MASTER'S THESIS

INTERACTION DESIGN

Designing Digital Engagement at Moesgaard Museum

Jacky Quan Cam Trinh
Niels Kristian Johansen
Sebastian Tor Douglas Stadsholt

AALBORG UNIVERSITET

June 6th, 2025

CS-25-HCI-10-13

Technical Faculty of IT and Design
Aalborg University
http://www.aau.dk

AALBORG UNIVERSITET

Title:

Designing Digital Engagement at Moesgaard Museum

Theme:
Master's Thesis

Project Period:
February 2025 - June 2025

Project Group:
Interaction Design 10, CS-25-HCI-10-13

Participant(s):
Jacky Quan Cam Trinh
Niels Kristian Johansen
Sebastian Tor Douglas Stadsholt

Supervisor(s):
John Stouby Persson

Report Page Numbers: 53

Appendix Page Numbers: 15

Date of Completion:
June 6, 2025

Abstract:

Museums increasingly adopt digital technologies to enhance cultural storytelling, yet many digital elements fail to sustain engagement due to poor integration and limited interactivity [18]. This master's thesis investigates how hybrid interaction can address these challenges by supporting short-term, meaningful engagement in museum installations. We explore this through the redesign of *The Commander's Tent* at Moesgaard Museum, a Tangible User Interface (TUI) exhibit that previously lacked feedback, variation, and multiplayer functionality. Using a Research through Design (RtD) approach, we developed a Hybrid User Interface (HUI) combining 3D-printed tokens with touchscreen interaction. Users construct physical formations that trigger real-time audiovisual battle simulations. The prototype, implemented on a MultiTaction MT557D table with QR-based tracking, was evaluated on-site using structured interviews, observations, datalogging, and a streamlined User Engagement Scale – Short Form (UES-SF). Results showed significant improvements in usability and engagement. 86.8% of participants preferred the redesigned version, highlighting the value of multiplayer interaction, feedback, and narrative alignment. We conclude by offering design implications for HUI museum experiences that support rapid onboarding and sustained user involvement.

Summary

This master's thesis investigates how hybrid interaction can enhance user engagement in museum installations, focusing on the redesign of *The Commander's Tent* at Moesgaard Museum. This thesis adopts a Research through Design (RtD) methodology, combining iterative prototyping with real-world evaluation to explore how tangible and digital modalities can be meaningfully integrated in a cultural heritage context.

The original installation relied solely on tangible interaction using wooden tokens but lacked variation, feedback, and multiplayer functionality. To address these limitations, we introduced a Hybrid User Interface (HUI) that connects 3D-printed tokens with a touch-based digital interface. Visitors use physical tokens to build formations, which trigger a real-time battle simulation on a MultiTaction table. This hybrid design aimed to balance physical engagement with digital responsiveness while supporting social interaction and sustained attention.

To evaluate the impact of the redesign, a comparative study was conducted on-site at Moesgaard Museum. Both the original and hybrid installations were assessed through structured interviews based on the User Engagement Scale – Short Form (UES-SF), direct observation, and interaction logging. 86.8% of participants preferred the hybrid prototype, highlighting its increased interactivity, multiplayer functionality, and feedback mechanisms. Although the original version was initially rated higher for its aesthetic coherence, this shifted after participants experienced the full museum exhibition. In the post-film phase, 81.5% favoured the hybrid version for its narrative alignment and perceived depth of engagement.

The study shows that HUIs can support rapid onboarding, sustained user attention, and diverse interaction preferences by blending physical and digital interaction styles. It also highlights the importance of contextual and thematic coherence, narrative integration, and social play in the design of interactive exhibits in museums.

Main Contributions:

- A fully functioning hybrid prototype of *The Commander's Tent*, combining tangible tokens with touchscreen interaction. The system enables strategic multiplayer gameplay, real-time feedback, and onboarding guidance. It was deployed on a MultiTaction MT557D table and evaluated through live use in a museum setting.
- A set of four design implications grounded in comparative evaluation and real-world engagement findings:
    1. *Support shared play and interactive variety to deepen attention*
    2. *Use embodied guidance to lower onboarding barriers*
    3. *Ensure digital elements preserve the visual and thematic coherence of the physical setting*
    4. *Design for rewarding experiences through narrative integration and emotional impact*

Resume

Dette speciale undersøger, hvordan hybrid interaktion kan øge brugerengagement i museumsinstallationer med udgangspunkt i redesignet af *Hærlederens Telt* på Moesgaard Museum. Projektet benytter en *Research through Design* (RtD)-tilgang, hvor iterativ prototyping kombineres med evalueringer i virkelige kontekster for at udforske, hvordan håndgribelig og digital interaktion meningsfuldt kan integreres i kulturarvsformidling.

Den oprindelige installation baserede sig udelukkende på fysisk interaktion med træbrikker, men manglede variation, feedback og understøttelse af multiplayer. I det redesignede system blev en hybrid brugergrænseflade (HUI) udviklet, som kombinerer 3D-printede brikker med en touchbaseret digital grænseflade. Brugerne bygger formationer med fysiske tokens, der aktiverer en kampsimulering i realtid på et MultiTaction-bord. Det hybride design søger at balancere fysisk involvering med digital respons, samtidig med at det styrker social interaktion og opmærksomhed.

En komparativ evaluering blev gennemført på Moesgaard Museum, hvor både den oprindelige og den redesignede installation blev vurderet gennem strukturerede interviews baseret på *User Engagement Scale – Short Form* (UES-SF), observation og datalogning. 86,8% af deltagerne foretrak den hybride prototype og fremhævede dens øgede interaktivitet, feedback og sociale dimension. Selvom den oprindelige version i begyndelsen blev vurderet højere æstetisk, ændrede dette sig efter oplevelsen af den samlede museumsformidling. Efter filmvisningen foretrak 81,5% den hybride version på grund af dens narrativt forankrede og engagerende udtryk.

Resultaterne viser, hvordan hybride installationer kan understøtte hurtig introduktion, fastholde brugerens opmærksomhed og favne forskellige interaktionspræferencer gennem en afbalanceret kombination af fysiske og digitale medier. Derudover understreges vigtigheden af narrativ indramning, tematisk sammenhæng og fælles leg i designet af interaktive museumsoplevelser.

Primære bidrag:

- En fuldt fungerende hybrid prototype af *The Commander's Tent*, som kombinerer fysiske tokens med en touchskærmsgrænseflade. Systemet understøtter strategisk multiplayer gameplay, realtidsfeedback og onboarding-hjælp. Prototypen blev implementeret på et MultiTaction MT557D-bord og testet i live-brug i en museumsudstilling.
- Fire designimplikationer baseret på komparativ evaluering og observationer fra virkelige brugssituationer:
    1. *Understøt fælles leg og interaktiv variation for at fastholde opmærksomhed*
    2. *Brug legemliggjort vejledning for at sænke adgangsbarrierer*
    3. *Sørg for, at digitale elementer bevarer den fysiske konteksts visuelle og tematiske sammenhæng*
    4. *Design for meningsfulde oplevelser gennem narrativ integration og emotionel påvirkning*

Contents

1 Introduction

Museums are increasingly integrating digital technologies to modernise cultural storytelling and enhance visitor engagement [18]. Tangible User Interfaces (TUIs), in particular, align well with museum goals of authenticity and physical engagement. Prior studies highlight their ability to support hands-on exploration, intuitive interaction, and social participation, especially for younger audiences and casual visitors [36, 2]. Multi-Touch Interfaces (MTI) and Graphical User Interfaces (GUI), by contrast, offer flexibility in control, dynamic content delivery, and clear feedback mechanisms [17]. As a result, hybrid approaches, such as Hybrid User Interfaces (HUIs), that can combine TUIs with visual or touch-based feedback, have gained traction in interaction design, offering the potential to merge the immediacy of physical action with the adaptability of digital systems [14, 33, 37].

Despite their promise, HUIs have rarely been evaluated in real museum contexts where they augment existing installations rather than replace them. Most prior work focuses on standalone prototypes, lacking comparative insights into how HUIs actually perform relative to physical-first exhibits under real-world conditions [16, 21, 34, 33, 25, 38]. Part of the reason for this gap may lie in the fragmented nature of the HUI concept itself. Satkowski et al. [33] describe how the term has become increasingly unspecific over time, encompassing a wide range of systems under inconsistent criteria. This definitional instability makes it difficult to generalise findings or compare systems meaningfully, further contributing to the lack of robust, comparative evaluation in the museum context.

One reason for this gap is that museums operate in a post-digital condition, where digital technologies are embedded but often poorly sustained. Digital features are frequently introduced as isolated, standalone solutions and then left untouched, leading to obsolescence and abandonment. These patterns are reinforced by institutional challenges such as limited staff capacity, unclear digital strategies, and weak collaboration between curators and technologists [28].

While HUIs expand interaction possibilities, they may also introduce complexity, particularly through the coordination of multiple input and output modalities. This can increase onboarding demands and reduce clarity for casual users, who must interpret layered feedback and learn blended interaction schemes in walk-up settings [40, 3]. As Zaky et al. [40] point out, switching between interaction modalities such as tangible input, touchscreen feedback, and mid-air gestures can impose cognitive load, disrupt interaction flow, and reduce overall clarity. These challenges are especially critical in unsupervised environments, where systems must communicate their use through design alone. Here, short-term engagement, immediate, intuitive, and brief, is essential, yet remains underexplored.

To address these gaps, we adopted a Research through Design (RtD) approach, developing and evaluating a HUI version of a TUI museum installation as part of our master's thesis, carried out over two consecutive semesters: an initial exploratory phase (P9), followed by a public deployment and evaluation phase (P10), both in collaboration with Moesgaard Museum.

In P9, we explored how digital elements could address limitations in tangible interaction. Using *The Commander's Tent* installation as a foundation, we developed a HUI prototype with audiovisual feedback and multiplayer support. The original installation at Moesgaard involved wooden tokens on a projected map but lacked social interaction and feedback.

We built a Unity-based prototype on an i3Touch touchscreen with 3D-printed tokens. Early testing showed improved clarity and usability, leading to the following research question:

> *How can a tangible museum installation be augmented with digital interaction to address its limitations and support a short-term, engaging user experience?*

In our tenth semester (P10), we formalised the collaboration with Moesgaard Museum to refine and publicly evaluate the second iteration prototype. This phase focused on improving user engagement and suitability for real-world use. We moved the system to a MultiTaction MT557D table with reliable QR-based token tracking and multi-user touch, through infrared camera tracking.

Following a pilot study at Aalborg University, the final version was deployed at Moesgaard and evaluated through interviews, observations, and data logging. User engagement was measured using a modified version of the User Engagement Scale - Short Form (UES-SF), adapted into a simplified comparative format better suited to the museum context and public exhibition setting.

The evaluation of the second prototype revealed a consistent preference for the redesigned installation across all data sources, offering new insight into how HUIs support engagement in museum contexts. Among the 38 participants interviewed pre-cinema, 84.2% found the redesigned installation more fascinating, 57.9% judged it easiest to understand, 44.7% preferred its visual design, and 86.8% felt it provided the best overall experience. Notably, while the original installation was initially rated higher in aesthetic appeal, this shifted after visitors had viewed the short film in the cinema, with 81.5% then feeling the redesigned installation better fit the overall exhibition. This suggests that narrative framing can influence how visitors evaluate engagement factors such as Focused Attention, Perceived Usability, Aesthetic Appeal, and Reward.

Key strengths included multiplayer interaction, immersion, and visual clarity. Visitors, especially children and teenagers, often played multiple rounds and even in some cases creating small tournaments. Observational notes supported this behaviour, and the datalogs confirmed efficient interaction and low error rates, with users quickly correcting misplaced tokens.

These results suggest that the redesigned installation effectively enhanced user engagement in the museum context.

In summary, this work contributes to a deeper understanding of how hybrid tangible-digital interaction can be applied to augment existing museum installations. Based on the results of our comparative evaluation and design process, the main contributions of this thesis are:

1. **Design Implications** – A set of practical insights for designing HUI installations for short-term museum engagement, grounded in our in-situ evaluation findings.
2. **Prototype Design** – A fully functional prototype that reimagines *The Commander's Tent* using tangible tokens and touchscreen interaction to enable multiplayer gameplay.

2 Background

This chapter outlines the broader context for our thesis by examining how museums integrate digital technologies into physical exhibitions and the challenges this poses for user engagement. It reviews relevant research on TUI and HUI, synthesises comparative findings from museum studies, and introduces our engagement framework based on the UES-SF model. Finally, it highlights current gaps in understanding how hybrid interaction can augment existing TUI exhibits in real-world, unsupervised settings.

2.1 Digital Transformation in Museums

Museums are increasingly integrating digital elements to modernise cultural and historical storytelling [18]. However, when such elements are poorly integrated into exhibition spaces, they risk diminishing user engagement. Overreliance on text-heavy screens, for instance, may lead to disengagement, as many visitors prefer tangible, hands-on experiences over screen-based interactions.

This highlights a central challenge in designing interactive museum installations: integrating digital technologies in a way that complements, rather than competes with, the authenticity of physical artefacts. Effective exhibition design must be grounded in a nuanced understanding of visitor behaviour, including how individuals engage with, sustain interest in, and eventually disengage from both digital and physical components.

Recent scholarship has described museums as operating in a ”post-digital” condition, where digital technologies are no longer perceived as novel, but are embedded in everyday museum practice [28]. Nonetheless, systemic challenges persist. Many institutions adopt digital features as isolated, ”one-time solutions” without considering their full lifecycle, leading to obsolescence, fragmentation, and abandonment. These issues are further complicated by organisational limitations such as staff shortages, underdeveloped digital strategies, and limited collaboration between curators and technologists.

These challenges become particularly evident when digital installations remain unchanged for many years. Without ongoing refinement, such systems risk becoming outdated and disengaging. This reveals a gap in how museums sustain, adapt, and improve long-term digital experiences.

An illustrative example of how digital technologies can be more meaningfully integrated is provided by Schou and Løvlie [34], who designed an RFID-enabled tangible interface for a Danish house museum. Their Research through Design process embedded narrative interactions directly into physical artefacts to support affective engagement. The study highlights how hybridisation can enrich visitor experiences while maintaining the spatial and historical authenticity of the setting.

This reinforces the importance of approaching digital transformation in museums holistically, ensuring that new technologies are integrated with long-term sustainability, narrative coherence, and attentiveness to visitor experience.

2.2 Hybrid User Interfaces: Blending Tangible and Digital Interactions

In this thesis, we define HUI as a bimodal or multimodal system that combines tangible and digital interaction [3, 37]. Here, hybrid refers to the combination of different input or display devices, such as physical objects and graphical screens, to make use of the strengths of each [33]. While TUIs let users interact with digital information through physical manipulation [35], they usually rely on a single input type. HUIs blend multiple modalities, thus the term remains fragmented and inconsistently defined in current research [33].

Building on this, one approach to fostering user engagement in interactive settings is through HUIs that combine tangible and digital interactions to create more immersive and intuitive experiences [33]. By incorporating elements of TUIs together with GUIs or MTIs, HUIs offer both hands-on physical interaction and the flexibility of digital systems [37].

To understand this combination more clearly, it is useful to consider the role of TUIs, GUIs and MTIs isolation. TUIs engage users through direct manipulation of physical objects, encouraging participation and social interaction in museum settings [37]. Research has shown that physical artefacts can promote deeper exploration, especially in informal learning environments [12]. However, TUIs alone may lack the adaptability needed to support dynamic or layered content, making GUIs a valuable complement [15].

GUIs and MTIs, in contrast, provide responsive visual feedback and are well suited for presenting detailed or hierarchical information [4]. While sometimes perceived as less embodied, they are highly adaptable and can enhance physical interaction by offering clarity and guidance throughout the experience. The DIRA model [4] highlights this adaptability by framing them as particularly effective in managing representations and assemblies, helping to structure interaction flow and system feedback within HUIs.

This complementarity is further supported by empirical comparisons. Campbell et al. [7] argue that combining multiple interface technologies enables more immersive and adaptable interaction techniques, tailored to diverse user needs and contexts. In their study, GUIs enabled faster and more efficient interactions, while TUIs fostered greater enjoyment and immersion due to their physical, hands-on nature. Participants found TUIs more intuitive, even if less precise. These findings suggest that HUIs can blend the efficiency and clarity of GUIs with the engaging and exploratory qualities of TUIs, offering a balanced and inclusive user experience.

