# A Procedural Content Generation for Conveying Historical Context of Digital Heritage Content: A Case Study of *Bongsudang Jinchan-do*

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**Keywords:** Procedural Content Generation (PCG), Digital Heritage, User Experience, Historical Interpretation, Emergent Narrative.

## Abstract

Procedural content generation (PCG) is widely utilized in digital recreation of large-scale historical sites and architectures. However, few studies examine how effectively such environments convey historical context. This study explores how PCG-generated digital heritage environments influence users' interpretation of history. While archaeogaming research demonstrates that anachronistic elements can foster emergent narratives, such approaches may pose risks of historical distortion in authenticity-requiring contexts. To address the balance between historical accuracy and user experience, this study proposes a heritage procedural content generation (HPCG) framework integrating (1) a database of historically verified items, (2) a time-period-based placement algorithm, and (3) a context-driven interaction system. The framework is applied to recreate the late-Joseon Dynasty court painting *Bongsudang Jinchan-do* in a 3D environment. An experiment with 30 participants in three groups is conducted: Group A experiences a fixed historically accurate environment, Group B experiences a historically accurate PCG environment, and Group C explores a PCG environment with deliberately anachronistic items. Results reveal that historically accurate PCG environments effectively balance authentic historical representation with enhanced user engagement. While PCG significantly improves immersion across experimental groups, only historically accurate PCG maintains educational integrity comparable to fixed environments, with anachronistic elements substantially diminishing users' historical comprehension and narrative coherence despite increased exploratory motivation.

This Study demonstrates that carefully designed PCG environments can effectively balance historical fidelity and user experience, offering a methodological foundation for digital heritage applications.

## 1. Introduction

The advancement of digital technologies has fundamentally transformed the preservation and transmission of cultural heritage. Immersive content technologies have been increasingly adopted in museums, exhibition spaces, and educational settings, enabling users to experience and interpret cultural heritage in more engaging and interactive ways. Beyond mere documentation, such technologies now serve as mediators of interpretation and experience. Within this context, procedural content generation (PCG) has gained attention as an efficient method for digitally recreating large-scale historical environments by reducing production time and cost (Lercari, 2017).

PCG enables the automated generation of lifelike environments across various media platforms such as games, virtual reality (VR), and augmented reality (AR), enhancing immersion and interactivity (Champion, 2016). In the game industry, PCG plays a central role in dynamically constructing content that reflects diverse variables and user interactions. This capability is highly applicable to digital heritage environments, where users actively explore and interpret cultural spaces.

However, the application of PCG to digital heritage requires careful consideration. Users are not passive recipients of visual information, but active agents who interact with and reinterpret their surroundings (Mortara et al., 2014). If the generated content deviates from historical accuracy, it may lead to misinterpretation based on distorted representations. Prior research has largely focused on the technical implementation of PCG or user immersion, often overlooking the accuracy with which historical context is conveyed (Copplestone & Dunne, 2017).

Emergent narratives in PCG environments—where the storyline unfolds through user exploration—can enhance narrative engagement. Yet, in historically grounded digital heritage content, such freedom may introduce inappropriate variations or anachronistic elements, undermining the integrity of historical interpretation. Therefore, PCG in digital heritage must be guided by a design framework that simultaneously considers historical accuracy and interpretative coherence.

To this end, this study proposes a novel heritage procedural content generation (HPCG) framework. The HPCG framework consists of three core components: (1) a database of historically verified items, (2) a temporal-context-aware placement algorithm, and (3) an interaction system that facilitates context-driven narrative emergence. As a proof of concept, the framework is applied to develop a 3D digital environment based on the late Joseon Dynasty court painting *Bongsudang Jinchan-do*, and an experiment is conducted under three different conditions to evaluate user interpretation, immersion, and learning outcomes.

This paper is structured as follows: Section 2 reviews related studies on digital heritage, PCG technologies, and archaeogaming-based narrative formation. Section 3 describes the structure and implementation of the HPCG framework. Section 4 presents the experimental design and analysis, while Section 5 concludes with key findings, limitations, and suggestions for future research.

