statistics and Machine Learning Toolbox were employed throughout this process to analyze spatial patterns and optimize clustering.

Weights were applied to define geospatial boundaries and prevent cluster overlap [58,59]. This approach can reduce navigation confusion and provide a clear exploration experience. As shown in Figure 5a,b, with a weighting of 1, the clusters were irregular, whereas a weighting of 3 resulted in more regular shapes but some overlap. The weighting of 8 (Figure 5c) produced the most organized and clearly separated clusters and was used further.

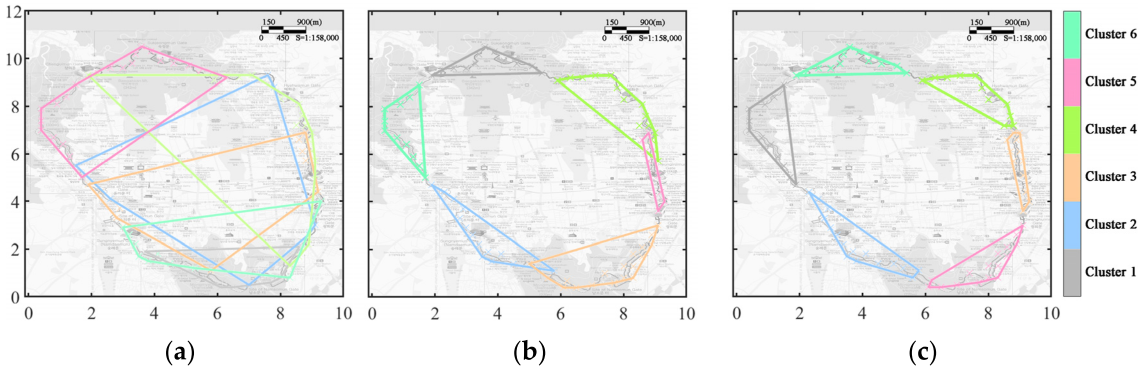


Figure 5. Cluster boundaries based on geographic data weighting. (**a**) With weight = 1. (**b**) With weight = 3. (**c**) With weight = 8.

The analysis classified each site into six clusters (Table 5). The clusters were differentiated by their geospatial traits and were distinct from the initial trekking routes. Clusters 1 and 6 resembled Trekking-1, whereas Clusters 2 and 4 were similar to Trekking-1 and

Trekking-3, with some overlap in other segments. Clusters 3 and 5 were distributed across the remaining segments, excluding Trekking-2 or Trekking-3. These geospatial clusters enable users to experience courses based on the terrain, enhancing realism and increasing the desire to visit the site.

Table 5. Results of k-means clustering for geospatially weighted data.

Cluster	Locations	Trekking-1	Trekking-2	Trekking-3
1	12	8	3	1
2	16	3	4	9
3	12	4	0	8
4	11	5	3	3
5	16	8	8	0
6	12	12	0	0

3.1.4. Sticker Mapping for the Extraction of Branch Nodes

Sticker mapping [37] was conducted to visually identify user preferences and aversions, with the goal of deriving scenario branch nodes. This method allowed for an analysis of how users reacted to specific spaces along the Hanyangdoseong route.

The survey included both experienced and new visitors to gather data from a variety of perspectives. The sample size of 20 was chosen to balance feasibility with the need to gather representative input (Table 6).

Table 6. Demographic Information of Sticker Mapping Survey Participants.

<table>
<tr><td rowspan="2">Gender</td><td colspan="2">Male</td><td colspan="2">Female</td></tr>
<tr><td colspan="2">10</td><td colspan="2">10</td></tr>
<tr><td rowspan="2">Age Group</td><td>19–29</td><td>30–45</td><td>46–62</td><td>63+</td></tr>
<tr><td>12</td><td>4</td><td>3</td><td>1</td></tr>
<tr><td rowspan="2">Visit Frequency</td><td>1–3</td><td>4–10</td><td>11–20</td><td>21+</td></tr>
<tr><td>11</td><td>4</td><td>3</td><td>2</td></tr>
<tr><td rowspan="2">Full Course Visit</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="2">6</td><td colspan="2">14</td></tr>
</table>

The participants, including ten men and ten women, placed stickers on a map in response to seven questions across three categories—basic, placed stickers on a map in response to seven questions across three categories—basic, positive, and negative aspects (Table 7). Multiple locations could be marked for each question (Figure 6).

Table 7. Sticker mapping questions and guidelines.