However, while the potential of HUIs is well recognised, their deployment in real-world museum settings remains underexplored, particularly in relation to augmenting rather than replacing existing exhibits.

2.3 Designing for User Engagement in Hybrid Interfaces

User engagement is a central design concern in interactive museum experiences, especially when interactions are brief and unsupervised. Visitors should be able to intuitively understand and enjoy an exhibit without requiring external guidance. In this context, usability is not a goal in itself, but a prerequisite that enables deeper forms of engagement, such as focused attention, exploration, and social interaction. Usability is typically defined by effectiveness, efficiency, and satisfaction [19].

We adopt a multidimensional understanding of engagement, operationalised through the *User Engagement Scale – Short Form (UES-SF)* [29], which defines four key factors:

- **Focused Attention** – the degree of absorption or involvement in the activity.
- **Perceived Usability** – how easily and efficiently users can interact with the system.
- **Aesthetic Appeal** – the visual and sensory impression of the system.
- **Reward** – the value, enjoyment, or fulfilment derived from the interaction.

This framing emphasises experience over performance: interfaces should not only function well, but invite curiosity, support intuitive interaction, and feel rewarding to use. Prior studies highlight that engagement is more likely when systems afford a sense of agency, exploration, and responsiveness [12, 15].

In museum contexts, where exhibits must cater to a wide range of visitors, usability plays a supporting role in enabling engagement. It ensures that interactions are accessible and intuitive, helping visitors focus on the experience rather than the interface. Key considerations include minimal instruction overhead [5], and clear physical or visual cues [18]. TUIs, in particular, benefit from strong affordances that naturally guide interaction.

Our thesis builds on these principles by investigating how a hybrid tangible-digital installation can support short-term engagement in a live exhibition setting, and how design decisions around complexity, interactivity, and guidance shape user experience. Despite growing interest in engagement metrics, few studies examine how these dimensions manifest in HUIs deployed in unsupervised, real-world museum environments.

2.4 Comparative Studies of Interactive Systems in Museums

Studies comparing interactive systems in museum settings have consistently shown that tangible and collaborative interfaces tend to foster richer, more engaging visitor experiences than static or text-heavy displays. Horn et al. [15], for example, observed that families using a tangible beat, making exhibit engaged in more playful and coordinated behaviours, such as shared manipulation and spontaneous dancing, than those using a visually similar multi-touch version. This underscores the value of co-located interaction in prompting social play and shared attention.

Michael et al. [25] further support this perspective in their comparative study at the Leventis Municipal Museum in Cyprus. They evaluated six exhibit types, five digital and one traditional, with nearly 200 children aged 9 to 11. Among these, a multi-touch table installation titled *The Walls of Nicosia* emerged as the most engaging. The interface allowed users to explore 3D models of the city's fortifications using natural gestures such as zooming, panning, and tilting, supported by ambient music and visual aids that enhanced immersion. The exhibit scored highest in engagement, suggesting that game-like, open-ended installations with intuitive control schemes can sustain attention and encourage prolonged interaction, particularly in younger audiences.

Building on this, ten Voorde [38] conducted a smaller-scale but complementary study with children aged 6 to 12 at the Museumfabriek in the Netherlands. Here, engagement was compared across a static

exhibition on beetles and an interactive exhibition on thunder and lightning. The interactive installation was rated significantly higher in all measured dimensions, cognitive, behavioural, and affective, and elicited more exploration, verbal communication, and emotional responses such as curiosity and excitement. This further indicates that interactive and hands-on exhibits may be especially effective in fostering learning and emotional involvement in informal educational contexts.

In addition to these findings on sustained engagement and emotional resonance, Ma et al. [23] highlight how interface design impacts onboarding. Their study compared visitor behaviour in a museum exhibit that used either a tangible interface with physical rings or a traditional multi-touch GUI. While both supported data exploration, the TUI was significantly more approachable: visitors engaged with it more readily and without instruction. The physical design provided natural affordances that guided appropriate interaction, whereas the GUI often required verbal or visual prompting to initiate use. This indicates that embodied interfaces not only support engagement during interaction but also lower the threshold for interaction to begin, an especially valuable trait in unsupervised, walk-up museum environments.

Taken together, these studies highlight the critical role of interactivity in shaping visitor experience. Whether through social play, embodied exploration, emotional resonance, or intuitive onboarding, interactive systems lower barriers to participation and invite sustained and meaningful engagement. Comparative evaluation offers valuable insight into how different exhibit designs affect visitor experience and provides an empirical foundation for developing HUIs in public exhibition settings. Yet, few studies use comparative methods to evaluate HUIs in authentic museum contexts, especially when these build on existing installations.

2.5 Narrative Framing and Emotional Engagement in Museum Interfaces

Emotional impact in museum installations is closely linked to how well interaction outcomes are embedded in broader narrative and thematic frameworks. Pietroni [30] argues that hybrid environments, where digital media are integrated into physical exhibitions, can evoke deep affective responses when they support storytelling and sensory coherence. She notes that ”a positive impact has indeed been observed in applications of gesture-based interaction in which the visitor must perform actual actions with the body [...] and not symbolic actions such as those performed through a device-based system like a joystick or a game console.” Similarly, Wang [39] highlights the role of emotional interaction design in shifting museums from static display models to experiential environments. By combining interactive technologies with cultural storytelling, museums can “enhance the emotional connection between exhibits and visitors” and foster lasting impressions. Antle et al. [2] further support this view by demonstrating how embodied metaphors, grounded in physical action, can strengthen comprehension and engagement in hybrid environments. Their findings suggest that interfaces which map bodily action to meaningful system responses help users reflect, learn, and connect more deeply with content. Together, these perspectives indicate that emotionally rewarding museum experiences arise not just from novelty or responsiveness, but from embodied, narratively integrated, and thematically coherent interactions.

Although prior research has shown the potential of TUIs and HUIs in museum settings, several key gaps remain. Few studies have examined how hybridisation, integrating digital augmentation with existing

physical installations, can enhance visitor engagement in unsupervised, walk-up environments. There is also limited understanding of how design decisions around interactivity, onboarding, and narrative framing influence short-term visitor engagement. Our thesis addresses this by exploring how a hybrid tangible-digital interface can enhance user experience in a real-world museum exhibit through comparative evaluation and situated observation.

3 Methodology

This chapter presents the methodological approach used to investigate how hybridisation can support user engagement in museum settings. Guided by a Research through Design (RtD) framework, this thesis unfolded through iterative prototyping, situated testing, and comparative evaluation. We analysed an existing installation, developed and tested two prototypes, and conducted three empirical studies across lab, semi-public, and museum contexts. Across all stages, the prototype functioned not only as an interactive exhibit but also as a research instrument, enabling us to generate insights through observation, interviews, thematic analysis, and datalogging.

3.1 Research Through Design

The RtD approach allows us to explore interaction design challenges through hands-on, iterative experimentation. According to Zimmerman et al. [41], RtD helps designers explore complex problems by creating and refining prototypes, using each version to reflect and gain insights. Rather than following a fixed sequence of stages, RtD unfolds through cycles of design, deployment, and reflection. Contributions may take the form of artefacts, methods, or theoretical insights.

This is especially relevant to our thesis, as we aimed to redesign The Commander's Tent through iterative prototyping in collaboration with Moesgaard Museum. By deploying and refining our HUI installation in real-world conditions, we could respond to situated challenges such as onboarding clarity, social interaction, and narrative coherence. RtD enabled us to treat each prototype not only as a functional exhibit but as a research instrument for uncovering user behaviours and generating design insights grounded in context.

A key distinction between RtD and conventional empirical approaches lies in its treatment of design itself as a structured form of investigation. Here, the artefact is not merely an outcome, but a research instrument, capable of revealing user behaviours, raising new questions, and embodying theoretical arguments. RtD thus supports the development of situated knowledge through critical reflection on design decisions and their real-world consequences [41].

3.1.1 Core Activities in Research Through Design

While RtD does not impose a rigid procedural framework, Zimmerman et al. [41] identify four recurring activities that often structure the process:

- **Problem Framing** – identifying a design challenge and situating it within its real-world context
- **Design Inquiry through Prototyping** – creating artefacts to explore possible solutions
- **Use and Evaluation in Context** – deploying artefacts to uncover user experiences and interaction dynamics
- **Reflection and Knowledge Generation** – analysing outcomes to produce transferable insights

Our thesis followed a trajectory that aligns with these activities:

- **Problem Framing** – We analysed the original Commander's Tent installation at Moesgaard Museum to uncover usability issues and design opportunities, see Chapter 4.
- **Design Inquiry through Prototyping** – We developed two prototypes as part of an iterative design process: a lab-tested first iteration, see Chapter 5, and a second iteration refined for public use, see Chapter 6.
- **Use and Evaluation in Context** – We conducted two studies to evaluate user engagement in increasingly realistic settings. These included a formative usability study of the first iteration prototype 5.2, and a final in-situ comparative evaluation at Moesgaard Museum 7. A pilot study at Aalborg University was also conducted to verify technical readiness prior to deployment and evaluation at Moesgaard.
- **Reflection and Knowledge Generation** – Insights from these evaluations were critically analysed and synthesised into design implications for HUIs, see Section 8.1.

Each of these activities reflects a core principle of the RtD process. In our thesis, the artefacts functioned not only as design outcomes, but also as research instruments that revealed user behaviours and informed our understanding of hybrid interaction. Insights gained through this process were critically reflected upon and ultimately synthesised into transferable knowledge in the form of design implications.

In this methodology chapter, we focus on the concrete methods used for:

- **Problem Framing** – through our analysis of the original Commander's Tent installation, see Chapter 4.
- **Use and Evaluation in Context** – through the following three empirical studies:
  - *First Iteration: Usability Study*, see Section 5.2
  - *Pilot Study*, see Section 3.1.4
  - *Comparative Evaluation*, see Chapter 7

3.1.2 Analysis of The Commander's Tent Installation

This phase corresponds to the problem framing stage of the RtD process. We began by analysing an existing interactive installation at Moesgaard Museum, *The Commander's Tent*, to identify usability issues and interaction challenges relevant to our design goals.

To structure this analysis, we applied Nielsen's Usability Problem Severity Ratings [27]. Over the course of approximately one hour, we engaged directly with the system and observed 11 visitors using the installation. While no demographic data were collected, this informal study surfaced recurring breakdowns in interaction clarity, system feedback, and multiplayer assumptions.

Usability Problem Severity Ratings

Nielsen's severity ratings provide a structured method for categorising usability problems based on their frequency, impact, and persistence [27]. We used this scale to evaluate both the original installation and our first prototype, enabling a consistent basis for comparison.

The severity levels are defined as follows:

- **0 – Not a usability problem**: No issue observed
- **1 – Cosmetic problem**: Only fix if time permits
- **2 – Minor usability problem**: Low priority, should be considered
- **3 – Major usability problem**: High priority, should be fixed
- **4 – Usability catastrophe**: Must be resolved before release

Using this method, we identified several core usability challenges, such as unclear token logic, insufficient feedback, and confusion around multiplayer interaction, which directly informed the first iteration prototype.

3.1.3 First Iteration: Usability Study

This study was part of the *use and evaluation in context* stage of the RtD process. We conducted a formative usability study of our first iteration prototype to explore how users interpreted and interacted with the system. While our broader aim was to support engaging experiences, this required ensuring that basic interaction mechanics were understandable and functional. Usability was therefore treated as a prerequisite for engagement, and the findings directly informed the design of the second iteration.

Overview and Methods

We conducted a structured usability study focused on usability and engagement. Three methods were used:

- **Usability Problem Severity Ratings** [27] – to assess and categorise interaction issues. This also enabled direct comparison with the problems identified in the original installation.
- **Semi-structured Interviews** [32] – to capture participants' experiences and perceptions of the system, and to explore engagement and usability themes in depth.
- **Thematic Analysis** [6] – to identify recurring patterns in interview feedback, guided by the categories *Usability* and *Engagement*.

Participants

Twelve university students (aged 20–28) were recruited via convenience sampling. While not statistically representative, the group was suitable for exploratory evaluation. Participants came from a range of academic backgrounds, offering varied perspectives on usability and engagement.

Procedure

The study took place in a usability lab equipped with a control room, two-way mirrors, and audiovisual recording equipment. The prototype was displayed on an i3Touch touchscreen, positioned between two tables, one holding laptops and the other a set of 3D-printed tokens.

Three researchers rotated across distinct roles: facilitator, observer, and interviewer. Only one researcher was present with the participants at a time.

The study was divided into three phases:

1. **Introduction** – A scripted briefing, including historical context about the Battle of Illerup Ådal
2. **Game Test** – Both participants played two rounds: one using tangible tokens, and one using only touch interaction.
3. **Debriefing Interview** – Semi-structured questions were used to explore user impressions and preferences

The interview guide is included in Appendix B.

Thematic Analysis

All interviews were recorded and transcribed. We analysed the responses using thematic analysis following the steps outlined by Braun and Clarke [6]. Our approach was deductive, guided by two predefined themes: *Usability* and *Engagement*.

We first read through all transcripts for familiarisation, then collaboratively reviewed and highlighted quotes. A quote was included if most researchers agreed it was descriptive, unexpected, aligned or conflicted with assumptions, or clearly reflected a user's impression. This process allowed us to systematically surface recurring concerns, positive reactions, and design-relevant themes.

3.1.4 Pilot Study

Before deploying the second iteration at Moesgaard Museum, we conducted a brief pilot study in a university cafeteria to assess system stability, onboarding clarity, and core interaction mechanics under semi-public conditions. This allowed us to observe spontaneous user behaviour and address any final usability issues before the comparative evaluation.

Participants

Nine groups took part, each with two to four participants. Most were university students with varied academic backgrounds and general familiarity with digital interfaces. None had prior exposure to the prototype.

Procedure

The pilot was conducted over the course of one day in a university cafeteria. The prototype was set up with a simple sign inviting passersby to try a historical strategy game. Participants engaged freely, without instruction, playing one or more matches. One researcher observed each session while participants were encouraged to think aloud. Post-interviews focused on clarity and user impressions. The interview guide is included in Appendix E.

Findings

All participant answers were collected and compiled in an Excel spreadsheet for structured review. The answers can be found in the Appendix folder in the file ”Pilot Answers.xlsx”, in Danish.

The pilot confirmed that the prototype was broadly understandable, engaging, and technically stable under semi-public conditions. Most participants quickly grasped the concept of placing tangible tokens to build formations and control units. The interaction was generally intuitive, with users often figuring out the mechanics without needing instruction. Several participants compared the experience to board games or real-time strategy video games, and described the tangible elements as satisfying to use.

While the overall response was positive, the pilot surfaced several minor usability issues. Some users were unsure how to get started or what to do next, particularly during their first moments of interaction. These moments of hesitation highlighted the need to strengthen onboarding and make the interaction flow clearer from the outset.

In response, we implemented a number of targeted refinements prior to the final evaluation at Moesgaard. More interface elements were given subtle animations to make them easier to notice without disrupting the overall aesthetic. We also expanded the guide hand animations to support more phases of the interaction flow, particularly around token placement and battle initiation. Technical adjustments included a more reliable AFK reset system, and slight adjustments to token placement sensitivity.

Although no critical bugs were encountered during the pilot study, the test confirmed that the prototype was stable and intuitive enough to support unguided, repeated use over the course of a full exhibition day.

3.1.5 Comparative Evaluation

This study was the last part of the *use and evaluation in context* stage of the RtD process. It involved deploying the second iteration prototype alongside the original Commander’s Tent installation at Moesgaard Museum. Data collection was triangulated through structured interviews, datalogging, and observational field notes. As the final evaluation in our process, this study provided the empirical foundation for the subsequent reflection and formulation of design implications.

Within-subject testing

We employed a within-subjects design, where each participant interacted with both the original and the redesigned installation. This design enabled us to isolate the impact of design changes on user engagement [20]. However, the lack of datalogs from the original installation limited our ability to statistically compare behavioural patterns, such as interaction issues or frequency of errors. As a result, the analysis primarily draws on qualitative data, including interviews and observations.