## 2. Related Works

### 2.1 Previous Research on Digital Heritage and Procedural Content Generation (PCG)

Digital heritage is a field that explores the application of technologies to the preservation and dissemination of cultural heritage. In recent years, various technical approaches have been explored, among which PCG has attracted growing attention not only in game development but also in the digital heritage domain. Williams et al. (2023) emphasized that PCG is a key technology enabling small development teams to efficiently create large-scale environments and analyzed recent algorithms and applications. However, Palombini (2023) pointed out that most studies on the integration of PCG into digital heritage have focused on technical feasibility, lacking empirical analysis on the effectiveness of conveying historical context.

### 2.2 Archaeogaming and the Recreation of Historical Environments

Archaeogaming is a research domain that deals with historical representation and interpretation within game environments. It provides a theoretical foundation for analyzing how users engage with and understand history through interaction. Kingsland (2023) proposed a method of deliberately inserting anachronistic bait items or bugs to encourage users to explore environments and develop their own interpretations. While effective for enhancing user immersion, McCall (2016) warned that such techniques may lead to historically inaccurate understandings, particularly in heritage education and preservation contexts.

Fraser et al. (2023) introduced the concept of generative archaeogaming by combining procedural generation with archaeological storytelling. Their work examined how user-driven interpretation forms archaeological narratives and highlighted the potential of integrating generative AI for personalized historical storytelling.

This study draws on archaeogaming perspectives while also emphasizing the necessity of historical validation. To this end, we propose the HPCG framework, which seeks a balance between user-driven interpretation and historically reliable communication.

### 2.3 Balancing User Experience and Historical Accuracy

The tension between user experience and historical accuracy has been a persistent research concern in digital heritage environments. Roussou et al. (2022) proposed design principles that promote user engagement while preserving historical fidelity. Similarly, Katifori et al. (2018) analyzed how users actively construct contextual understanding through interaction with digital reconstructions.

Nonetheless, as Maleki & Zhao (2024) have observed, there remains a lack of PCG algorithms specifically tailored to heritage contexts, and studies addressing East Asian cultural heritage are particularly scarce (Rahaman & Tan, 2011).

In response to these limitations, this study presents a methodologically grounded application of PCG to digital heritage through the HPCG framework, offering a context-aware, historically informed approach.

## 3. Proposed Method

To verify the effectiveness of PCG in digital heritage environments, this study develops the HPCG framework and applies it to a 3D representation of the Joseon Dynasty court banquet painting. This section describes the structure and principles of the HPCG framework, the implementation process, and the experimental design and evaluation methodology.

### 3.1 HPCG Framework

The HPCG is a procedural content generation methodology designed to enhance user experience while maintaining historical accuracy. It consists of the following three core components. The HPCG framework structure and components are presented in Figure 1, while Figure 2 shows an application example of this framework.

#### 3.1.1 Historically Verified Item Database

The first component is a digital item library verified by historical sources and expert review. The database is constructed through a step-by-step approach:

(1) Primary source collection: information on items used in the Joseon Dynasty court context is systematically gathered from multiple historical sources, including textual records (Uigwe: The royal protocols of the Joseon Dynasty, Uigwe of Hwaseong fortress, Annals of the Joseon Dynasty), archaeological artifacts from major Korean museums, and court paintings. Data collection focuses specifically on court protocols, ceremonial procedures, and daily life documentation to ensure comprehensive coverage of historical contexts.

(2) Expert validation: a rigorous three-stage validation process ensures historical accuracy through specialized expertise.

**Stage 1**. Joseon Dynasty clothing researchers and traditional culture specialists from Korea National University of Heritage (KNUH) conduct initial screening, focusing on primary source authentication and contextual verification.

**Stage 2**. Digital heritage experts from KNUH perform detailed reviews, examining material accuracy and ceremonial usage patterns through virtual heritage reconstruction expertise.

**Stage 3**. Collaborative cross-validation by Stage 1 and 2 experts using primary historical sources to verify spatial placement rules and social hierarchy protocols.

Items undergo assessment covering historical authenticity, contextual appropriateness, material accuracy, and spatial placement rules. Only items achieving expert consensus (>80% agreement) across all validation stages are included in the final database.

(3) Metadata structuring: each validated item is assigned comprehensive metadata following a standardized schema for historical accuracy and algorithmic processing. Core attributes include period classification, human categories spanning royalty to court personnel and servants, social hierarchy reflecting high to low rankings within the court system, and clothing specifications covering military, ceremonial, and daily wear contexts with boolean indicators for accessories.