<table>
<tr><th>Category</th><th>Target</th><th>Sticker Shape</th><th>Instruction</th></tr>
<tr><td rowspan="3">Basic</td><td>Entry point</td><td>Green star</td><td>Place green star stickers in areas you consider entrances to Hanyangdoseong.</td></tr>
<tr><td>Arrival point</td><td>Red star</td><td>Place red star stickers in areas where you feel you have “arrived”.</td></tr>
<tr><td>Scenery</td><td>Green arrow</td><td>Place green arrow stickers to indicate pleasant scenery.</td></tr>
<tr><td rowspan="2">Positive</td><td>Favorite place</td><td>Red heart</td><td>Place red heart stickers in favorite places.</td></tr>
<tr><td>Attractive path</td><td>Red circle</td><td>Place red circle stickers on paths you find attractive.</td></tr>
<tr><td rowspan="2">Negative</td><td>Disliked place</td><td>Blue heart</td><td>Place blue heart stickers in places you prefer less or dislike.</td></tr>
<tr><td>Boring path</td><td>Blue circle</td><td>Place blue circle stickers on paths where you felt bored.</td></tr>
</table>

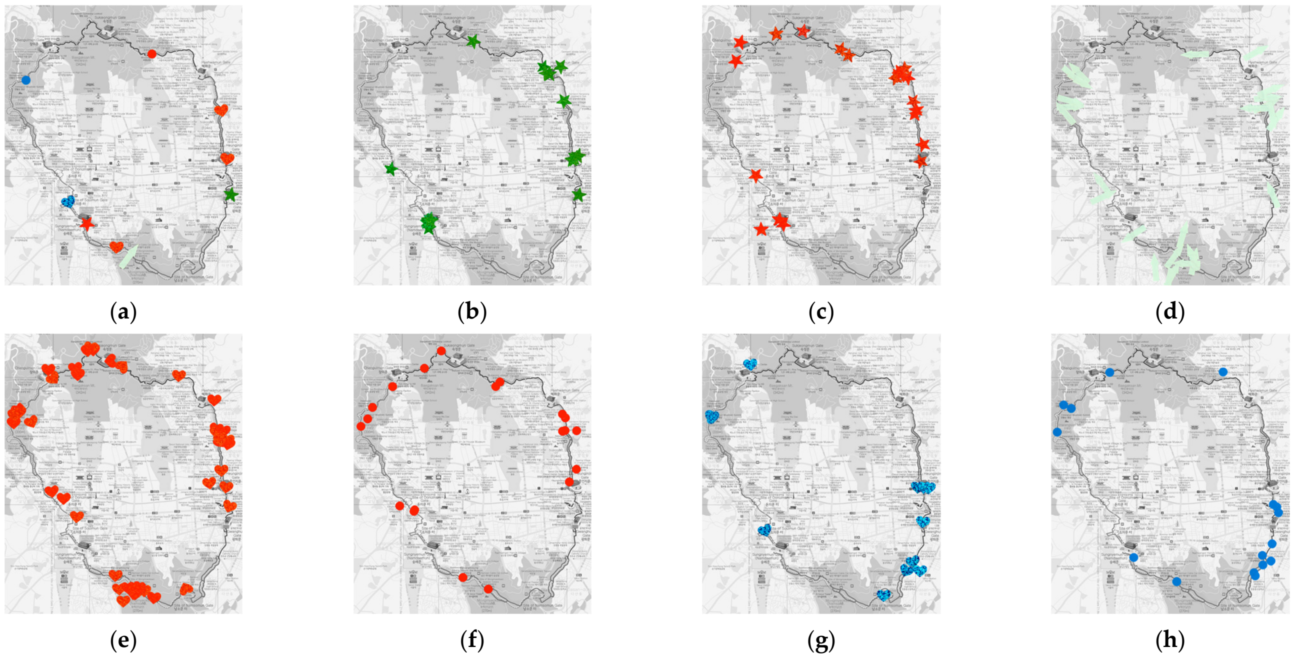


Figure 6. Survey example and sticker mapping results. (**a**) Example survey. (**b**) Entry point. (**c**) Arrival point. (**d**) Scenery. (**e**) Favorite place. (**f**) Attractive path. (**g**) Disliked place. (**h**) Boring path.

The data were organized by location, resulting in 21 branch nodes. Figure 7a shows the sticker counts and rankings, which represent the total number of stickers placed by participants at each location, and the rankings are based on user preferences. Figure 7b visually presents the preference mapping, highlighting the distribution of preferences along the Hanyangdoseong route. Preferences were ranked using the frequency interval method, and the corresponding sections of each trekking cluster were marked. The branch nodes are located along the Hanyangdoseong route, although some are in spaces not directly related to Hanyangdoseong. These points were interpreted as critical intersections where preferences and aversions overlap, a phenomenon that can be explained by the concepts of place attachment and place aversion [60]. That is, some individuals feel a positive attachment to certain spaces, whereas others feel negative and tend to avoid them.