Structured Interviews

To support direct comparison between the two installations, we conducted structured interviews. As described by Rogers et al. [32], structured interviews involve asking all participants the same set of predefined questions in a fixed order. This approach ensures consistency, minimises interviewer bias, and makes it easier to compare responses across participants. It is particularly useful when the goal is to evaluate specific aspects of an experience in a systematic and replicable way.

Participants

In total, we spoke with 38 visitors: 24 adults, 11 teenagers, and three children. All had just experienced both installations. Of these, 27 participants took part in follow-up interviews after viewing the short film about the Battle of Illerup Ådal in the cinema. The age distribution is visualised below. Some variation occurred between the two time points, as a few visitors did not continue into the cinema, while others joined their companions there and participated only in the post-cinema interview.

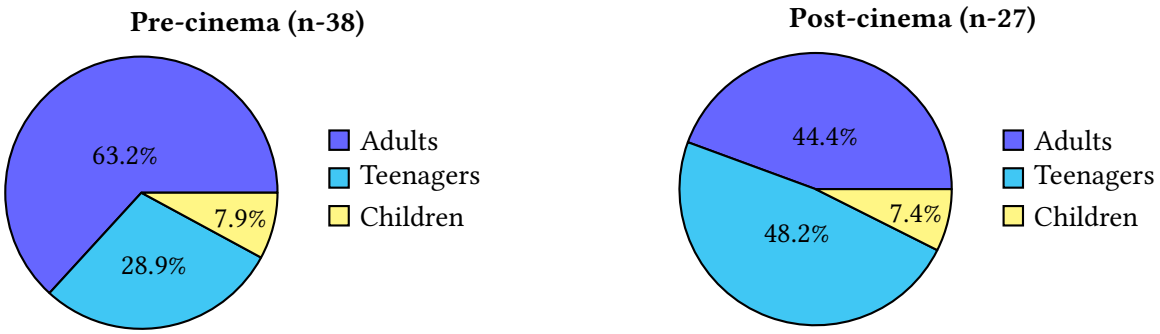


Figure 3.1: Age distribution of participants.

Procedure

To support a triangulated analysis approach, we employed four complementary methods:

- **User Engagement Scale -Short Form (UES-SF** – to evaluate user engagement across four validated factors
- **Structured Interviews** – to collect comparative verbal feedback
- **Datalogging** – to capture usage metrics
- **Observation** – to document real-time behaviours and breakdowns

Visitors were encouraged to interact with both systems before participating in interviews. A follow-up interview was conducted after the cinema, allowing us to capture reflections shaped by the full narrative experience. Additional insight was gained through continuous observation and automated datalogs.

User Engagement Scale - Short Form

To evaluate how users experienced each installation, we applied the UES-SF, a rigorously tested instrument developed by O'Brien et al. [29]. The UES-SF was specifically designed for digital systems and interactive experiences, making it well-suited for evaluating museum interfaces.

The short form condenses the original 31-item UES into a concise 12-item scale, while retaining strong internal consistency and conceptual coverage across four core factors:

- **Focused Attention (FA)** – The extent to which users feel absorbed in the experience and lose awareness of time or surroundings
- **Perceived Usability (PU)** – How effortful or intuitive the interaction feels, including control, clarity, and frustration

- **Aesthetic Appeal (AE)** – The user's impression of the system's visual and sensory qualities
- **Reward (RW)** – The degree to which users find the experience worthwhile, interesting, or personally valuable

The UES-SF is grounded in empirical validation and is widely used for evaluating engagement in HCI and digital museum contexts.

Adaptation for a Museum Setting

Given the constraints of a public exhibition setting, we adapted the UES-SF into a structured comparative interview format. One representative question was selected for each factor, and participants were asked to compare the original and redesigned installation. Each participant was then invited to elaborate on their answer, allowing for both structured comparison and open-ended feedback.

Prior work has shown that the UES has been adapted to fit contextual needs [13], supporting our use of comparative format. In line with recommendations from the *Evaluation Toolkit for Museum Practitioners* developed by Renaissance East of England [31], we simplified the UES-SF by reducing the number of questions and rephrasing them using clear, accessible language suited to a museum setting. The toolkit emphasises the importance of clarity, simplicity, and avoiding unnecessary or overly complex questions in informal public contexts.

The following four questions reflect each of the UES factors in simplified form:

- **Focused Attention:** "Which table was the most fascinating?"
- **Perceived Usability:** "Which table was easiest to understand?"
- **Aesthetic Appeal:** "Which table had the best visual design?"
- **Reward:** "Which table provided the best overall experience?"

As age can influence how visitors engage with museum content [9], we also noted the age category of each participant (child, teenager, or adult). The full pre-cinema interview guide is available in Appendix F.

After watching the short film about the Battle of Illerup Ådal in the cinema, participants were interviewed again to explore how experiencing the full exhibition context influenced their reflections. The follow-up interview began by confirming whether participants had interacted with both installations. Those who had were then asked three additional questions:

- Which table fits best with the overall experience, now that you've been to the cinema?
- Which of the following best explains your choice: immersion, usability, visual appeal, or value of the experience?
- Why?

To aid the post-cinema interview, a printed response sheet listing the four categories was shown, allowing participants to point to the label that best fit their reasoning. These terms, *immersion*, *usability*, *visual appeal*, and *value of the experience*, correspond to the four UES factors: Focused Attention, Perceived Usability, Aesthetic Appeal, and Reward, respectively. This format was chosen especially with younger visitors in mind, as pointing to a visual aid reduces pressure and supports accessibility for children [22]. The rewording also aligns with guidance on using clear, public-facing language in informal evaluation settings [31]. The full post-cinema questionnaire is provided in Appendix G.

This two-phase interview format ensured that our engagement data was grounded not only in isolated interactions, but also in how the installations contributed to visitors' overall interpretive journey. These findings were then triangulated with behavioural data to strengthen the analysis.

To support this triangulation, we applied two methods in parallel: datalogging and observational field notes.

Datalogging

Datalogging is a well-established method in interaction design research for capturing unobtrusive, time-based measures of use and performance [11]. To capture detailed behavioural data, our prototype automatically logged user interactions. This included session durations, formation selections, view times, marker placements, etc. These logs were used to triangulate findings from interviews and observations.

Observational Notes

Observation is a foundational technique in field-based HCI studies, offering rich contextual understanding of user experience that complements structured data collection [32]. Two researchers documented interaction patterns and visitor behaviours during the evaluation. This included noting points of confusion, social dynamics, hesitation, and visible signs of engagement or disengagement. Observational insights provided important contextual grounding for interpreting interview responses and datalogs.

4 The Commander's Tent

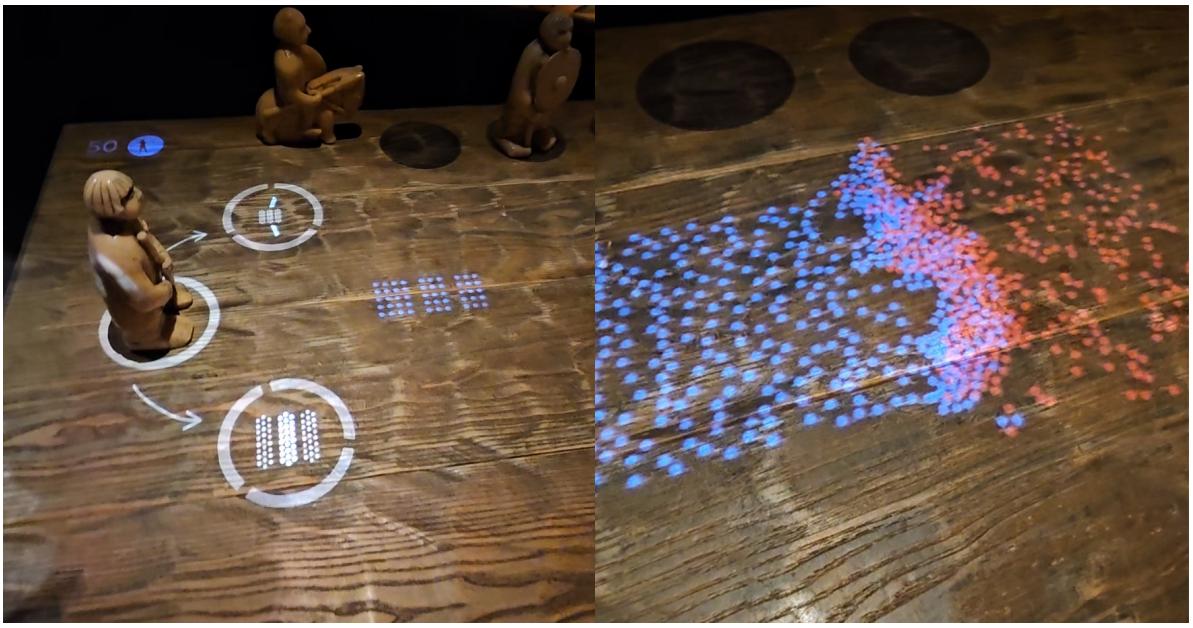
Moesgaard Museum, located near Aarhus, Denmark, is known for its integration of archaeology, anthropology, and interactive technologies [26]. As part of our initial site visits, we identified *The Commander's Tent* as a promising candidate for redesign due to its strong use of tangible interaction, narrative context, and potential for visitor engagement, see Figure 4.1b.

Originally installed in 2014 as part of the opening of the new Moesgaard Museum building. The Commander's Tent is one of the first installations in the museum's Iron Age exhibition. Visitors interact with a wooden strategy table placed inside a full-sized canvas tent, see Figure 4.1a, creating a distinct enclosed space that enhances the immersive experience. It is part of a larger exhibition revolving around *The Battle of Illerup Ådal*[1], which forms a central narrative within the Iron Age exhibition. It allows visitors to simulate battle tactics from the conflict. By placing wooden tokens into illuminated rings, users can activate and choose between different battle formations. Once a formation is selected, a digital battle is projected onto the table surface, visualising the outcome between a blue (player) and red (enemy) army, see Figure 4.2b.

(a) The Commander's Tent. (b) The table inside.

Figure 4.1: The Commander's Tent installation at Moesgaard Museum.

[1] https://www.sciencenordic.com/anthropology-archaeology-denmark/an-entire-army-sacrificed-in-a-bog/1375773



(a) Formation selection via illuminated rings. (b) Simulated battle in progress.

Figure 4.2: Screenshots of The Commander's Tent installation.

4.1 Usability Evaluation Results

To assess the usability of the original installation, we applied Jacob Nielsen's Usability Problem Severity Ratings [27], as outlined in Section 3.1.2. This method allowed us to identify and prioritise issues based on their severity, supporting structured iteration and redesign.

- **Cosmetic Problems (Severity 1):**
  - *Projection misalignment:* The projection slightly missed the table, resulting in parts of the projection being displayed on the floor.
- **Minor Usability Problems (Severity 2):**
  - *Lack of back buttons:* The interface did not include back buttons to navigate to previous states.
  - *Token activation inconsistency:* Although there were three tokens, only one could be active at a time. Archers, even when inactive, sometimes appeared on the team according to the selected formation.
  - *Lack of audio feedback:* The game lacked audio, which could have enhanced the feedback and immersion.
  - *Multiplayer misunderstanding:* Several users assumed that the installation supported two-player interaction from opposite sides. In reality, only one side was active, which led to confusion and reduced engagement.

- **Major Usability Problems (Severity 3):**
  - *Token interaction confusion:* It was not initially clear that only one token could be active at a time and that the same token needed to be moved to the other field to select a formation.
  - *Initial learning curve:* It was unclear how to interact with the table at first. It took some time to realise how it worked, including the meaning of red rings under the tokens, which indicated either incorrect placement or unsuitable units for a battle.

Our evaluation of The Commander's Tent uncovered several usability issues that highlighted clear opportunities for refinement. Minor problems included inconsistencies in token activation, where certain tokens, such as the spearman, would spawn both spearmen and archers, even when the archer's token had not been placed. There was also notable confusion around multiplayer interaction. Some users assumed the installation allowed two players to engage from opposite sides, only to discover that formation selection was restricted to a single side. This misunderstanding reduced engagement and limited the perceived openness of the system. More critical issues involved unclear interaction mechanics. For example, many users did not realise that only one token could be placed on the battlefield at a time, and that the same token had to be used to select between two available formations. As a result, several participants attempted to place all three tokens simultaneously.

These findings informed the redesign priorities for our first iteration prototype, discussed in the following chapter.

5 First Iteration

This chapter presents the first iteration prototype developed during P9, based on our initial analysis of The Commander's Tent. The prototype introduced new mechanics and interaction modes, which were evaluated through a usability study. Findings from this evaluation helped guide the development of the second iteration.

5.1 The Commander's Tent: First Iteration

Our first redesign reimagined the exhibit as a HUI, combining tangible tokens with touchscreen interaction. Leveraging an i3Touch touchscreen and Unity, the prototype enabled dynamic token placement and supported multiplayer. It introduced features such as varied map layouts, randomised weather effects, and sound design to improve usability and user engagement. While preserving the core mechanics of the original installation.

Below are three photos of the prototype:

Figure 5.1: First iteration being played.

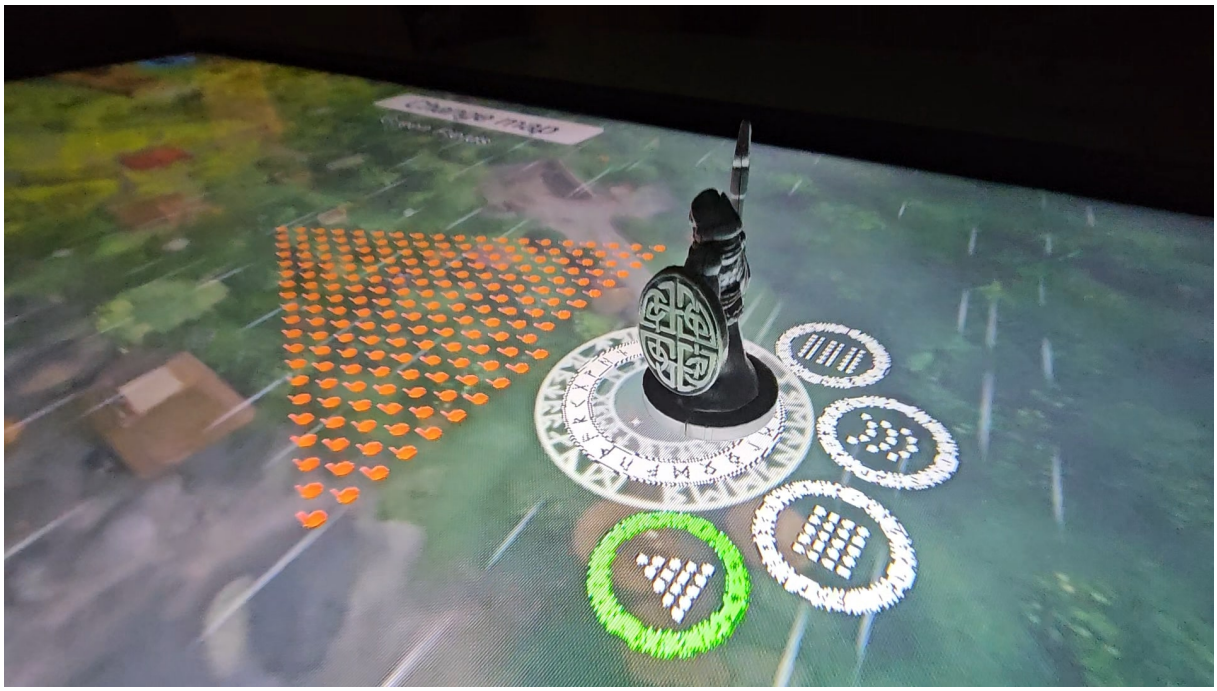


Figure 5.2: Close-up of a token using the wedge formation.

Figure 5.3: Screenshot of the game.

5.2 Analysis and Results

This section summarises findings from our Usability Problem Severity Ratings and thematic analysis. It builds on insights from the first iteration usability study presented in Section 3.1.3.

5.2.1 Usability Problem Severity Ratings

After the usability study, we reviewed observation notes and video recordings to identify and rate usability issues using the severity scale described in Section 3.1.2.

All observed issues were compiled and categorised by severity: six cosmetic, ten minor, nine major, and one catastrophic.