Contextual metadata encompass ceremonial usage categories for the Five Rites of State including Auspicious, Felicitous, Guest, Military, and Sorrowful Rites, spatial zone designations for various palace locations such as main throne halls, banquet spaces, audience chambers, and reception rooms, along with interaction types classified as static display, interactive, or narrative trigger components. These structured metadata serve as primary inputs for the placement algorithm, enabling contextually appropriate item distribution throughout the virtual heritage environment.


https://doi.org/10.5194/isprs-annals-X-M-2-2025-123-2025  

(4) 3D modelling: validated items undergo systematic 3D reconstruction through historically informed workflows balancing authenticity with performance requirements. Expert consultations with costume historians and digital heritage specialists ensure accurate proportions, materials, and decorative details based on primary sources and archaeological evidence.
Performance optimization includes progressive mesh decimation, texture atlas compression, and four-tier level of detail (LOD) systems enabling real-time rendering across diverse hardware configurations. Quality assurance protocols maintain historical accuracy while meeting interactive performance benchmarks for immersive virtual heritage experiences.

### 3.1.2 Temporal Context-Aware Placement Algorithm

The second component is an algorithm that places items appropriately based on the historical period and cultural context. Implemented in Unity3D using C#, this algorithm follows these principles:

(1) Constraint-based placement rules: historical rules regarding item placement (e.g., seating by social rank, ritual object positioning) are encoded as constraints.
(2) Probabilistic variation range: to preserve historical accuracy while providing diversity, each constraint is given a variation range based on metadata importance. Items with high ceremonial usage and social hierarchy significance (comprising 75% of decision weight) are restricted to narrow variation ranges (±5%), while medium-priority spatial considerations (15% weight) allow moderate flexibility (±15%), and low-priority interaction elements (10% weight) permit wider variability (±30%). Algorithmic validation cross-references multiple metadata fields to prevent historically inconsistent combinations, ensuring that high-weight historical factors maintain strict accuracy while allowing controlled diversity in secondary elements.
(3) Context-aware generation: the algorithm dynamically placed items suitable for each context and randomized user starting positions to ensure that exploration naturally revealed historical context.
(4) Parameter controls: parameters are implemented to adjust environmental complexity, density, and diversity, enabling systematic variation based on experimental conditions.

### 3.1.3 Contextual Interaction System

The third component is an interaction system that links user interaction with historical context. Its features include:

(1) Item recognition interface: when a user encounters an item, a trigger activates an interface displaying historical information via text, images, or narration.
(2) Narrative trigger system: key locations and items are embedded with narrative triggers to allow users to experience historical narratives in a structured way. These triggers ensure consistency even in PCG environments.
(3) Perspective control: users could switch between first-person and third-person views to explore the environment from multiple angles.