The branch nodes identified here can be used as foundational data for route design, user experience planning, and event placement in future SL scenarios to maximize user immersion.

3.2. *Implementation of Storyliving Virtual Reality*

The implementation of SL requires an approach that is different from traditional VR. This section explains how the data and scenario elements from Section 3.1 are integrated into the VR environment.

3.2.1. Scenario Design

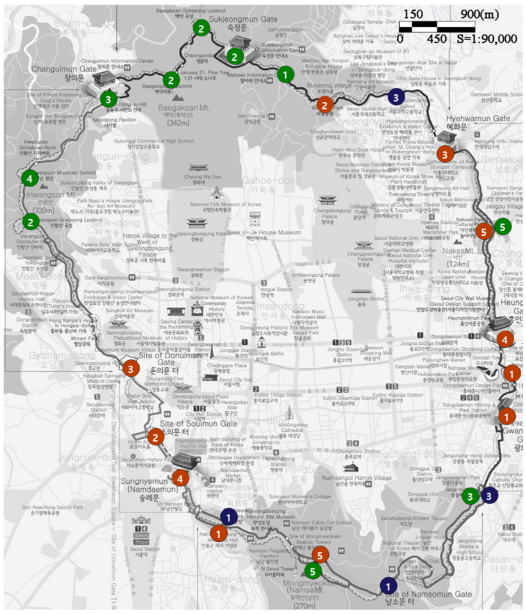
To offer choices to users, we designed the scenario with multiple nodes and types of trekking and geospatial routes (Figure 8).

The node types include start, branch, event, and end nodes. In the start node, users watch an introductory video about Hanyangdoseong's history and choose an entrance. Branch nodes, set at 21 high-preference locations, allow users to change routes or experience events.

In the event nodes, users choose a preferred node from three trekking routes to experience a particular sense-of-place. Background music (BGM) suitable for each section enhances the experience, including rustling leaves for nature, slow piano music for relaxation, and light car noises for urban areas. After selecting a trekking route, users can further immerse themselves by choosing geospatial routes that align with the actual terrain, providing a more realistic exploration.

Ranking	Location	Total	Preference	Clusters
1	Naksan Park	24	5	1, 2
2	Namsan	20	5	1, 2
3	Inwangsan Peak	16	4	1
4	Sungnyemun	14	4	2
5	Heunginjimun	14	4	2
6	Hyehwamun	11	3	2
7	Jangchung Gymnasium	9	3	1, 3
8	Site of Donuimun	7	3	2
9	Changuimun	7	3	2
10	Baekakgokseong	5	2	1
11	Waryong Park	5	2	2
12	Baekak Maru	4	2	1
13	Site of Soeuiumun	4	2	2
14	Sukjeongmun	4	2	2
15	Inwangsan Gokseong	4	2	1
16	Gwanghuimun	3	1	1
17	Dongdaemun Design Plaza	3	1	2
18	Site of Namsomun	2	1	1
19	Seoul Science High School	2	1	1
20	Hanyangdoseong Museum	2	1	2, 3
21	Malbawi Information Center	2	1	1

(**a**)



(**b**)

Figure 7. Preference mapping based on sticker counts. (**a**) Sticker counts and rankings. (**b**) Preference mapping.