A full list of issues (in Danish) is available in Appendix C. Below are selected examples from each severity level:

- **Cosmetic Issues (Severity 1):**
  - *Tokens overlapping the tip:* Tokens could occasionally overlap the tip displayed at the end of the game. Users could still access the tip by moving the token, but this extra step reduced the seamlessness of the experience.
  - *Missing sound for 'Ready' button:* The sound did not play when the last participant clicked the 'Ready' button. This did not impact functionality but reduced the perceived polish of the system.
- **Minor Usability Issues (Severity 2):**
  - *Formation overlap:* Formations could occasionally overlap, creating a visually odd appearance. However, this resolved itself once the game started.
  - *Units spawning inside objects:* Units could spawn inside objects, but would quickly pop outside once placed. While functional, this introduced unnecessary friction to the interaction.
- **Major Usability Issues (Severity 3):**
  - *Tokens placed too close together:* If a token was placed too close to another token, users were required to pick it up and place it again further away, disrupting the flow of gameplay.
  - *Moving tokens after placement:* Moving a token after it was placed broke the illusion that tokens and units were tied together, diminishing the immersion.
  - *Units failing to spawn:* Users sometimes couldn't spawn units, requiring them to reposition the token and try again, adding unnecessary effort to the interaction.
- **Usability Catastrophes (Severity 4):**
  - *Can't spawn units:* One participant was unable to spawn units, which meant that the game could never start. This required us to intervene and restart the game.

5.2.2 Thematic Analysis

To analyse the interview data, all transcripts were first produced and then examined using the six-step thematic analysis process described in Section 3.1.3.

This process led to 276 initial quotes, which were transferred to a shared *Miro* board for collaborative coding. Through iterative refinement, we grouped and reorganised the material, ultimately condensing it into 185 quotes sorted across nine categories, labelled **C1** to **C9**.

A summary of these categories is provided in 5.1, the full thematic analysis with key quotes is available in Appendix D.0.2. The interview answers can be found in the Appendix folder in the file "First Iteration - Interview Answers.xlsx". The full interview transcripts from the usability study can be found in the Appendix folder as PDF files, in Danish.

Codes (*N*)	Sample Codes	Categories	Themes
9	"It's fairly intuitive."	**(C1)** *Learning Curve*	**Usability**
23	"More fun to place the figures."	**(C2)** *Interaction*	
16	"I think there was a need for more control."	**(C3)** *Control*	
11	"I wouldn't want to give away too much."	**(C4)** *Visibility Issues*	
34	"It would be cool if we could rotate them."	**(C5)** *Improvements*	
19	"You feel like (horses) should be strong."	**(C6)** *Expectations*	**Engagement**
15	"I really liked the atmosphere."	**(C7)** *Immersiveness*	
14	"We want to beat each other."	**(C8)** *Multiplayer*	
44	"I thought it was really fun."	**(C9)** *Entertainment*	

Table 5.1: Overview of themes derived from participant interviews, categorised under Usability and Engagement.

5.2.3 Summary

The thematic analysis showed that participants generally found the game intuitive and enjoyable, praising its visual design, immersive atmosphere, and simple mechanics. Many highlighted the engagement offered by tangible interaction compared to touch-only play.

However, several issues were raised. Participants noted imbalances between unit types, especially involving horses and archers, and felt limited in how their tactical choices influenced outcomes. Technical frustrations such as alignment problems, frozen elements, and unclear resetting or repositioning also emerged. The shared screen setup further reduced strategic secrecy by making it easy to react to an opponent's moves. To improve the experience, participants suggested more flexible unit placement and rotation, dynamic battlefield elements like weather or historical context, and clearer digital visuals for unit types to support immersion.

These findings, together with the results from the usability problem ratings, directly informed the development of our second iteration prototype. They helped identify key barriers to user engagement, including unclear feedback, limited tactical influence, and interaction issues. The next prototype focused specifically on augmenting short-term engagement by improving feedback clarity, refining unit behaviour, and increasing player agency.

6 Second Iteration

This chapter presents the second iteration of the Commander's Tent prototype, developed during P10. This version aimed to improve feedback clarity and overall user engagement. The following sections describe the system's functionality, technical implementation, and physical setup as deployed for evaluation at Moesgaard Museum.

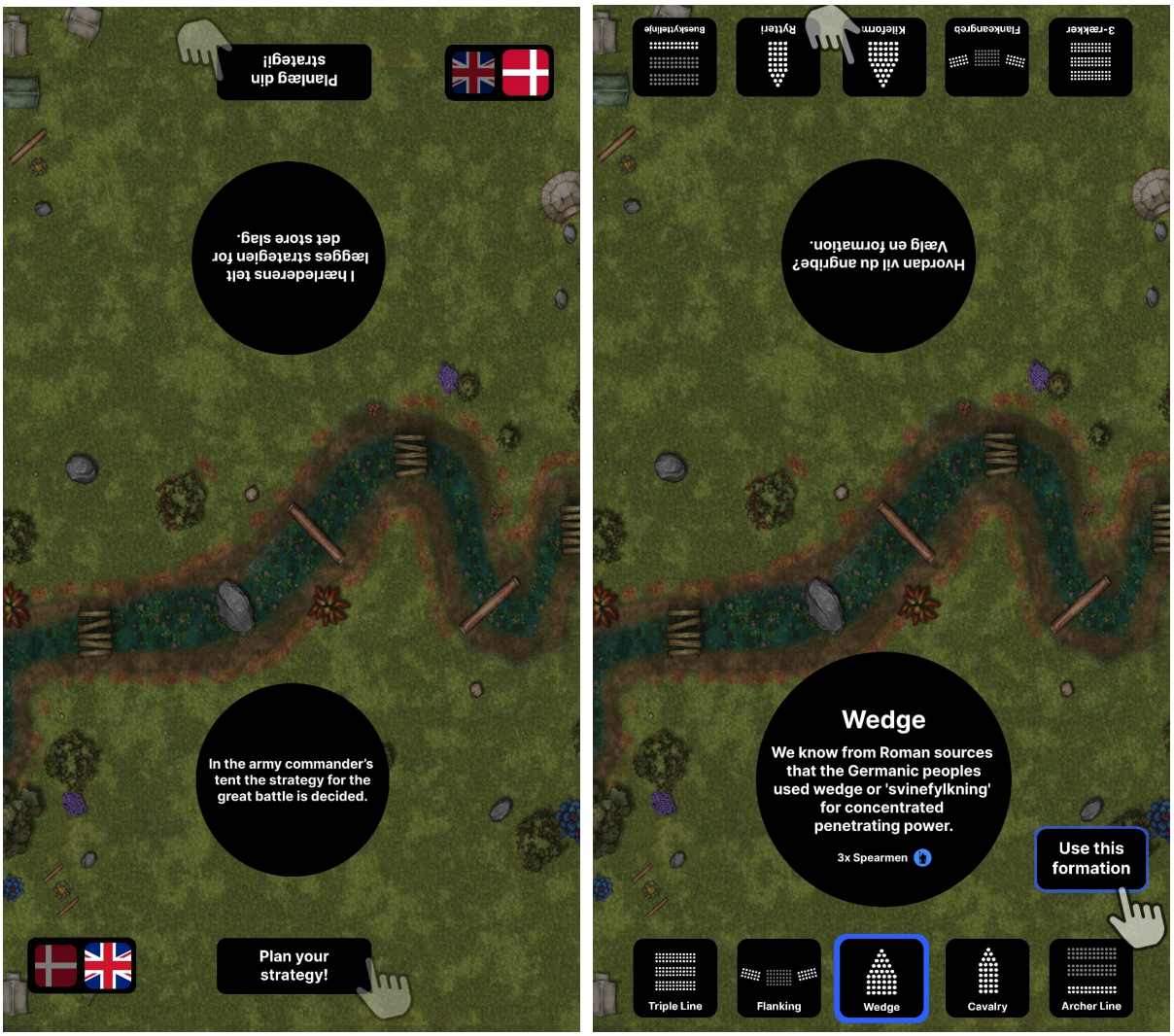
6.1 The Commander's Tent: Second Iteration

The second iteration of the prototype builds upon the concept of The Commander's Tent. While still implemented in Unity, it now runs on a MultiTaction MT557D table, as shown in Figure 6.1, which enables real-time recognition of fiducial markers attached to 3D-printed tokens.

Figure 6.1: The prototype setup at Moesgaard.

Each player begins by selecting their preferred language using the touch interface, see Figure 6.2a. Language selection is independent for each player, and their game states prior to battle are also handled separately. This means one player can still be reading about formations and deciding which to choose, while the other may already be building their formation.

Following language selection, players proceed to formation selection, see Figure 6.2b. The menu presents all five available formations, each accompanied by descriptive text. Players can freely browse between options, select a formation, and return to the menu if they wish to change their choice. This stands in contrast to the original installation, where players chose between only two options per token and received descriptive feedback only after the battle.



(a) Language selection interface.

(b) Formation selection menu.

Figure 6.2: Touch interface used for selecting language and formation.

Once a formation is selected through the touch interface, players must construct it by placing the corresponding tokens on their side of the table, see Figure 6.3a. The required configuration depends on the chosen formation. For example, building the Wedge formation involves placing three spearman tokens in a triangular layout. When positioned correctly, the system spawns a wedge-shaped arrangement of units, see Figure 6.3b. Other formations, such as Archer Line or Flanking, use a mix of token types like spearmen and archers. The system detects both the type and position of each token and uses this information to assemble the complete formation dynamically. Once both players have placed their tokens on the placement markers on the field, a five-second countdown begins. If a token is moved away from its placement marker during this phase, the units will once again follow the token, and the countdown will be cancelled.

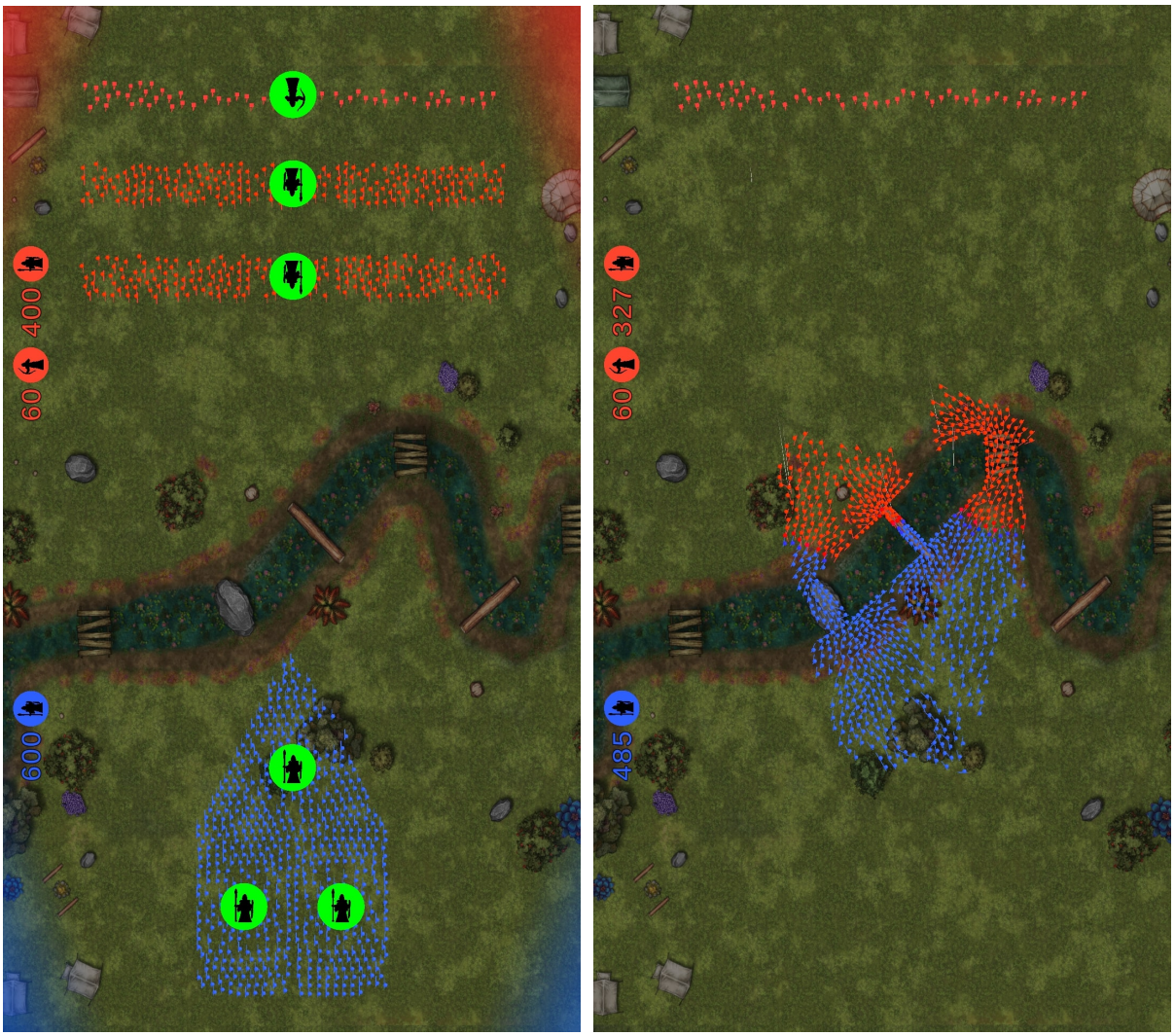
(a) Unit groups spawning based on token placement.

(b) Formation being constructed with tokens.

Figure 6.3: Players build formations using physical tokens.

Before the battle begins, each team's units are counted and visually represented along the edge of the battlefield, see Figure 6.4a. This allows any observers to follow the composition of each army. In the example shown, the blue team has selected the Wedge formation, placing three spearman tokens with 200 units each (600 spearmen total). The red team has selected the Archer Line formation, consisting of two spearman tokens (400 spearmen total) and one archer token, spawning 60 archers.

During the battle, the three unit types behave differently, see Figure 6.4b. Cavalry units move faster and have higher health. Archers remain at range and only engage in melee combat if enemies come close. Spearmen advance directly and rely on overwhelming numbers.



(a) Units getting counted.

(b) Battle begins.

Figure 6.4: Players build formations using physical tokens.

After the battle, players are shown a short explanation describing why their side won or lost, based on unit matchups, see Figure 6.4b. The game follows a rock–paper–scissors logic: cavalry defeats archers by reaching them quickly with their speed, spearmen overwhelm cavalry through numbers, and archers counter spearmen by attacking from a distance before they can get close.

The prototype also logs all interactions during a session. These logs serve two purposes: they support evaluation and generate in-game statistics. At the end of each battle, the game displays a summary showing how many soldiers fell during the battle, how many commanders have tested their strategy so far that day, and the total number of soldiers defeated across all games that day, see Figure 6.5b. The end screen also informs players that they are now ready for battle, serving as a narrative transition and encouraging them to continue to the short film in the cinema that follows in the exhibition.

(a) Narrative end screen.

(b) Battle statistics summary at the end of a game.

Figure 6.5: End-of-game screen providing narrative and statistical feedback.

In addition to gameplay features, the system includes an automated AFK (away-from-keyboard) mechanism. If no interaction is detected for a defined period of time, the system resets to the start screen. This ensures that new visitors do not encounter the prototype in the middle of other players' sessions, supporting consistent onboarding and uninterrupted flow.

Several changes distinguish this prototype from the original installation:

- Support for multiplayer interaction and multiple tangible inputs
- Formation selection through a browsable menu with detailed descriptions
- Physical construction of formations using individual tokens
- Pre-battle guidance and visual feedback
- Updated map layout and visual design

- Integrated sound effects
- Post-battle explanations tailored to outcome
- Language selection interface
- Logging of all relevant player actions, to show the daily usage

6.2 Implementation

This section describes how the prototype was built, including marker tracking, Unity integration, and physical design.

6.2.1 Fiducial Tracking

To enable physical interaction with the digital game interface, we used fiducial markers on the bottom of 3D-printed tokens, see Figure 6.6. These markers are recognised by the MultiTaction table's built-in infrared camera grid, which continuously tracks their position and rotation on the screen surface.

Figure 6.6: Picture of a fiducial marker.