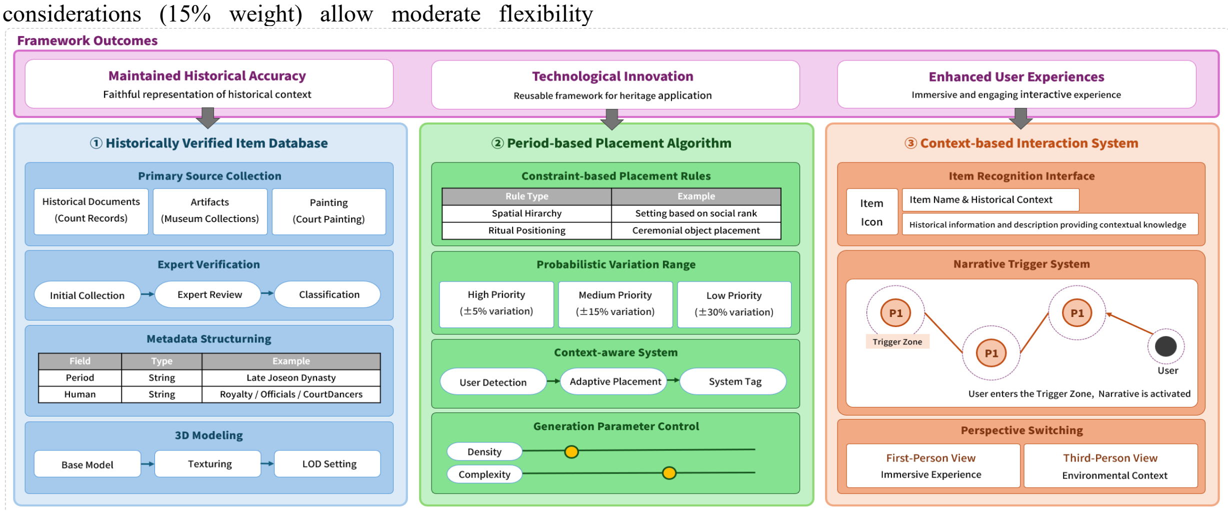


Figure 1. Structure and components of the HPCG framework

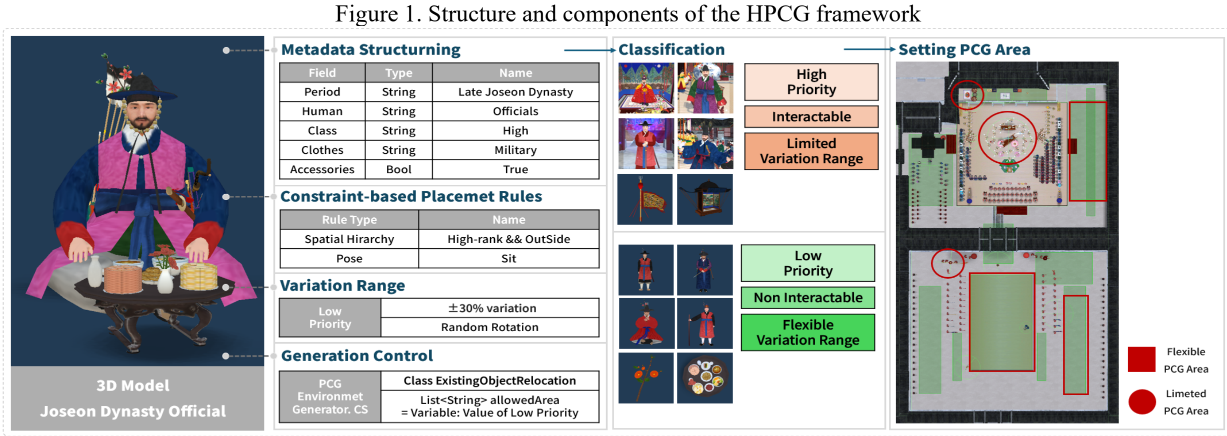


Figure 2. Application example of the HPCG framework

### 3.2 Implementation of the 3D Environment

To validate the HPCG framework, this study develops a 3D environment based on *Bongsudang Jinchan-do*, a late Joseon Dynasty court painting that documents a royal banquet held by King Jeongjo in 1795 at Bongsudang to celebrate Hyegyeonggung Hong's 60th birthday.

#### 3.2.1 Historical Data Analysis and Spatial Composition

(1) Primary source analysis: historical documents such as the *Bongsudang Jinchan-do* and related paintings are reviewed to extract information about Bongsudang's architecture, spatial organization, and participants.
(2) Spatial modelling: based on the analysed sources, the architecture and surrounding environment of Bongsudang are modelled in 3D. Structural details are referenced from both historical records and surviving contemporary buildings.
(3) Environmental settings: seasonal and temporal elements corresponding to the original banquet are implemented to enhance historical ambiance. Figure 3 illustrates the comparison between the original historical painting (left) and the implemented 3D digital environment (right).

#### 3.2.2 Application of PCG System

(1) Classification of fixed and variable elements: fixed elements include the architecture and main ritual spaces, while variable elements such as decorations, object placements, and participant positions are procedurally generated.

| Element Classification for PCG Implementation | | |
|---|---|---|
| Category | Fixed Elements | Variable Elements |
| Architecture | ·Building Layout<br>·Main Halls | ·Decoration<br>·Interior |
| Ritual Space | ·Ceremonial Area<br>·King’s Position | ·Object Placement<br>·Participant position |