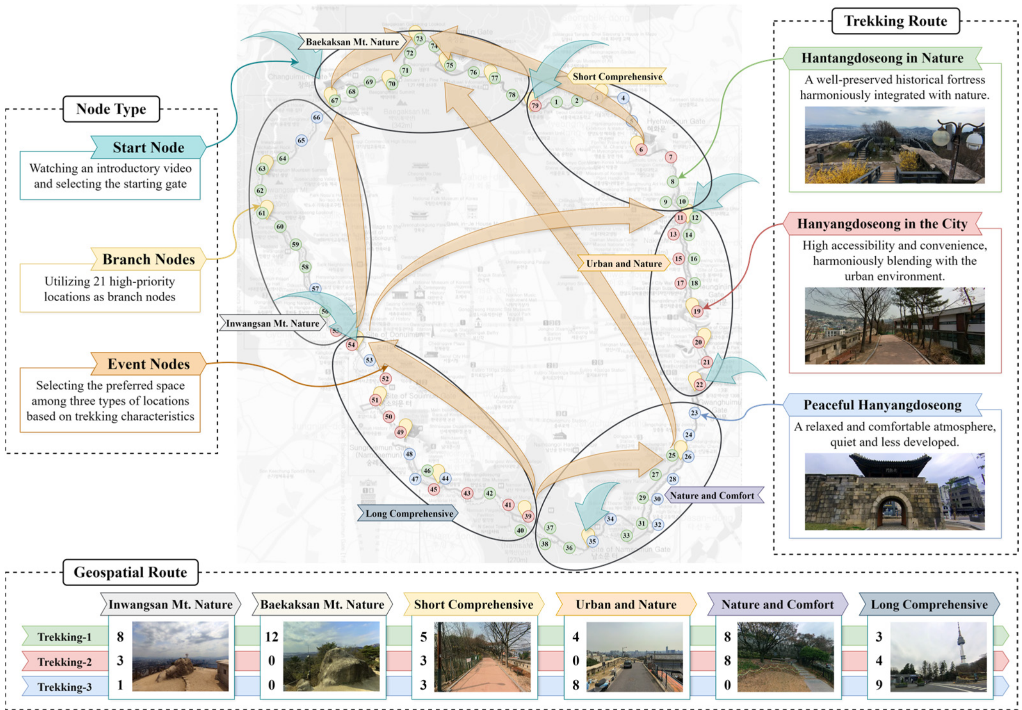


Figure 8. Scenario design based on node types.

In the end node, users encounter four different endings after having explored all the locations of the same type or visited all locations along Hanyangdoseong.

The timing of a selection event in a VR environment is implemented through three mechanisms (Table 8). First, users are offered a choice at each branch node, allowing them to select the next path or experience events. Second, users can move to different routes at any point, enabling free exploration. Third, when users traverse the same type of route more than four times, new choices are presented to avoid repetition and encourage diverse experiences.

Table 8. Mechanisms of selection events.

Mechanism	Description	Effect
Arrival at branch node	Provides various options on reaching a branch node	Allows for the selection of the next path or the experience of specific events
Free movement	Offers the option to move to a different choice at any time	Enables free exploration and progression of the story in the desired direction
Prevent repeated movement	Provides new options after moving through the same type of space more than four times	Prevents repetitive movement and encourages diverse experiences

This scenario design offers a nonlinear exploration in which user choices at branch nodes influence routes and events, leading to multiple possible endings. Users can immerse themselves deeply in Hanyangdoseong, enjoying particular experiences based on their decisions.

3.2.2. System Configuration

Technical implementation involved multiple data collection and processing steps, organized into the pipeline shown in Figure 9. Two-dimensional panoramas and images were captured using an Insta 360 One X2 (manufactured by Insta360, Los Angeles, CA, USA) and a digital camera, with BGM sourced from Pixabay. The assets were processed using Insta 360 Studio, Adobe Photoshop (Version 25.9), and a sound editor.

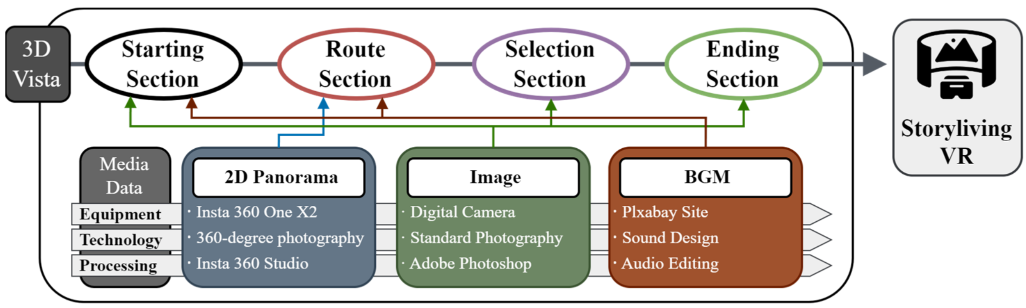


Figure 9. Storyliving virtual reality implementation pipeline.

The pipeline was simplified to essential data within the 3D Vista VR tool for HMD VR implementation. Excessive data provision was avoided to prevent user discomfort. Our approach lays the foundation for the implementation of SL VR, allowing users to explore Hanyangdoseong more vividly.

3.2.3. User Interface Design

The user interface (Figure 10) is designed in stages to enable users to explore Hanyangdoseong and experience historical and cultural spaces. Navigation within the system is conducted through handheld controller clicks.

This design accommodates the vast expanse of Hanyangdoseong, allowing users to explore and transition between locations efficiently. It also supports frequent scene transitions, which are integral to the storyliving structure, while helping to reduce the risk of cybersickness [24,25]. The process is divided into starting, route, selection and repetition, and ending sections.