Tracking data is transmitted to our Unity application using the TUIO protocol, an open standard for tangible interaction. We integrated this with Unity through the open-source Uniducial library[1], which interprets marker movements and relays them as game inputs. This allowed each token to act as a persistent game object, which could be moved, repositioned, and used to trigger in-game events in real time.

[1] `https://code.google.com/archive/p/uniducial/`

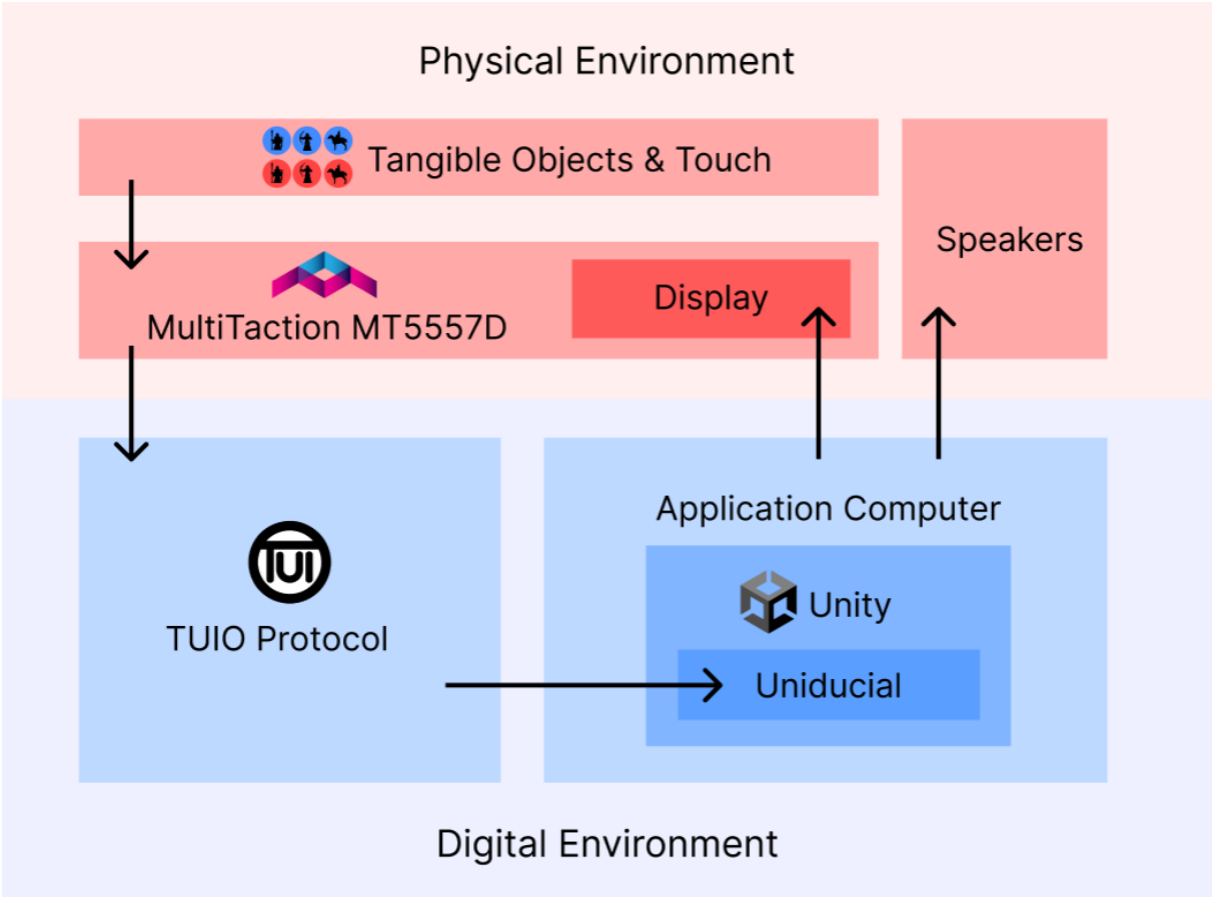


Figure 6.7: Overview of the components used.

6.2.2 Unity

The digital component of the prototype was developed in Unity. We began by building a foundational system where markers could be tracked and linked to in-game spawner objects. Each spawner served as an anchor point for a group of units that followed it as it moved, allowing the physical tokens to control digital unit formations.

To manage unit movement, we used Unity's built-in NavMesh system, which is part of its AI framework. Each unit was implemented as a NavMeshAgent to enable autonomous navigation within the environment. This ensured smooth, collision-aware movement as units adjusted their positions during battles or formation shifts.

We imported the core spawning and combat logic from the first iteration of the game, adapting it to support new player-driven formation creation. Instead of selecting formations from a menu centered on the individual tokens, players now physically construct formations by placing tokens in specific layouts on the screen surface.

6.2.3 Physical Design

To support repeated public use, we designed a physical enclosure around the MultiTaction table. This structure provided a space for storing tokens, concealed the computer and cables beneath the table. While aesthetics were kept simple, the design prioritised practicality and durability.

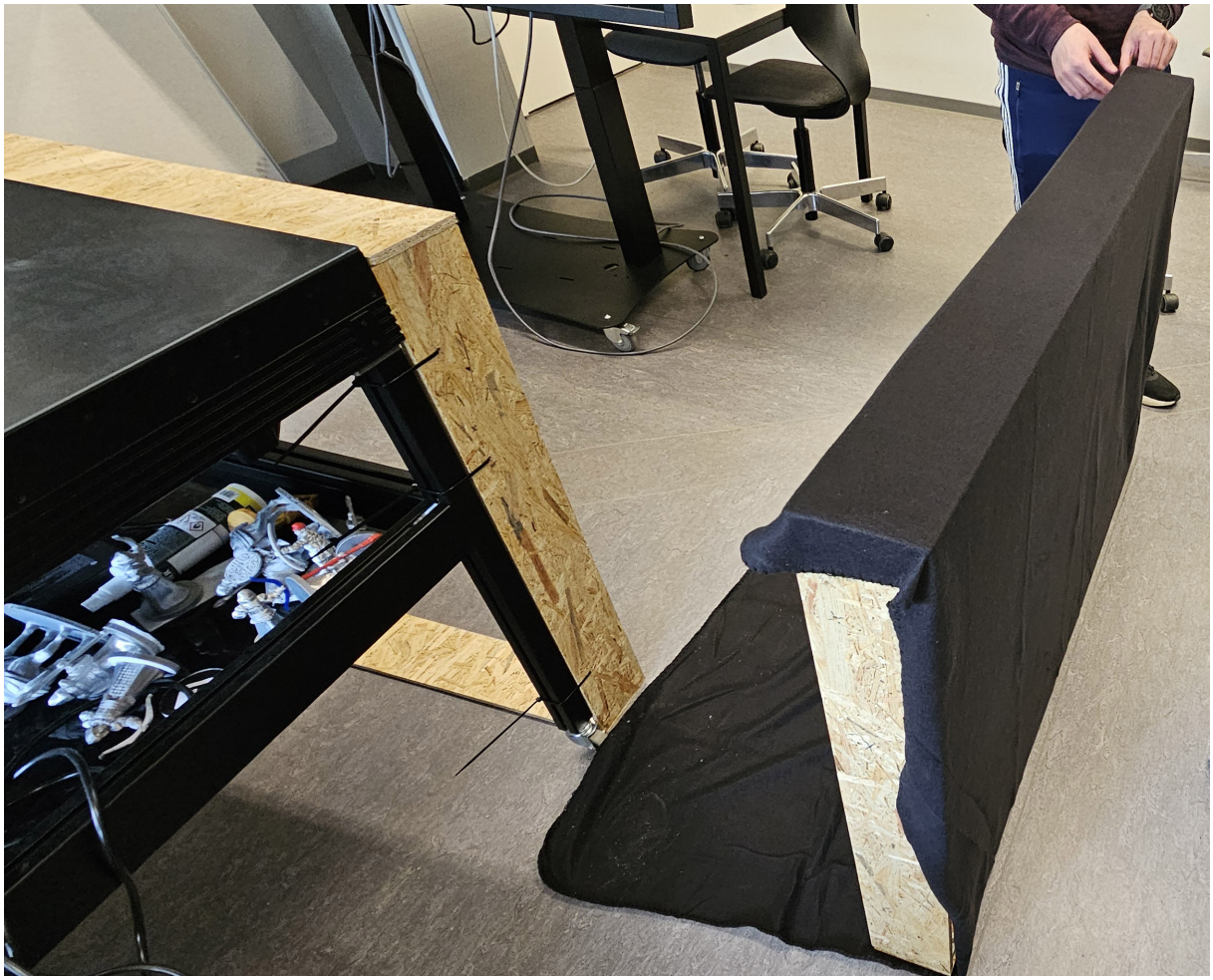


Figure 6.8: Picture of the construction of the enclosure.

Alongside the enclosure, we produced a set of 3D-printed tokens: spearmen[2], archers[3], and cavalry tokens. The cavalry tokens were assembled by combining a modified spearman model[4] with a horse rider model[5], using Blender to align and merge them into a single printable figure. Each token was fitted with a coloured base to indicate team affiliation, either blue or red.

[2] https://www.thingiverse.com/thing:5572320
[3] https://www.thingiverse.com/thing:5574307
[4] https://www.thingiverse.com/thing:1296083
[5] https://www.thingiverse.com/thing:4267780

(a) The Spearman token. (b) The Cavalry token. (c) The Archer token.

Figure 6.9: The tokens.

Each team was limited to seven units to support five of the six original formations from the Commander's Tent installation. We excluded the "drive-by cavalry" formation, where cavalry would ride by once and throw spears. Formations such as Triple Line and Flanking required precise unit combinations, which led us to include three spearmen, two archers, and two cavalry tokens per team.

Figure 6.10: Overview of the 14 tokens.

7 Comparative Evaluation

This chapter presents the main findings from the final stage of the thesis. The focus of this comparative evaluation is engagement, examined through a comparative study of the second iteration prototype and the original Commander's Tent installation. The study was carried out in situ at Moesgaard Museum, where 38 visitors experienced both systems.

To assess engagement, we applied structured interviews based on the User Engagement Scale - Short Form, supported by observational field notes and datalogging. These methods are described in detail in Section 3.1.5 of the Methodology chapter. Together, they provided a triangulated foundation for understanding how users interacted with and responded to each version of the installation.

Interview responses were analysed through the four UES engagement factors: Focused Attention, Perceived Usability, Aesthetic Appeal, and Reward. These dimensions structured both the pre-cinema and post-cinema interview formats. In the sections that follow, we present these interview results, followed by insights drawn from observations and the datalogs. The chapter concludes with a summary of findings.

7.1 Pre-cinema Interviews

We applied a deductive coding approach guided by the four UES engagement factors, as detailed in Section 3.1.5. Each factor was represented by a single comparative interview question. In total, 76 quotes were extracted and collaboratively coded. Participants frequently referred to the two systems as "touch" (the redesigned installation) and "wood" (the original installation), and these terms are retained in the quotes.

The pre-cinema interview answers can be found in the Appendix folder in the file "Pre-cinema Answers.xlsx".

Quotes were first grouped by interview question using a shared *Miro* board. Through iterative refinement, these were then clustered into 13 thematic categories **(C1–C13)**, each mapped to one of the four engagement factors. Participant groups are referenced as "G".

Table 7.1 summarises these categories and their associated engagement factor.

Codes (*N*)	Sample Quotes	Categories	Factors (UES)
5	"[Touch] because there was more strategy involved." (G4)	**(C1)** *Strategy*	Focused Attention
3	"Because [touch] was multiplayer." (G2)	**(C2)** *Social Aspect*	
6	"[Touch] is more interactive." (G4)	**(C3)** *Interaction Possibilities*	
6	"[Wood] was more authentic." (G8)	**(C4)** *Atmosphere*	
9	"[Wood] just felt simpler." (G6)	**(C5)** *Simplicity*	Perceived Usability
4	"I didn't understand the wooden table." (G13)	**(C6)** *Confusion*	
4	"[Touch] There were guide hands." (G1)	**(C7)** *Guidance*	
5	"[Touch] was more modern." (G7)	**(C8)** *Modernity*	Aesthetic Appeal
6	"The wooden table had a better atmosphere." (G6)	**(C9)** *Authenticity*	
9	"[Touch] Nice screen and beautiful figures." (G4)	**(C10)** *Design*	
7	"[Touch] Multiplayer was fun." (G10)	**(C11)** *Social Aspect*	Reward
4	"[Touch] More tactics and strategies." (G13)	**(C12)** *Design*	
8	"Touch felt more alive." (G7)	**(C13)** *Depth*	

Table 7.1: Overview of 76 coded quotes from participant interviews, grouped into 13 categories and linked to the four UES-SF engagement factors based on the evaluation questions. Group numbers are noted in parentheses.

7.1.1 Which installation is the most fascinating? *(Factor: Focused Attention)*

38 participants answered this question. Of these, 32 found the redesigned installation to be the most fascinating, while four preferred the original installation. The remaining two gave no clear preference. This distribution is visualised in Figure 7.1.

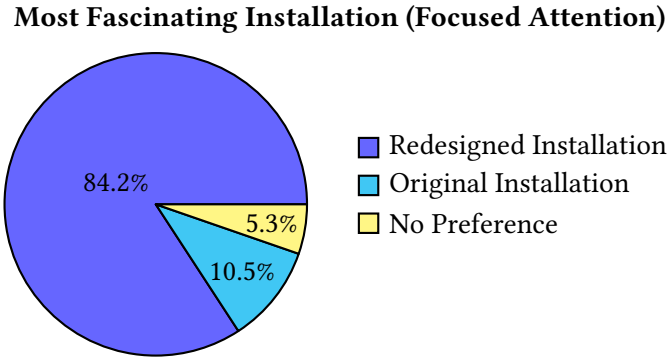


Figure 7.1: Participant responses to which installation was most fascinating (n=36).

(C1) Strategy

Several participants highlighted game strategy and tactics as key reasons why they found the redesigned installation fascinating. One explained, *"Because there was more strategy involved."* (G4). Another remarked, *"Because it's RTS (Real Time Strategy), which I personally enjoy playing."* (G3). A third elaborated, *"Because there were maps, and the battlefield actually mattered with obstacles."* (G15). Visual complexity also played a role, with one participant noting, *"There were more characters in the game. Also because it was an RTS game. Also a real game."* (G11).

These responses suggest that adding strategic depth and dynamic content can help sustain attention by encouraging users to think, plan, and actively participate in the experience.

(C2) Social Aspect

The multiplayer feature was another major source of fascination. One participant said, *"Because it was multiplayer."* (G10), while another noted, *"You could do more, and it was multiplayer."* (G7). A third highlighted the competitive aspect, stating, *"Because of multiplayer. You could play against each other."* (G2).

These reflections point to the power of social engagement and shared play. Competition appeared to deepen users' attention and sustain their involvement.

(C3) Interaction Possibilities

Participants frequently highlighted the variety of features in the redesigned installation as a source of fascination. One noted, *"Because it was more interactive. There were more things you could do with it."* (G4), while another observed, *"There were more elements on the touch table. There were more options."* (G8). Visual dynamics also contributed, as one participant explained, *"The screen was more fascinating with the different maps."* (G1).

Rather than a single standout feature, it was the combination of interactive elements, visuals, options, and responsiveness that appeared to capture and hold attention over time.

(C4) Atmosphere

A smaller group of participants found the original installation more fascinating, often citing its atmosphere, authenticity, and nostalgic quality. One participant wrote, *"It was more authentic."* (G8), while another expressed wonder at the hidden technology: *"Because it was amazing to understand how such a simple wooden table could work. I couldn't see any wires."* (G13). A third highlighted a personal connection, saying, *"I found the wooden table most fascinating because I find it nostalgic. I've visited and used it over several years."* (G6). Another described it as, *"It's more rustic, like a proper strategy table."* (G17).

These responses remind us that fascination is not only driven by complexity or novelty. Material qualities and contextual fit also play a vital role in sustaining attention.

Summary

Most participants found the redesigned installation more fascinating, often pointing to its interactivity, multiplayer format, and strategic complexity. These elements appeared to promote sustained attention by encouraging exploration, competition, and decision-making. At the same time, a smaller group valued the original's authenticity and atmospheric coherence, underscoring that focused engagement can also arise from simplicity and material presence. Together, these insights suggest that HUIs should offer multiple pathways to engagement, both digital and physical.