Table 1. Classification for PCG implementation

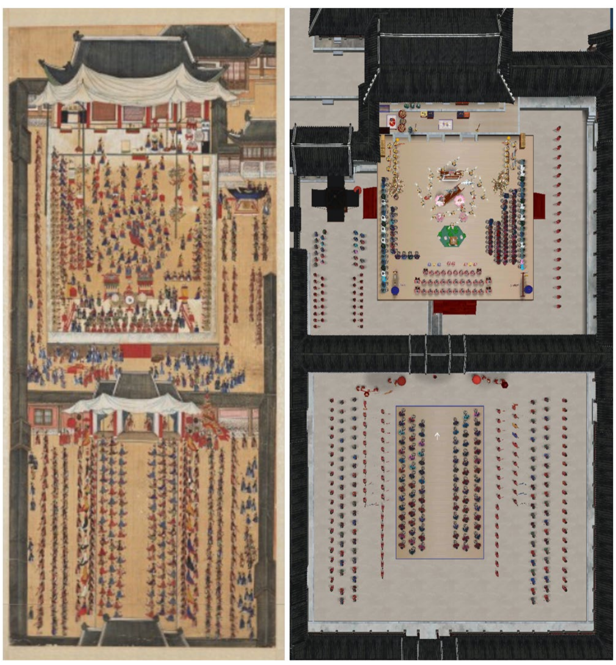

Figure 3. *Bongsudang Jinchan-do*, National Palace Museum Collection (left), 3D digital environment implemented based on court painting (right)

(2) Implementation of three environment versions: to support comparative analysis, three types of environments are created as summarized in Table 2. These environments include a static historically accurate environment (E.A), a dynamic environment with historically accurate items placed via PCG (E.B), and a PCG environment containing deliberately anachronistic elements (E.C).

| Experimental Group Environment | | |
|---|---|---|
| Name | Type | Description |
| E.A | Limitation | Historically accurate items and environment presented in a fixed, unchanging form |
| E.B | PCG Historical | Historically accurate items and environment with PCG-driven variations and placement |
| E.C | PCG Anachronistic | PCG environment containing some deliberately anachronistic items and contextually inappropriate placements |

Table 2. PCG group setting

(3) Design of anachronistic elements: in E.C, items that were not present during the Joseon Dynasty (e.g., Western-style furniture, modern tools) are placed in ways that are identifiable but not excessively disruptive to immersion. Table 3 categorizes these anachronistic elements, showing how non-period furniture and modern technological items are designed to be recognizable while maintaining contextual integration. As illustrated in Figure 4, the practical implementation of these anachronistic elements—such as modern vending machines against traditional palace architecture (left) and a smartphone placed on a traditional ceremonial floor (right)—demonstrates how such elements are visually distinct yet harmonized within the historical setting to stimulate user curiosity without completely breaking immersion.

| Anachronistic Elements in E.C Environment | | |
|---|---|---|
| Category | Examples | Design |
| Non-Period Furniture | Not presented in Joseon Dynasty | Clearly identifiable but not overly intrusive |
| Modern Tools / Object | Modern lighting, technological items | Integrated within the historical context |

Table 3. Anachronistic elements in E.C environment

Figure 4. Anachronistic elements in E.C environment

#### 3.2.3 Implementation and Immersive Presentation

(1) Navigation mechanism: users control their avatar using a joystick interface, enabling them to freely explore the virtual environment. The interface allows both movement and viewpoint switching between first-person and third-person perspectives.

(2) Information access: when a user's avatar enters a trigger zone associated with an item, the system detects the avatar and displays a UI button for viewing historical information. This minimizes unnecessary pop-ups and maintains user immersion. Upon tapping the button, related historical information is shown in text format, and a voice narration is automatically activated.

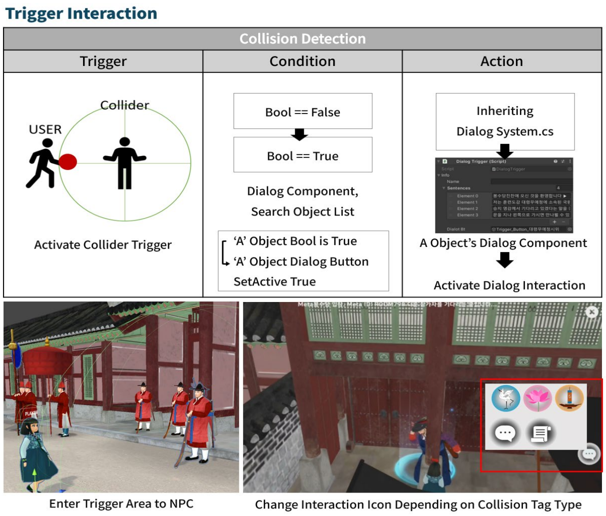


Figure 5. Trigger-based interaction system implementation

(3) Interaction types: users, as participants in the banquet scene, can interact with various figures and objects. Information is provided in a dialog-based format to enhance narrative immersion and allow users to more fully engage with the historical environment. Figure 5 illustrates the implementation of this trigger-based interaction system, showing the technical workflow from collision detection (top) to practical application in the environment (bottom). The figure demonstrates how triggers are activated when users approach NPCs (bottom left) and how different interaction icons appear based on the collision tag type (bottom right), providing an intuitive interface for accessing historical content without disrupting the immersive experience.