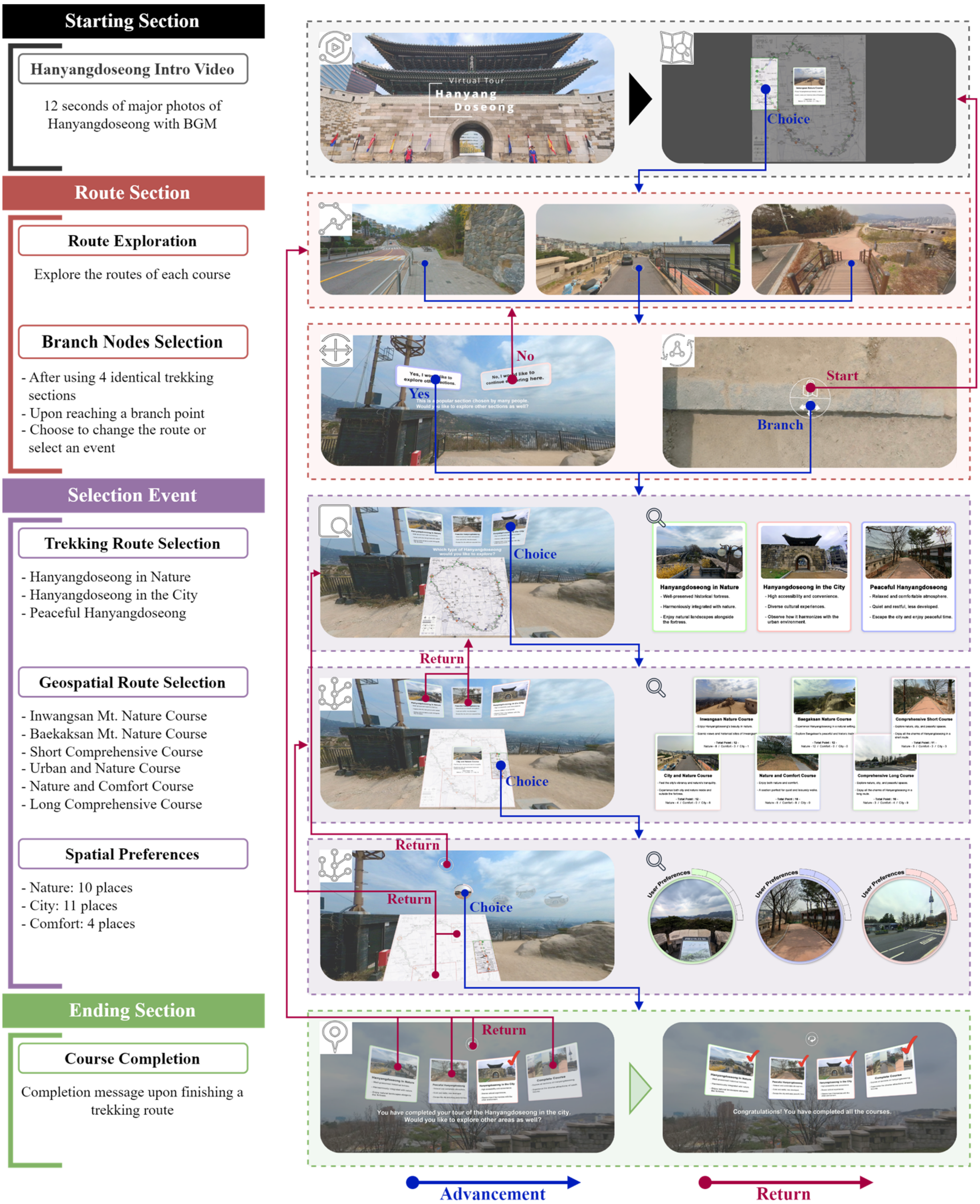


Figure 10. Nonlinear configuration of the user interface.

In the starting section, users watch an introductory video showing Hanyangdoseong's key spaces to enhance immersion. Then, the map of Hanyangdoseong is displayed, and the users select one of six courses to begin.

In the route section, users explore the 79 locations along Hanyangdoseong. When they reach a branch point or repeatedly traverse the same section, route change or event options are provided. The free movement feature allows users to return to the starting point or select another course at any time.

In the selection and repetition section, users listen to the descriptions of each trekking route and choose an option: Hanyangdoseong in Nature, Hanyangdoseong in City, or Peaceful Hanyangdoseong. They then explore preferred locations distinguished by terrain and enjoy the unique experiences at each site.

In the ending section, the completion of at least one trekking route triggers a completion message and a checkmark for that course. When all courses are completed, a final message is displayed, indicating that the user has thoroughly explored all the locations of Hanyangdoseong and gained a deep understanding. The system configuration provides features that allow users to move to different locations or return to previous ones at each stage, enabling an immersive, nonlinear exploration experience.