7.1.2 Which installation was easiest to understand? *(Factor: Perceived Usability)*

38 participants answered this question. Of these, 22 found the redesigned installation easiest to understand, while 12 preferred the original installation. The remaining four gave no clear preference. This distribution is visualised in Figure 7.2.

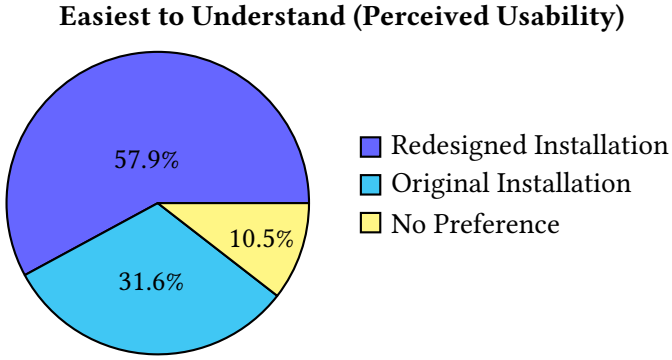


Figure 7.2: Participant responses to which installation was easiest to understand (n=38).

(C5) Simplicity

Participants who found the original installation easiest to understand often cited its minimalism and reduced complexity. One participant said, *"The wooden table is more simple. Fewer options."* (G6), while another explained, *"The wooden table seemed easiest, but maybe only because I'm older."* (G9). Others described it as *"more straightforward"* and *"just a board, not overloaded with impressions"* (G22). The physical simplicity also extended to interaction, with comments like *"Because only two movements were required"* (G2) and *"There were fewer movable pieces, and it felt more streamlined."* (G24). These responses suggest that reduced interaction complexity can support usability by lowering cognitive load.

At the same time, several participants appreciated how the redesigned installation balanced complexity with intuitive onboarding. One remarked, *"It was easy to understand. You could get started quickly."* (G14), while another noted, *"The format was familiar, you already know how games work."* (G14). This contrast highlights how usability may stem from either simplicity or familiarity, depending on users' expectations and prior experiences.

(C6) Confusion

Some participants found the original installation harder to grasp, especially without clear indicators of what to do. One said, *"The touch table was easier because the wooden one seemed mysterious."* (G18), while another explained, *"We didn't understand the wooden table at first. I actually thought it was a touchscreen."* (G20). Others simply stated, *"The wooden table was harder to understand."* (G22).

These comments point to the risk of ambiguity in tangible-only systems, especially when affordances are not made visually or physically explicit.

(C7) Guidance

Participants frequently praised the digital guidance features built into the redesigned installation. The combination of guide hands, text prompts, and visual highlights helped users quickly understand how to interact. One participant wrote, *"There were those guide hands showing what to do."* (G1), while another explained, *"There were technical aids we're familiar with, highlighting and guide hands, for example."*

(G14). A third noted, *"There was both text and a guide hand to guide you."* (G23).

These responses highlight the role of embedded cues and familiar visual metaphors in improving onboarding and overall usability.

Summary

Most participants found the redesigned installation easier to understand, often citing its use of familiar visual cues and built-in guidance features. These digital aids helped reduce onboarding friction and made the experience more accessible across age groups. At the same time, a significant portion of participants preferred the original installation's simplicity, which they associated with clarity and ease of use. These contrasting perspectives suggest that usability in HUIs can be supported through either intuitive digital scaffolding or reduced interaction complexity, depending on the visitor's prior experience and preferences.

7.1.3 Which installation had the best visual design? *(Factor: Aesthetic Appeal)*

38 participants answered this question. Of these, 20 felt the original installation had the best visual design, while 17 preferred the redesigned installation. The remaining participant gave no clear preference. The results are visualised in Figure 7.3.

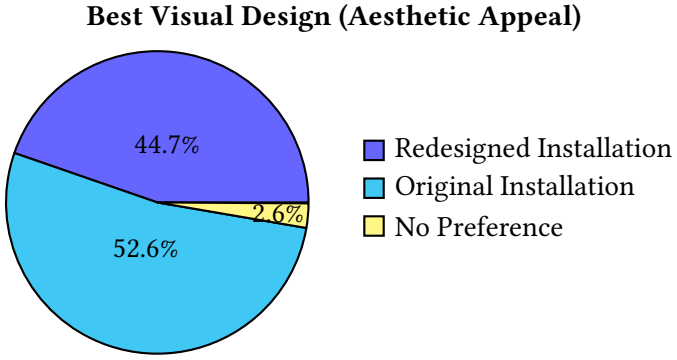


Figure 7.3: Participant responses to which installation had the best visual design (n=38).

(C8) Modernity

Participants who preferred the redesigned installation often pointed to its modern, digital aesthetic. One participant simply stated, *"It's more modern."* (G7), while another highlighted the multimedia elements: *"Because of the sound, lights, colours, and the touch interface."* (G18). Others appreciated the increased visual richness and interactivity, commenting on features like *"There were many more colours."* (G16) and *"Because it actually had a real screen."* (G5).

These comments reflect an appreciation for high-tech visuals and sensory stimulation, particularly among visitors drawn to interactive or digitally-enhanced museum experiences.

(C9) Authenticity

In contrast, many participants valued the original installation for its authentic, handcrafted appearance and how well it fit the surrounding context. One wrote, *"Because it is more authentic."* (G8), while another shared, *"I prefer things made of wood."* (G3). Several pointed to the wooden figures as aesthetically appealing, with one saying, *"I liked the wooden figures."* (G1).

The setting also played a role in how the visuals were perceived. One participant remarked, *"The wooden table had a better atmosphere inside the tent."* (G9), while another explained, *"It had atmosphere. It matched the rustic surroundings."* (G17). A third summarised, *"The wooden table is more old school and more atmospheric with the tent and everything."* (G6).

These responses indicate that aesthetic appeal is not solely about polish or visual effects, but also about the consistency of materials, the fit with the physical and historical context, and the emotional atmosphere created. Participants valued how the wooden elements contributed to a sense of authenticity, reinforcing the immersive qualities of the installation.

(C10) Design

Participants commented on individual design elements across both installations. The redesigned version was described as having a *"nice screen and beautiful figures"* (G11), a *"nicer screen and better-looking figures"* (G4), and being *"much more inviting with tips and guidance"* (G14). One also appreciated the inclusion of *"maps"* (G13), which added visual context to the gameplay.

Meanwhile, the original installation was praised for its clean, minimal aesthetic. As one participant noted, *"Because the wooden table was simple."* (G2), and another added, *"The wooden figures were prettier."* (G1).

These reflections suggest that aesthetic preferences varied not only by visual style but also by the perceived harmony between design and setting.

Summary

Unlike the other engagement factors, most participants felt that the original installation had the best visual design. This preference was often linked to its authentic materials, atmospheric coherence, and alignment with the physical setting. By contrast, those who favoured the redesigned installation highlighted its modernity, visual richness, and digital responsiveness. These opposing views suggest that aesthetic appeal in HUIs is not purely a matter of visual polish, but also of contextual fit and emotional tone. Designers must carefully balance digital enhancements with the surrounding environment to maintain immersion and thematic integrity.

7.1.4 Which installation gave the best overall experience? *(Factor: Reward)*

38 participants answered this question. Of these, 33 felt that the redesigned installation provided the best overall experience, while five preferred the original. The results are shown in Figure 7.4.

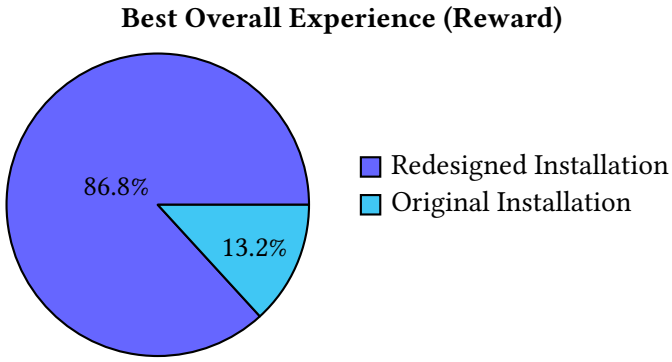


Figure 7.4: Participant responses to which installation provided the best overall experience (n=38).

(C11) Social Aspect

A key part of the redesigned installation's appeal was the ability to play together. Several participants described the multiplayer functionality as especially fun and engaging. One said, *"It was fun with multiplayer."* (G10), while another highlighted, *"There was multiplayer. You could play against your friends."* (G2). The social dynamic was further reinforced by one group who remarked, *"Everyone could play together. We took turns. It felt like a little tournament."* (G5). Another added, *"Because there was multiplayer, and you could interact across the table."* (G17).

These responses suggest that the social dynamics of multiplayer play contributed significantly to the sense of enjoyment. Playing against others and interacting across the table made the experience feel more engaging and memorable, reinforcing the idea that shared play can enhance the perceived value of an interactive installation.

(C12) Design

The experience with the redesigned installation was also driven by the game's depth, variation, and tactical elements. One participant described it as *"more interactive, with more tactics and strategies."* (G4), while another wrote, *"There's more replayability. More variation."* (G14). Another participant added, *"Because of the terrain and challenges. More strategy and immersion."* (G13).

Some also appreciated the level of control and feedback, as one wrote, *"Because of the options. There were statistics and battlefield obstacles. It would've been great if there were a custom mode."* (G11). The game experience was sometimes compared to known formats, as one participant noted, *"It reminded me a bit of a board game with logic. Almost like Stratego."* (G18), and another said, *"It could do much more, and there were more characters."* (G16).

A few participants still preferred the original installation due to its physical setting. One simply stated, *"Because of the atmosphere."* (G5), pointing to the importance of the tent environment and the installation's integration with the larger exhibition.

These reflections indicate that the redesigned installation's depth and flexibility played a central role in shaping the overall experience. Participants valued not only the strategic variation and replayability, but also the sense of control and familiarity it offered through features like environment, feedback, and recognisable game elements. While a few still appreciated the original installation's atmosphere, the majority found the expanded interaction possibilities of the redesign to be more engaging and satisfying.

(C13) Depth

Design and physical interaction also played a role in shaping the experience. One participant explained, *"Because of the screen you could touch."* (G1), while another noted, *"Touch was better. It felt more alive."* (G7).

Some reflections also addressed age-related preferences. One participant said, *"Old folks like me prefer something beautiful, whereas young people probably prefer digital tables."* (G9). Another added, *"The touch table was better because it was more colourful."* (G12). A further comment highlighted the added richness of content and interaction: *"You could do more, and it was more fun and exciting to see statistics about how many had died in the battle, and how many others had played during the day."* (G16).

These responses suggest that the redesigned installation's sensory richness and interactive qualities contributed to a more vivid and engaging experience. Participants described it as feeling more "alive", with some linking their preferences to age or visual appeal. This points to how physical interactivity and digital responsiveness can enhance depth, while also highlighting the influence of personal and generational expectations on what feels rewarding.

Summary

Most participants felt that the redesigned installation delivered the best overall experience, often citing the social dynamics of multiplayer gameplay, the strategic variety, and the responsive interface. The ability to play together, explore different tactical options, and receive visual feedback contributed to a sense of enjoyment and engagement that felt richer and more interactive. At the same time, a few participants still valued the original installation's atmospheric setting, pointing to the role of physical context in shaping user satisfaction. Overall, the findings suggest that rewarding experiences in HUIs are supported by both meaningful variation and opportunities for shared, socially engaging interaction.

7.2 Post-Cinema Interviews

To analyse the post-cinema interviews, we used a deductive coding approach based on the four engagement factors from the UES-SF: *Focused Attention*, *Perceived Usability*, *Aesthetic Appeal*, and *Reward*.

This analysis focused on how participants assessed the two installations within the context of the complete exhibition experience. Quotes were chosen for their clarity and relevance to how the short film in the cinema may have influenced perceptions.

Unlike the initial interviews, these responses were not grouped into categories but were directly assigned to one of the four UES-SF factors. In total, 26 quotes were coded across these factors.

(GAx) indicates responses from Group After (Cinema), referring to participants interviewed following the cinema experience.

The post-cinema interview answers can be found in the Appendix folder in the file "Post-cinema Answers.xlsx".

Representative examples from this analysis are presented in Table 7.2.

Codes (*N*)	Sample Quotes	Preferred Installation	Factor (UES-SF)
11	*"Fun to be in control."* (GA1)	Redesigned	Focused Attention
2	*"More about storytelling and context."* (GA9)	Original	Focused Attention
4	*"Beautiful light and colours."* (GA10)	Redesigned	Aesthetic Appeal
3	*"Matched the video context."* (GA2)	Original	Aesthetic Appeal
2	*"Easy like a board game."* (GA10)	Redesigned	Perceived Usability
0	—	Original	Perceived Usability
3	*"Learned about formations."* (GA9)	Redesigned	Reward
1	*"Best for information and context."* (GA6)	Original	Reward

Table 7.2: Overview of participant responses post-cinema, grouped by preferred installation and mapped to the four UES-SF engagement factors. Each quote includes its original group ID.

7.2.1 Which table best suits the overall experience, now that you've been to the cinema?

Following the cinema experience, 27 participants answered questions about how the two installations fit within the exhibition as a whole. Of these, 22 said that the redesigned installation best complemented the overall experience, while five preferred the original. The results are shown in Figure 7.5.

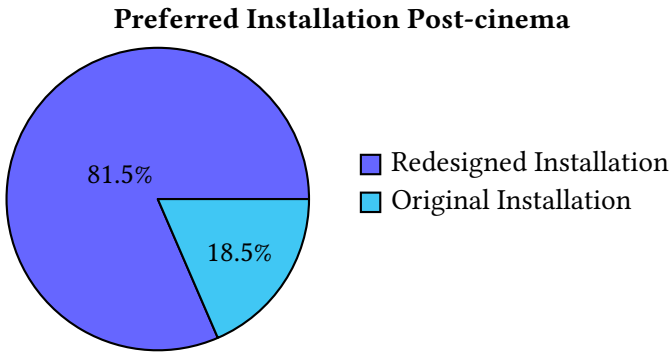


Figure 7.5: Participant preference after viewing the short film in the cinema (n=27).

Participants were then asked to select a primary reason for their choice from four categories, which we rephrased for their clarity: immersion (Focused Attention), usability (Perceived Usability), visual appearance (Aesthetic Appeal), and takeaway from the experience (Reward).

Figure 7.6 shows how these reasons were distributed between those who preferred the redesigned installation and those who favoured the original. Immersion was overwhelmingly the most common reason among supporters of the redesigned version, while the few participants who preferred the original installation also cited immersion or visuals, though to a much lesser extent.

Interestingly, although the original installation had earlier been favoured for its visual design, the post-cinema interviews revealed a shift in how aesthetic appeal was evaluated. Once participants had experienced the full exhibition, including the film, more began to recognise the redesigned installation's visual appearance. This suggests that aesthetic impressions were partially dependent on narrative context, and that the redesigned installation's graphical style fit more convincingly within the overall

experience than initially expected.