### 3.3 Experimental Design and Evaluation

To assess the effectiveness of the HPCG framework, an experiment is designed and conducted as follows.

#### 3.3.1 Research Questions

This study aims to address the following research questions:

**Q1**. How does a PCG-generated digital heritage environment affect users' understanding of historical context?
**Q2.** Is there a difference in user experience and historical comprehension between a historically accurate PCG environment and one that includes anachronistic elements?
**Q3.** To what extent do emergent narratives formed by users in PCG environments align with the intended historical context?

#### 3.3.2 Participant Recruitment and Group Assignment

(1) Participant recruitment: based on an a priori power analysis targeting 80% power with $p<0.05$ significance level and expected small to medium effect size (Cohen's $d = 0.3$), a minimum of 30 participants is required for detecting meaningful differences between groups. Thirty adult participants aged 20 to 30 are recruited through purposive sampling from university communities and cultural heritage organizations. Efforts are made to ensure balanced representation in terms of historical knowledge (assessed via pre-survey questionnaire), gaming experience (classified as low/medium/high), and gender distribution (targeted 50:50 ratio). The sample size of 10 participants per group provides adequate power for detecting medium effect sizes in heritage PCG studies, following established guidelines for experimental heritage research (Cohen, 1988; UNESCO Charter on the preservation of digital heritage, 2003).

(2) Group assignment: participants are randomly assigned to one of the following three groups:
· Group A: experience a fixed historical environment
· Group B: experience a historically accurate PCG
· Group C: experience an anachronistic PCG

(3) Pre-survey: all participants complete a preliminary questionnaire assessing their familiarity with Joseon Dynasty history and digital environments.

#### 3.3.3 Experimental Procedure

(1) Participants are briefed on basic navigation and interface usage. Each participant experiences their assigned content type twice. Information about the nature of the environment (fixed, PCG, anachronistic) is not disclosed.

(2) Environment experience: participants freely explore their assigned environment for 10 minutes per session. Those in PCG groups experience the content twice. During exploration, movement paths and dwell time are recorded.

(3) Task completion: after exploration, participants complete a questionnaire assessing their understanding of historical events and rituals. The questionnaire includes both multiple-choice and short-answer questions.

## 4. Experimental Results

### 4.1 Participants Demographics

A total of 30 participants take part in the experiment, with 10 individuals randomly assigned to each of the three groups (A, B, and C). Participants are in their 20s (60%) and 30s (40%), with a balanced gender distribution (53% male, 47% female). Their occupations include university students (30%), graduate students (23%), researchers (13%), office workers (27%), and others (7%), representing a diverse range of backgrounds.

### 4.2 Quantitative Evaluation Results

Participants' comprehension of historical context is measured using two indicators: the degree to which the environment reflects historical features, and the participants' understanding of historical context after content exploration. Group A (fixed environment) scores 4.2 and 3.9, respectively, while Group B (historical PCG) scores 4.0 and 4.3. Group C (anachronistic PCG) scores 3.1 and 2.8.

ANOVA analysis reveals statistically significant differences among the groups ($F(2,27)=18.37$, $p<0.001$). Although the difference in feature reflection between Groups A and B is not significant ($p=0.42$), Group B shows a significantly higher score in contextual understanding than Group A ($p=0.04$). Group C scores significantly lower in both categories ($p<0.001$).

In the consistency evaluation, there is no significant difference between Groups A and B in terms of temporal consistency (p=0.16), but Group C shows significantly lower consistency scores (p<0.001). Additionally, Group C scores significantly higher in the detection of anachronistic elements (p<0.001).

| Group | Feature Reflection | Context Understanding |
|---|---|---|
| A | 4.2(SD=0.42) | 3.9(SD=0.57) |
| B | 4.0(SD=0.47) | 4.3(SD=0.48) |
| C | 3.1(SD=0.74) | 2.8(SD=0.92) |