Unlike conventional VR systems, which often focus on providing linear, visually-driven simulations with predetermined viewing points, this storyliving approach offers users the freedom to explore multiple pathways. By making meaningful choices throughout their journey, users can foster deeper engagement and develop a more personal understanding of Hanyangdoseong.

3.3. Storyliving Verification

We conducted self-validation for an initial verification of the VR system, focusing on the identification of cognitive and situational immersion factors. The feedback and results from this initial analysis provided foundational data for system enhancement. The initial validation was conducted solely by the VR researcher who developed the system, using the Meta Quest 3 headset to ensure reliable testing.

Each factor was analyzed based on Csikszentmihalyi's flow theory, which describes the psychological states users experience when deeply engaged in an activity. This theory is crucial for assessing immersion levels [40,41]. This methodology has been applied to evaluate whether science museum mixed reality exhibitions foster visitor immersion [42] and was used here to validate the SL VR system with HMD devices.

The cognitive immersion factors were Clear Goals, Logical Process, Exploratory Structure, Story Structure, and Tactile Interface (Table 9). These factors emphasize environments in which users set clear goals and immerse themselves through logical problem-solving [40,41]. Gardner's multiple intelligences theory, which addresses users' diverse intellectual approaches, was applied to comprehensively evaluate problem-solving interactions in the VR environment [42,61]. For example, the Verbal Approach assessed linguistic problem-solving interactions, whereas the Logical Approach evaluated logical thinking interactions, effectively measuring cognitive immersion.

The situational immersion factors were Physical Engagement, Immediate Feedback, Interactive Communication, Content Manipulation, and Challenging Tasks. These factors promote active participation in the VR environment and enable users to experience immediate responses [40,41]. We used Steiner's 12 senses theory to provide a framework to evaluate users' responses to external stimuli, which is crucial for analyzing sensory immersion in the VR environment [62,63]. For example, Sight Sense was used to evaluate visual immersion, whereas Hearing Sense was used to assess auditory immersion.

The analytical method involved verifying whether each factor met established criteria, then scoring according to Gardner's multiple intelligences theory, with one point awarded for each element, for a maximum score of 5. For the sensory evaluation, 0.5 points were added per sense. This method was used to assess each immersion factor's impact on the user's overall immersive experience.

Table 9. Analytical criteria for cognitive and situational immersion.

Category for Cognitive Immersion	Criteria Drawing on Multiple Intelligence Theory
Clear Goals Clearly set goals that users can achieve. **Logical Process** Provide a process whereby users can logically solve problems. **Exploratory Structure** Support users to explore and find information. **Story Structure** Provide a consistent storyline. **Tactile Interface** Provide an interface that users can physically manipulate.	**Verbal Approach (VA)** Solving problems through dialogue or narration. **Logical Approach(LA)** Solving logical puzzles or problems. **Quantitative Approach (QA)** Solving problems with figures and numbers. **Fundamental Approach (FA)** Addressing fundamental questions and philosophical approaches to phenomena. **Aesthetic Approach (AA)** Addressing sensory and aesthetic factors through visual and auditory elements. **Experiential Approach (EA)** Directly experiencing and interacting with situations. **Collaborative Approach (CA)** Solving problems through cooperation and discussion among users.
Category Based on Situational Immersion	**Analytical Criteria Based on External Stimuli Senses**
Physical Engagement Support users to actively participate in the VR environment through their physical senses and movement. **Immediate Feedback** Provide users with real-time responses to their inputs, enhancing immediacy and engagement. **Interactive Communication** Facilitate user interaction and communication through responsive dialogues and actions. **Content Manipulation** Allow users to control and modify content, enhancing their sense of agency. **Challenging Tasks** Engage users with interesting and challenging tasks through problem-solving, encouraging deeper immersion and sustained focus.	**Sight Sense (SS)** Quality of graphics, vibrancy of colors, and visual immersion. **Hearing Sense (HS)** Audio quality, accuracy of spatial sound, and immersion. **Taste Sense (TS)** Taste reproduction technology and satisfaction. **Touch Sense (Tcs)** Realism of the tactile interface and appropriateness of feedback. **Smell Sense (SmS)** Smell reproduction technology. **Temperature Sense (TpS)** Reproduction of temperature and realism of perceived temperature. **Vitality Sense (VS)** User perception of physical state and fatigue. **Movement Sense (MS)** Sense of natural movement and interaction in the environment. **Balance Sense (BS)** Realism and accuracy of balance and spatial awareness. **Language Sense (LS)** Accuracy and naturalness of dialogue and voice recognition. **Reasoning Sense (RS)** Realism of story progression and character reasoning. **Self-awareness Sense (SaS)** Impact of user-character interaction on self-awareness.