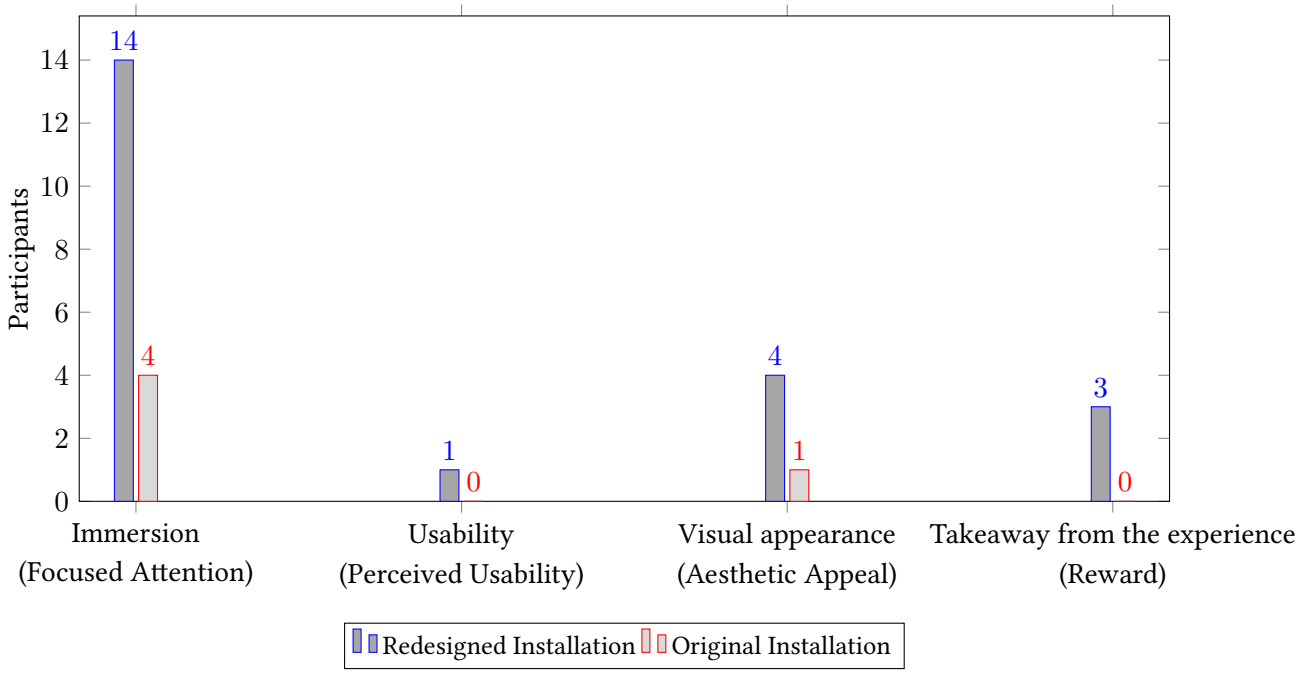


Figure 7.6: Reasons for installation preference by type (n=27).

Immersion *(Factor: Focused Attention)*

Immersion was most frequently associated with the interactive and strategic nature of the redesigned installation. Many participants felt it allowed them to take control of the battle and actively influence its outcome. One participant said, *"It was fun to be in control."* (GA1), and another added, *"A good introduction to strategy."* (GA1). Others emphasised agency, stating, *"Because you could choose your own strategy."* (GA4) and *"It clearly showed how strategy works and gave a good visual of the battle."* (GA3).

The interactive nature of the system was also highlighted. One participant noted, *"Touch had more steps. It gave a sense of control."* (GA7), while another remarked, *"The ability to immerse yourself in it. You could roleplay."* (GA5).

Some participants who preferred the original installation also described immersion, but from a different perspective. For example, one explained, *"It gave a better understanding of the formations and conveyed something educational through the game."* (GA9).

These responses suggest that the redesigned installation enhanced immersion by providing participants with a greater sense of agency and strategic involvement. The ability to control outcomes and interact meaningfully with the content appeared to make the experience more engaging and memorable, particularly when considered in the context of the cinematic experience.

Usability *(Factor: Perceived Usability)*

A few participants cited usability as their main reason for preferring the redesigned installation. One described it as *"easy to understand, like a board game."* (GA10), and another explained, *"You used the figures like when playing Risk."* (GA10). This suggests the familiarity of the interface made the

experience more accessible. Another added, *"It gave a better understanding of the formations in the battle and helped you learn through play."* (GA9).

These comments suggest that participants found the redesigned installation easier to understand due to its familiar gameplay structure and intuitive interaction. Comparing it to board games like Risk helped users quickly grasp the interface, indicating that recognisable patterns can support accessibility in HUIs.

Visual appearance *(Factor: Aesthetic Appeal)*

Those who selected visual appearance highlighted both the aesthetics of the installation and its integration into the surrounding context. Participants described the redesigned installation's graphics and digital effects as *"nice-looking maps"* (GA2), and one highlighted, *"the light and colours made it beautiful"* (GA10). Another participant said it gave *"a good representation of the battle"* (GA2), while another explained, *"It gave a good visual example of how strategy works."* (GA2).

Those who preferred the original installation emphasised how it visually matched the tent setting and the film. One noted, *"The visuals matched the context of the video well."* (GA2), another simply said, *"the aesthetics"* (GA6), and a third referred to *"the atmosphere inside the tent."* (GA6).

While the redesigned installation was praised for its vivid colours and dynamic battle visuals, several participants appreciated the original version for its handcrafted materials and how well it fit the atmosphere of the surrounding tent. This suggests that aesthetic appeal was influenced not just by visual richness, but by how well the installation aligned with the physical setting and narrative tone of the exhibition.

Takeaway from the experience *(Factor: Reward)*

Several participants based their preference on what they learned or retained from the experience. One stated the redesigned installation gave a *"better understanding of formations in battle"* (GA9), while another in that group appreciated the *"freedom to choose formations"* and found it *"fun to play against each other"* (GA9).

Others felt the original installation better supported reflection and understanding. One explained, *"The wooden table was best for information and context. It focused more on reading and understanding."* (GA6).

These responses show that participants evaluated the experience based on what they felt they gained from it, whether through playful interaction or reflective insight. While most appreciated the redesigned installation's opportunity to physically build and experiment with formations through strategic choices, a few found the original version more effective for understanding historical context. This suggests that reward varied depending on whether participants prioritised action or contemplation.

Summary

Overall, most participants felt that the redesigned installation best complemented the exhibition after experiencing the full narrative, including the short film in the cinema. Immersion was the most frequently cited reason, with participants highlighting the sense of agency and interactive engagement offered by the redesign. Others appreciated the installation's visual clarity and game-like usability, especially when compared to familiar formats such as board games.

However, a smaller group preferred the original installation, especially for its atmospheric qualities and how its handcrafted materials aligned with the tent setting and historical tone. This indicates that aesthetic appeal and perceived reward were shaped not only by interface design but by how well each installation supported either active involvement or reflective understanding within the broader exhibition context.

7.3 Observation Insights

During our evaluation at Moesgaard Museum, we observed strong interest and engagement from a wide range of visitors, including children, teenagers, and adults. The redesigned installation attracted more visitors overall. Children and teenagers were especially drawn to the digital elements, with several groups staying longer to play multiple rounds. Many tried to start new games and grew impatient waiting for the system to reset. They showed great enthusiasm, cheering each other on, taking turns, and inventing informal tournament formats.

Teenagers also demonstrated high levels of energy and curiosity, with many experimenting with different formations. Adults were generally more reserved but became engaged after reading the brief introduction. Many took the time to read instructions carefully and discussed tactical considerations in depth. Some adults played multiple rounds to improve their performance, and on several occasions, strangers teamed up or played against one another. This reflects the installation's strong potential to foster social interaction.

Several visitors noted the contrast between the two installations. The original installation was frequently described as more authentic and historically resonant, while the digital features of the redesigned installation were more appealing to younger audiences.

Moesgaard Museums' exhibition design team also visited and expressed great interest. They offered valuable feedback and ideas for future development, such as adding more feedback, integrating lighting effects into the placement areas for tokens when they aren't in play, and introducing deeper layers of strategic interaction. The team also inquired about the development process, what kind of table we used, and discussed the potential use of this technology in upcoming museum projects.

In summary, the comparative evaluation demonstrated that the redesigned installation successfully engaged a broad audience and encouraged interaction and dialogue among visitors, even though it was at times difficult to ensure that all users had the opportunity to try both versions without experiencing excessive waiting times.

7.4 Datalog Insights

The prototype's datalog, covering 86 games and nearly two hours of combined interaction time, was processed to extract key metrics. A full summary of all sessions is available in the file "Datalog.xlsx", located in the appendix folder, and the most relevant findings are presented in Appendix H.

The average session duration was 82.5 seconds, supporting our goal of enabling short, engaging interactions suited to museum contexts. Most players completed their formation in under 15 seconds. In 22% of games, both teams selected the same formation. "Flanking" was the most commonly picked formation, appearing in 29.6% of battles, followed by "Cavalry" (22.7%), "Archer Line" (19.2%), "Wedge" (18%), and "Triple Line" (10.5%).

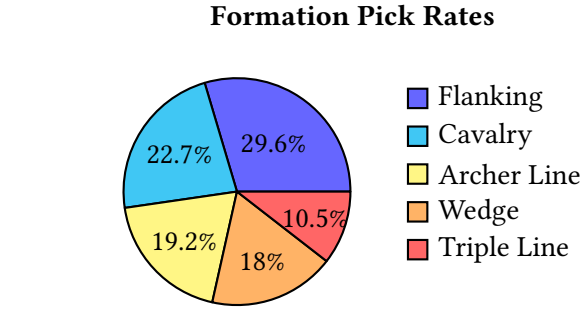


Figure 7.7: Distribution of formation pick rates across all games.

Formation view times averaged 4.72 seconds. "Archer Line" received the longest average attention at 6.93 seconds, followed by "Flanking" (6.23), "Wedge" (5.68), "Triple Line" (5.57), and "Cavalry" (4.5).

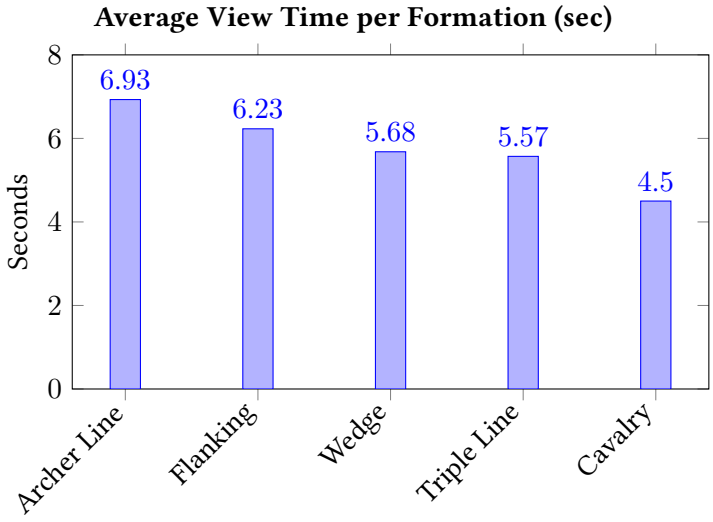


Figure 7.8: Average view time per formation.

Usability data showed that 68.6% of games had no token misplacements, suggesting that most users placed them correctly without confusion. This aligns with our observations. When misplacements did occur, they were typically brief. Games with a single misplaced token averaged just 2.08 seconds, reflecting users' ability to quickly adjust placement. The overall average of 5.32 seconds was raised by a few ignored tokens that remained on the surface without affecting gameplay. These results suggest that the system handled user input robustly even when minor errors occurred.

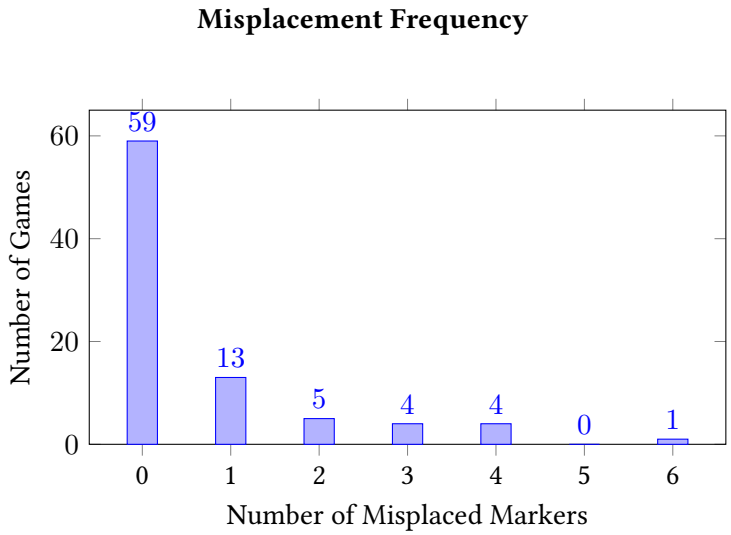


Figure 7.9: Distribution of games by number of misplaced markers.

Although 50 games included rigging, the win distribution remained skewed. Red won 60.5% of all games and 72.2% of non-rigged games, due to map layout.

7.5 Summary

The comparative evaluation revealed a consistent preference for the redesigned installation across all data sources, providing new empirical insights into how HUIs support engagement in museum contexts. Among the 38 participants interviewed before viewing the short film in the cinema, 84.2% found the redesigned system more fascinating, and 86.8% felt it offered the best overall experience. Other feedback was more mixed: 55.3% judged the redesign easiest to understand, while 42.1% preferred its visual design. Interestingly, although the original installation was initially rated higher in aesthetic appeal, post-cinema interviews showed a shift, with 81.5% now feeling that the redesigned installation better complemented the exhibition as a whole, immersion being cited as the most important reason.

These results suggest that HUIs may support focused attention and perceived reward more effectively than TUI installations, particularly when interactivity, agency, and multiplayer functionality are foregrounded. Observational data reinforced this: children and teenagers demonstrated sustained interest, often replaying rounds or inventing their own informal game formats. Adults, while slower to engage, responded positively to clear instructions and formation variation. The installation supported social engagement across age groups, including strangers cooperating or competing in shared play. Datalogs further supported the observational and interview data. Most sessions lasted under 90 seconds, with users completing interactions quickly and reliably. Token misplacements were infrequent and typically brief, suggesting that the HUI did not hinder accessibility or increase cognitive load.

Taken together, the comparative evaluation indicates that HUIs can meaningfully reshape engagement dynamics in public exhibition spaces. Rather than merely outperforming the original installation, the redesigned installation surfaced how interaction patterns shift when digital responsiveness and social play are introduced. These findings informed the design implications presented in the next chapter, offering a research-based contribution to museum interaction design.

8 Discussion

This chapter reflects on the findings from our comparative evaluation and explores broader challenges and trade-offs in designing HUI museum installations. Rather than treating the study as a direct comparison between two interface versions, our aim was to generate insights into how HUI interaction can support and shape visitor engagement.

The results indicate that HUIs can foster short-term engagement through features such as multiplayer interaction, responsive feedback, and hands-on formation building. At the same time, the comparative evaluation revealed tensions between interactivity and traditional museum values, including authenticity, simplicity, and thematic coherence.

The chapter begins by presenting a set of design implications grounded in qualitative data and structured around the four UES-SF engagement factors. This is followed by a discussion of key challenges introduced by hybridisation, including onboarding, coherence, and inclusivity. We then outline the study's limitations and suggest directions for future work.

8.1 Design Implications for HUI Museum Installations

Building on the comparative evaluation, this section presents the core research contribution of the thesis: a set of design implications for HUI museum installations, derived from qualitative analysis of visitor experiences with both versions of the Commander's Tent.

Table 8.1 presents these implications, along with the reasoning behind them.

Table 8.1: Design implications for HUI museum installations, structured by the four UES-SF engagement factors.

Design Implication	Description
DI1: Support shared play and interactive variety to deepen attention **UES Factor: Focused Attention**	The redesigned installation increased engagement by enabling multiplayer interaction and responsive feedback. Participants repeatedly described how playing together made the experience more enjoyable and attention-holding. This implication draws on categories *Social Aspect* (C2)[7.1.1] and *Interaction Possibilities* (C3)[7.1.1], and is supported by Horn et al. [15], who found that tangible exhibits encouraged rich collaborative behaviours like shared manipulation. Michael et al. [25] similarly observed that interactive group-based installations promoted sustained attention. Mast et al. [24] highlight how co-located play, clear feedback, and spectator dynamics support sustained participation in museum settings.
DI2: Use embodied guidance to lower onboarding barriers **UES Factor: Perceived Usability**	The redesigned installation improved usability by introducing "guide hands" and visual cues that supported intuitive interaction. Participants found these aids helpful for getting started, especially compared to the original setup's ambiguity. This implication is grounded in the category *Guidance* (C7)[7.1.2], and is supported by Ma et al. [23], who show how physical affordances ease onboarding, and Mast et al. [24], who highlight how poor feedback or unclear affordances can deter engagement. HUIs can scaffold early use by combining tangible interaction with responsive digital guidance.
DI3: Ensure digital elements preserve the visual and thematic coherence of the physical setting **UES Factor: Aesthetic Appeal**	Although the redesigned installation introduced engaging digital effects, many participants felt it clashed with the historical setting and reduced the sense of authenticity. This implication draws on the category *Authenticity* (C9)[7.1.3], where visitors expressed a preference for the original's visual and thematic coherence. These concerns are in line with observations by Ai and Phaholthep [1] and Dong [10], who argue that digital content should ideally harmonise with spatial and material context to support a sense of immersion. Hybridisation should enhance rather than disrupt the atmosphere of physical exhibits.
DI4: Design for rewarding experiences through narrative integration and emotional impact **UES Factor: Reward**	The redesigned installation felt more meaningful when outcomes were tied to the broader narrative. Participants responded positively to features like visible unit losses and end-of-game summaries, which helped situate the interaction within a larger journey. They could also see how many other visitors had played that day, reinforcing a sense of shared experience and encouraging reflection on their own performance. This implication draws on categories *Social Aspect* (C11)[7.1.4] and *Depth* (C13)[7.1.4], and is consistent with research by Pietroni [30] and Antle [2], who suggest that emotionally resonant and embodied storytelling can support reflection, comprehension, and engagement in HUI museum experiences.