Table 4. Historical context comprehension results

| Group | Temporal Consistency | Detection of Anachronisms |
|---|---|---|
| A | 4.5(SD=0.53) | 1.3(SD=0.48) |
| B | 4.2(SD=0.42) | 1.4(SD=0.52) |
| C | 2.4(SD=0.70) | 4.2(SD=0.63) |

Table 5. Consistency evaluation results

Immersion is evaluated in terms of user engagement during environment exploration, motivation within the PCG environment, and the inducement of exploration driven by anachronistic elements.

| Group | Engagement | Motivation | Inducement of Exploration |
|---|---|---|---|
| A | 3.6(SD=0.52) | N/A | N/A |
| B | 4.3(SD=0.48) | 4.5(SD=0.53) | N/A |
| C | 4.1(SD=0.57) | 4.4(SD=0.52) | 4.7(SD=0.48) |

Table 6. Immersion evaluation results

Groups B and C, both using PCG, show significantly higher engagement than Group A (p<0.01). There is no statistically significant difference in immersion between Groups B and C, although Group C's anachronistic elements clearly stimulate user curiosity and motivation to explore.

Learning outcomes are assessed based on knowledge acquisition, contextual understanding, and confusion caused by anachronistic elements.

| Group | Knowledge Acquisition | Contextual Understanding | Confusion Due to Anachronisms |
|---|---|---|---|
| A | 4.1(SD=0.57) | N/A | N/A |
| B | 4.3(SD=0.48) | 4.0(SD=0.67) | N/A |
| C | 3.2(SD=0.79) | 3.1(SD=0.74) | 4.2(SD=0.63) |

Table 7. Learning evaluation results

There is no significant difference between Groups A and B in terms of knowledge acquisition, but Group C scores significantly lower than both (p<0.01). Participants in Group C also report that anachronistic elements cause confusion in understanding the historical context.

### 4.3 Qualitative Evaluation Results

In addition to quantitative measures, participants are asked to provide open-ended feedback on their experience. The responses are analysed using qualitative coding to extract key themes related to historical perception, interaction, and emergent narrative.

(1) Historical Perception

Participants in Groups A and B comment that the spatial arrangement and items help them intuitively understand the structure of the banquet and the flow of the ritual. One participant in Group B notes, "The environment felt authentic, and I could picture how people were seated according to rank." In contrast, participants in Group C express confusion about the period, with one stating, "I wasn't sure if this was supposed to be from the Joseon era. Some objects didn't feel right."

(2) Interaction and Information Access

Users appreciate the item recognition interface (trigger-based interaction system) that provides historical information through voice and text. Many participants respond positively to the ability to interact with historical figures and learn through narrative explanations. A participant from Group B says, "It was interesting to 'talk' with the figures and hear short stories that helped explain their roles."

(3) Emergent Narrative Alignment

To assess the degree to which user-created narratives align with historical context, three experts independently evaluate participants' storytelling responses on a 100-point scale. The average scores are calculated based on five criteria, each worth 20 points:

(a) Accurate identification of the historical period
(b) Understanding the essential nature of the event
(c) Awareness of participants and social hierarchy
(d) Comprehension of ritual procedures and spatial usage
(e) Appropriate interpretation of cultural context

As illustrated in Figure 6, the quantitative assessment of historical narrative congruence shows significant differences between the three groups. Group A achieves the highest congruence score (87%), followed closely by Group B (82%), while Group C demonstrates substantially lower congruence (54%). This visual representation clearly highlights the impact of environment type on narrative coherence.

Participants in Groups A and B describe consistent and structured interpretations of the banquet, while those in Group C report difficulties maintaining a coherent narrative. For instance, a Group C participant mentions, "The modern-looking items made it difficult to stay immersed, and I started creating strange backstories that didn't fit." This suggests that historical inconsistencies lead to a divergence from the intended interpretive framework.