4. Results

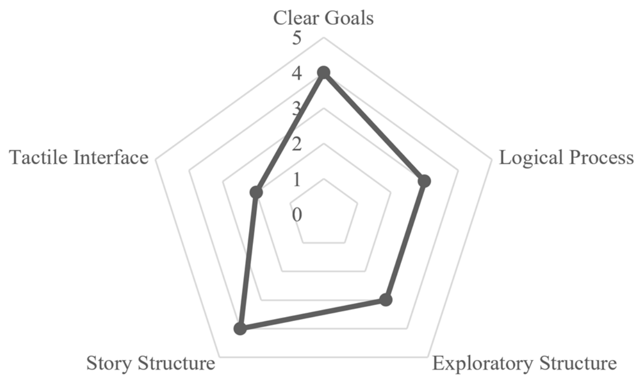
Insights into the effectiveness of the SL VR system were obtained through the analysis of the cognitive and situational immersion factors (Table 10).

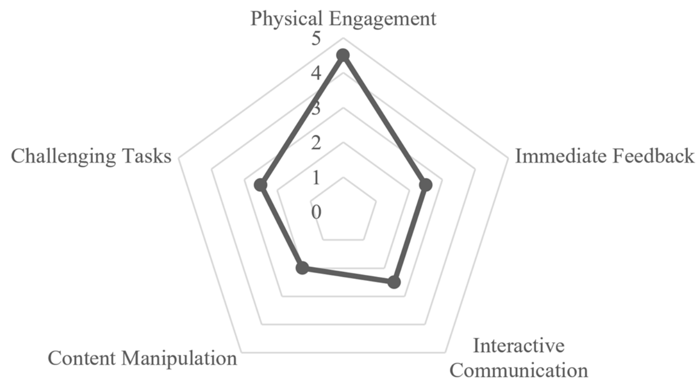
For cognitive immersion, Clear Goals and Story Structure had high scores, showing that users could set objectives at each exploration point. Clarity in setting goals facilitates deep engagement with the content and encourages logical thinking and collaboration; these factors can contribute to a better understanding of the historical and cultural significance of Hanyangdoseong. The nonlinear narrative structure was effective in maintaining the narrative flow and providing users with personalized experiences. The branching structure enabled users to follow various paths logically connected to the overarching story, which can deepen their narrative immersion.

Table 10. Analysis results for cognitive and situational immersion.

Cognitive Immersion		
Category	**Analysis**	**Results**
Clear Goals	VA	Introduce the significance of Hanyangdoseong.
	LA	Induce logical thinking through trekking route selection.
	EA	Present goals for exploration through trekking route selection.
	CA	Encourage collaboration among parties to achieve overall goals.
Logical Process	LA	Transfer historical and cultural information through route exploration.
	QA	Support accurate data collection during exploration.
	EA	Provide direct experiences during exploration of the routes.
Exploratory Structure	VA	Support user understanding by explaining exploratory activities.
	LA	Induce logical deduction and analysis through exploratory activities.
	EA	Provide exploratory activities at various points.
Story Structure	VA	Provide narrative structure in a nonlinear format.
	QA	Manage information accurately during story progression.
	AA	Provide visual and auditory experiences during the story.
	EA	Provide various stories based on user choices.
Tactile Interface	AA	Provide sensory experiences through interface manipulation.
	EA	Allow physical manipulation of the interface through VR experiences.
Immersion Level (1 point per element)		

Situational Immersion		
Category	**Analysis**	**Results**
Physical Engagement	SS	View of VR surroundings
	HS	Trekking-based BGM
	Tcs	Experience of unfolding a map
	VS	Feeling of vitality during experience
	MS	Movement recognition
	BS	Sense of balance
	LS	Understanding and use of language
	RS	Problem-solving and deduction
	SaS	Self-recognition
Immediate Feedback	SS	Immediate visual feedback
	HS	Sound feedback based on location
	MS	Immediate movement feedback
	BS	Balance feedback
	RS	Problem-solving feedback
Interactive Communication	SS	Visual feedback during interactions
	HS	Sound interaction
	MS	Gesture interaction
	LS	Text interaction
	RS	Problem-solving during conversation
Content Manipulation	SS	Visual confirmation of content changes
	HS	Manipulation based sound
	MS	Manipulation based movement
	RS	Manipulation based problem-solving
Challenging Tasks	SS	Visual presentation of tasks
	HS	Explanations and instructions for tasks
	MS	Physical movement recognition during task completion
	BS	Balance during task completion
	RS	Problem-solving and deduction during task completion
Immersion Level (0.5 points per element)		





Tactile Interface had low scores because of interface simplification, which aimed to minimize VR sickness but limited the degree of physical interaction. Although basic operations could be performed readily, the lack of more complex physical interactions is a barrier to achieving deeper cognitive immersion.

Among the situational immersion factors, Physical Engagement had high scores, indicating that users could actively engage with the VR environment to experience a strong sense of realism, which contributes to immersion. The system's effectiveness in recognizing user movements and providing a realistic sense of balance enhanced the immersive experience.

Content Manipulation had lower scores, suggesting challenges in the manipulation of content because of nonintuitive controls or a less user-friendly interface. These results identify areas needing improvement to enhance user experience and overall immersion.

The Immediate Feedback mechanisms, which included visual, auditory, and movement-based responses, were less effective. The moderate score showed that users did not consistently perceive immediate responses to their actions, indicating that although some feedback elements were effective, others did not adequately reinforce a sense of presence in the virtual environment.

An examination of the overall immersion levels (see radar charts in Table 9) shows that cognitive immersion had excellent outcomes, particularly in the areas of Clear Goals and Story Structure, which are crucial for engaging users in the narrative and helping them understand the progression of the story. Slightly lower overall scores were obtained for situational immersion, primarily because of lower scores in Content Manipulation and Immediate Feedback.

The results suggest that although the system is effective in providing a realistic and interactive environment, it faces challenges in the areas of user interface design and feedback mechanisms, which are critical for maintaining situational immersion.

5. Discussion

The development and evaluation of the SL VR system provided valuable insights into approaches to balancing cognitive and situational immersion within a nonlinear narrative framework. We hypothesized that a well-structured branching narrative would effectively engage users and offer a rich educational experience, particularly in the context of cultural heritage. This hypothesis was supported by the high levels of cognitive immersion obtained, especially in the areas of Clear Goals and Story Structure. Our findings indicate that users could navigate the content with a clear sense of direction and establish a personal connection with the narrative through their choices, thereby deepening their engagement with and understanding of the historical context of Hanyangdoseong.

However, we identified several areas in need of further development. The lower scores for Tactile Interface and Content Manipulation indicate that whereas the simplification of the controls helped reduce VR sickness, it may have inadvertently limited the system's capacity for immersive physical interaction. This limitation emphasizes a common challenge in VR development—balancing user comfort with the depth of interaction. The findings suggest that future iterations of the SL VR system should explore more nuanced control schemes that enhance physical engagement without sacrificing user convenience.

A comparison of the cognitive and situational immersion results reveals an intriguing disparity; although users were highly engaged cognitively, their situational immersion was lower because of limitations in physical interaction and feedback responsiveness. This discrepancy emphasizes the need for a holistic approach to VR system design, in which narrative engagement and physical interaction receive equal attention.

In conclusion, although the SL VR system shows promise for the use of nonlinear narratives to enhance cognitive immersion, the achievement of a more balanced immersive experience will require further advancements in the physical interaction and feedback systems. The findings provide guidance for future improvements to create a more integrated immersive tool for cultural heritage education.

6. Conclusions

This study aimed to develop an SL VR system to enhance the understanding of cultural heritage by providing users with personalized, immersive experiences. We used an SL scenario design process to construct scenarios by clustering quantitative data based on the sense-of-place characteristics of Hanyangdoseong. By employing k-means clustering and sticker mapping techniques, we segmented trekking and terrain sections to design scenarios that maximize user immersion.

The quantitative data clustering method used in this study has the advantage of allowing the construction of scenarios based on objective and quantitative data. This stands in contrast to older approaches using interviews with urban experts or literature reviews. Our design approach allowed for the objective development of highly immersive content for a range of user groups. Further, our data-driven approach provides universality, enabling the application of the same methodology to other cultural heritage sites or types of VR content.

This study provides fundamental data for the digital transformation and educational use of cultural heritage through a valuable case study involving the development of VR content based on nonlinear narratives. Our approach can be expected to increase the appeal of cultural heritage and provide users with immersive experiences. This research makes important contributions to studies and practices related to digital heritage, especially through the provision of methodologies for enhancing immersive experiences in VR environments.

One limitation of the current study is the lack of comprehensive user evaluations, as assessments were primarily conducted by the research designers, potentially limiting the diversity of perspectives on usability and effectiveness. To overcome this limitation, future research will include in-depth validation with a more diverse range of user groups, focusing on balancing user convenience with active participation while maintaining immersion in the storyliving experience. Additionally, user surveys and electroencephalography analyses will be employed to optimize the system's usability and satisfaction, providing objective and subjective data to meet the needs of diverse audiences better.

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