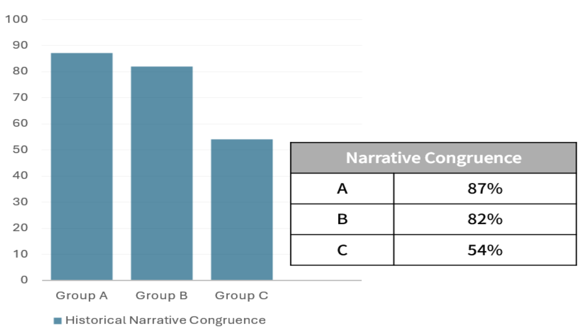


Figure 6. Historical narrative congruence

As shown in Table 8, participants' affective responses to environmental elements reveal distinct patterns across the three groups. Group A participants emphasize the accuracy and clarity of historical representation, Group B participants value the dynamic discovery aspects of PCG, while Group C


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participants find interest in the novelty of anachronistic elements despite historical inconsistencies.

| Affective Elements | |
|---|---|
| | Response |
| A | "The structure and placement of architectural elements were accurately arranged."<br>"The layout of the ritual space was clearly presented."<br>"The court event scene was impressive." |
| B | "It was enjoyable to discover the dynamic composition of the environment."<br>"I could discover new spaces through positional changes."<br>"The various placements of objects were intriguing." |
| C | "It was interesting to discover modern objects blended into the environment."<br>"Finding anachronistic elements felt like playing a game."<br>"Anachronistic elements stimulated curiosity." |

Table 8. Participant perceptions of environmental elements

Table 9 presents the analysis of participants' exploration path characteristics, demonstrating how the environment type influences navigation behaviours. Group A follows structured routes and focuses on ritual areas, Group B exhibits more diverse and repetitive exploration patterns to discover dynamic PCG variations, and Group C shows fragmented exploration with a focus on anachronistic elements rather than holistic understanding.

| Exploration Path Characteristics | |
|---|---|
| A | · Followed structured, predefined routes<br>· Spent extended time in key ritual areas. |
| B | · Displayed diverse paths and exploration patterns.<br>· Revisited locations to discover dynamic elements. |
| C | · Explored in a non-linear and fragmented manner.<br>· Focused on anachronistic element locations.<br>· Prioritized distinct features over holistic understanding. |

Table 9. Analysis of participants' content exploration paths

These qualitative responses support the quantitative findings, indicating that PCG environments with historical fidelity foster both narrative immersion and accurate historical understanding, while environments containing anachronistic elements may hinder comprehension and coherence. The themes emerging from open responses—particularly regarding confusion in Group C and structured interpretation in Groups A and B—mirror the patterns identified in statistical outcomes such as comprehension scores, immersion ratings, and learning indicators, thereby reinforcing the validity of the quantitative analysis.

# 5. Conclusion

This study proposes and validates the HPCG framework, which applies PCG technology to digital heritage environments to achieve a balance between historical contextualization and user experience enhancement. The HPCG framework is implemented in a 3D reconstruction of the late Joseon Dynasty court painting *Bongsudang Jinchan-do*, and user experiments are conducted across three types of environments (fixed, historically accurate PCG, and anachronistic PCG). The findings are summarized as follows:

## 5.1 Summary of Results

First, the historically accurate PCG environment built using the HPCG framework provides a comparable level of historical contextual understanding as the fixed environment, while significantly enhancing user immersion and satisfaction. This demonstrates the potential of PCG to improve user experience without compromising historical accuracy.

Second, the anachronistic PCG environment effectively stimulates user curiosity and exploratory motivation but results in significantly lower scores in historical contextual understanding and narrative congruence. This suggests that anachronistic bait items or bugs, a common technique in archaeogaming, may have a negative impact on historical narrative formation in digital heritage contexts.

Third, analysis of exploration paths shows that users in PCG environments exhibit more diverse and unstructured exploration patterns and engage more actively with the environment. This indicates that PCG facilitates autonomous exploration and contributes to the formation of emergent narratives.

## 5.2 Limitations and Future Works

This study has several limitations, which suggest directions for future research.

First, the experiment is conducted with a limited sample size of thirty participants within a specific age range of twenties to thirties. Future studies should involve a broader demographic with diverse backgrounds.

Second, the study is based on a single case—the *Bongsudang Jinchan-do*. Further research should explore the applicability of the HPCG framework across various historical periods and cultural contexts.

Third, the current PCG algorithm is built upon a limited set of metadata, placement rules, and interaction parameters. Future advancements should incorporate machine learning and AI to enable more sophisticated, context-adaptive environment generation.

This research represents an initial step in exploring the potential of PCG within the digital heritage field. Continued technological advancements and interdisciplinary collaboration are expected to contribute to the development of more refined HPCG frameworks, facilitating the digitization and public engagement of cultural heritage. Utilizing PCG to offer immersive experiences while maintaining historical accuracy could serve as a vital approach to bridging digital technology and cultural heritage.

## Acknowledgements

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