DI1, which relates to the UES-SF factor **Focused Attention**, reflects that our participants repeatedly emphasised how playing together made the redesigned installation more engaging, especially when feedback and outcomes were shared among users. These findings build on earlier observations by Horn et al.[15] and Michael et al.[25], who pointed to social interaction and interactive variety as important factors in sustaining attention in public exhibit contexts. Our results reaffirm the importance of co-present interaction, particularly in HUIs. These insights are further reinforced by Mast et al. [24], who observed that shared play, spectator dynamics, and collaborative use were critical to initiating and maintaining participation in museum settings. Designing museum installations that support collaborative exploration, rather than solitary or strictly linear use, is therefore essential to sustaining attention and encouraging deeper user engagement.

However, whereas Michael et al. [25] treat prolonged or repeat interaction as an unqualified positive, relying on child-centric tools like the Again Again Table to measure willingness to re-engage and evaluating exhibits in isolation, our approach prioritised short-term but meaningful interaction designed to complement the broader museum journey, supporting clarity, pacing, and allowing visitors the cognitive space to engage with other parts of the exhibition.

While DI1 focuses on sustaining attention through social play, this kind of engagement also depends on how easily visitors can get started in the first place. For many, especially first-time users, that initial point of contact is critical. If the interaction is confusing or unclear, engagement may break down before it begins.

DI2, which relates to the UES-SF factor **Perceived Usability**, addresses this challenge. Ma et al. [23] argue that tangible interfaces tend to afford onboarding by embedding guidance into the interaction. Their TUI-based exhibit allowed visitors to intuitively begin exploring without instruction, in contrast to the GUI version, which often required verbal explanation. These findings are supported by our participants' feedback, who cited the effectiveness of the "guide hands" and visual cues added to the redesigned installation. As in Ma's study, the immediacy of physical affordances played a key role in lowering interaction barriers.

Mast et al. [24] contribute to this perspective by showing how onboarding breakdowns, such as unclear affordances, poor feedback, or lack of visual cues, could lead participants to disengage before active play began. Their analysis suggests the importance of scaffolding early interaction with responsive, discoverable design features that support both newcomers and hesitant users.

While Ma et al.[23] and Mast et al.[24] highlight the value of embedded cues for onboarding, others caution that multimodal systems often introduce complexity that can overwhelm users, particularly in walk-up-and-use settings [40, 3]. However, our findings suggest that this risk did not materialise in practice. On the contrary, the redesigned installation supported onboarding more effectively than the original TUI-only version, with participants frequently citing the clarity of the visual cues and the complementary flow between touch and token interaction. This suggests that, when carefully designed, HUIs can sidestep expected complexity and instead offer a more accessible starting point for visitors.

While onboarding helped make the interaction more accessible, some participants still preferred the original installation for its sense of authenticity.

DI3, which relates to the UES-SF factor **Aesthetic Appeal**, captures this tension. Participants felt that, although the digital features were engaging, they didn't match the tone of the original design, which better aligned with the historical setting. Similar concerns are echoed by Ai and Phaholthep [1], who argue that digital exhibits must align visually and conceptually with visitors' expectations in order to maintain a coherent experience. Their comparative study of six museum environments highlights how mismatches between digital media and the surrounding context can disrupt the overall sense of cohesion and immersion. Dong [10] similarly emphasises that immersive exhibition design depends not only on what is displayed, but on how spatial, visual, and technological elements reinforce the thematic atmosphere. When digital content contradicts this tone, it can compromise the coherence of the visitor experience. Still, some participants felt features like the touch screen, though not fitting aesthetically, sparked curiosity and drew attention to the installation.

While some preferred the original installation for its historical coherence, others described the redesigned installation as more rewarding, especially when its outcomes felt tied to the broader story.

DI4, which relates to the UES-SF factor **Reward**, highlights how HUI installations can create more meaningful experiences through narrative structure and emotional consequence. Participants in our study noted that the redesigned installation felt more meaningful when its interactive outcomes were tied to the story that followed. This resonates with Wang [39], who argues that emotional engagement in museums is most effective when interaction design supports a coherent narrative arc. His case studies show how immersive props and ambient soundscapes transform visitors from passive observers into active participants. Similarly, Pietroni [30] stresses the importance of integrating digital content within strong narrative and sensory frameworks, suggesting that meaningful stories enhance both memory and emotional involvement, though her work tends to lean on speculative applications of emerging technologies.

Our findings support this view: several participants described how consequences like unit losses, cumulative results, and end-of-game summaries helped the interaction "make sense" as part of a larger journey rather than feeling isolated. Seeing how many other visitors had played that day also reinforced a sense of shared experience. These insights are further supported by Antle et al. [2], whose work highlights how thoughtful mappings between interaction design and conceptual outcomes can enhance reflection and comprehension.

Taken together, these findings suggest that reward in museum settings does not stem from interactivity alone, but from how well that interactivity is embedded in a thematically coherent and emotionally meaningful structure.

8.2 Challenges around Hybridisation

While the design implications provide targeted strategies for supporting engagement, implementing hybrid interaction also introduced broader challenges that cut across multiple UES-SF factors. This section reflects on those tensions and trade-offs.

Transitioning from a TUI-only interface to a HUI installation introduced tensions around authenticity, interaction clarity, and accessibility for a broad audience. A key challenge was preserving the physical authenticity that defined the original installation. With its wooden table and handcrafted tokens, the installation fostered a sense of historical immersion, which the touchscreen risked undermining by drawing attention away from the material elements. This tension was reflected in our comparative

evaluation, where some participants appreciated the original installation's simplicity and spatial coherence. Such concerns align with Hornecker's argument that digital layers can detract from the embodied qualities that support engagement in museum contexts [18].

This also reflects a broader difference in how engagement is conceptualised and measured. Hornecker notes that "[...] we regard prolonged (or repeated) interaction as positive, indicating that visitors find an exhibit engaging and interesting" [18]. While we acknowledge that extended interaction can indeed signal engagement, in our context, it was not an unqualified good. The exhibition's narrative required a sense of pacing, so we prioritised concise but meaningful interactions. Prolonged engagement at a single point risked disrupting the overall journey and leaving visitors with an uneven experience of the exhibition.

Audience inclusivity presented an additional concern. While the redesigned installation was generally well received across all age groups, a few adults expressed a preference for the original's simplicity and materiality. In terms of visual design, the 24 adults were evenly split between the two versions, with 12 picking each. This reflects broader challenges in HCI, where HUIs must accommodate users with varying levels of digital familiarity and comfort [8, 17].

Despite these challenges, the redesigned installation was widely seen as more engaging than the original. Participants especially valued the added interactivity, multiplayer functionality, and clearer feedback. These results suggest that HUIs, when thoughtfully designed, can increase visitor engagement without compromising usability or the intent of the exhibition.

8.3 Limitations

The limitations of this study are informed by established research quality criteria, as outlined by Lazar et al. [20].

This thesis was based on a single HUI installation evaluated in a specific museum context. This limits external validity, as the findings may not transfer directly to other cultural settings or types of exhibitions. Internal validity is also constrained, as participants only interacted with the system for one day, making it difficult to assess long-term engagement or behavioural patterns over time.

The comparative evaluation was primarily qualitative, drawing on interviews and observations. This supports authenticity by highlighting user perspectives in a naturalistic setting, but it limits reliability. In particular, the lack of datalogs from the original installation prevents consistent comparison of interaction data across versions.

Overall, the contributions should be seen as situated and exploratory, offering design-oriented insights within a specific context rather than universally generalisable conclusions.

8.4 Future Work

This thesis investigated how HUIs can support visitor engagement through the redesign of a TUI installation in a museum. While our findings contribute targeted design implications, they also raise new questions and suggest avenues for further research.

One is to explore how interaction unfolds over time. Since the comparative evaluation was based on single-visit experiences, it offers only a snapshot of user engagement. Repeated or longitudinal studies would improve internal validity by capturing how understanding and preferences develop with familiarity.

Reliability could be strengthened by combining observational and interview data with datalogs from comparable installations. In our case, the original installation did not collect any interaction data, which limited opportunities for systematic comparison. Consistent logging methods across systems would support more robust and replicable evaluation.

A further step is to apply the design implications to other TUI installations. Digitalising existing exhibits using features like embodied guidance or shared feedback could test how well the approach transfers across different content types and settings. This would enhance external validity by showing how hybrid interaction strategies perform in varied public environments.

Taken together, these directions would help refine the proposed design principles and support the continued development of HUIs as a situated and adaptable approach to exhibition design.

9 Conclusion

This thesis explored how HUIs can enhance user engagement by redesigning a long-standing TUI installation at Moesgaard Museum. Through the comparative evaluation of two versions of The Commander's Tent, we investigated how added interactivity, multiplayer functionality, and responsive feedback influenced short-term engagement in a live exhibition setting. The results suggest that HUIs can offer more dynamic and rewarding experiences, especially for younger audiences and small groups, while also surfacing tensions around authenticity, onboarding, and thematic coherence.

Rather than framing HUIs as inherently superior, this thesis contributes a situated analysis of how tangible and digital interaction can be meaningfully combined. The design implications developed through this process highlight the importance of social play, intuitive guidance, aesthetic alignment, and emotional resonance in supporting museum interaction. These findings emphasise that user engagement is not a matter of novelty alone, but of how well the interface aligns with the context, content, and expectations of diverse visitors.

This thesis also demonstrates that redesigning existing installations can be a valuable way to innovate within institutional constraints, while enhancing both relevance and visitor experience. Future work should investigate how HUIs, such as this, perform over longer periods, how user engagement changes with repeat visits, and how such systems can support different audiences without compromising clarity or coherence.

As HUIs become more prevalent in public exhibitions, thoughtful integration will be key. Ongoing, context-aware evaluation and design iteration will be essential to ensure that such systems remain engaging, coherent, and inclusive over time.

10 Acknowledgements

We would like to thank Moesgaard Museum for their collaboration and support in setting up the comparative evaluation. We also thank our supervisor, John Stouby Persson, for his guidance throughout the master's thesis project.

11 Bibliography

[1] Lu Ai and Charanya Phaholthep. 2025. Evaluating Museum Environment Composition Containing Digital Media Interaction to Improve Communication Efficiency. *Buildings* 15, 7 (2025), 1186. https://doi.org/10.3390/buildings15071186

[2] Alissa N. Antle, Greg Corness, and Milena Droumeva. 2008. What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments. *Interacting with Computers* 21, 1-2 (10 2008), 66–75.
https://doi.org/10.1016/j.intcom.2008.10.005
arXiv:https://academic.oup.com/iwc/article-pdf/21/1-2/66/2160195/iwc21-0066.pdf

[3] Muhammad Zeeshan Baig and Manolya Kavakli. 2020. Multimodal Systems: Taxonomy, Methods, and Challenges. *CoRR* abs/2006.03813 (2020). arXiv:2006.03813
https://arxiv.org/abs/2006.03813

[4] Joanna Bergström and Kasper Hornbæk. 2025. DIRA: A model of the user interface. *International Journal of Human-Computer Studies* 193 (2025), 103381.
https://doi.org/10.1016/j.ijhcs.2024.103381

[5] Stephen Bitgood. 1991. Suggested Guidelines for Designing Interactive Exhibits. *Visitor Behavior* 6, 4 (1991), 4–11.

[6] Virginia Braun and Victoria Clarke and. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101.
https://doi.org/10.1191/1478088706qp063oa

[7] X. Carandang and J. Campbell. 2012. Comparing graphical and tangible user interfaces for a tower defense game. *18th Americas Conference on Information Systems 2012, AMCIS 2012* 2 (01 2012), 905–913.
https://aisel.aisnet.org/amcis2012/proceedings/HCIStudies/11/

[8] Peter Dalsgaard, Christian Dindler, and Kim Halskov. 2011. Understanding the Dynamics of Engaging Interaction in Public Spaces. In *Human-Computer Interaction – INTERACT 2011 (Lecture Notes in Computer Science, Vol. 6947)*, Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler (Eds.). Springer, Berlin, Heidelberg, 212–229. https://doi.org/10.1007/978-3-642-23771-3_17

[9] Roberta Della Croce, Luisa Puddu, and Andrea Smorti. 2019. A qualitative exploratory study on museum educators' perspective on children's guided museum visits. *Museum Management and Curatorship* 34 (07 2019), 383–401.
https://doi.org/10.1080/09647775.2019.1630849

[10] Xiaonan Dong. 2024. Study on the Strategy of Creating the Atmosphere of Thematic Exhibition Space. In *Proceedings of the 3rd International Conference on Culture, Design and Social Development (CDSD 2023)*. Atlantis Press, 594–607.
https://doi.org/10.2991/978-2-38476-222-4_72

[11] Susan Dumais, Robin Jeffries, Daniel Russell, Diane Tang, and Jaime Teevan. 2014. *Understanding User Behavior Through Log Data and Analysis.* Springer, New York, NY, 349–372. https://doi.org/10.1007/978-1-4939-0378-8_14

[12] Naomi Haywood and Paul Cairns. 2006. Engagement with an Interactive Museum Exhibit. In *People and Computers XIX — The Bigger Picture*, Tom McEwan, Jan Gulliksen, and David Benyon (Eds.). Springer London, London, 113–129.

[13] Geoffrey Hookham, Keith Nesbitt, and Frances Kay-Lambkin. 2016. Comparing usability and engagement between a serious game and a traditional online program. In *Proceedings of the Australasian Computer Science Week Multiconference* (Canberra, Australia) *(ACSW '16)*. Association for Computing Machinery, New York, NY, USA, Article 54, 10 pages. https://doi.org/10.1145/2843043.2843365

[14] Michael Horn, Zeina Atrash Leong, Florian Block, Judy Diamond, E. Margaret Evans, Brenda Phillips, and Chia Shen. 2012. Of BATs and APEs: an interactive tabletop game for natural history museums. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. Association for Computing Machinery, New York, NY, USA, 2059–2068. https://doi.org/10.1145/2207676.2208355

[15] Michael S. Horn, Amartya Banerjee, David Bar-El, and Izaiah Hakim Wallace. 2020. Engaging families around museum exhibits: comparing tangible and multi-touch interfaces. In *Proceedings of the Interaction Design and Children Conference* (London, United Kingdom) *(IDC '20)*. Association for Computing Machinery, New York, NY, USA, 556–566. https://doi.org/10.1145/3392063.3394443

[16] Michael S. Horn, Erin Treacy Solovey, R. Jordan Crouser, and Robert J.K. Jacob. 2009. Comparing the use of tangible and graphical programming languages for informal science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, 975–984. https://doi.org/10.1145/1518701.1518843

[17] Eva Hornecker. 2008. "I don't understand it either, but it is cool" – Visitor Interactions with a Multi-Touch Table in a Museum. In *2008 3rd IEEE International Workshop on Horizontal Interactive Human Computer Systems (TABLETOP)*. IEEE, 113–120. https://doi.org/10.1109/TABLETOP.2008.4660193

[18] Eva Hornecker and Matthias Stifter. 2006. Learning from interactive museum installations about interaction design for public settings. ACM, 135–142. https://doi.org/10.1145/1228175.1228201

[19] International Organisation for Standardisation 2018. *ISO 9241-11:2018: Ergonomics of human-system interaction – Part 11: Usability: Definitions and concepts.* International Organisation for Standardisation, Geneva, Switzerland.

[20] Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. 2017. *Research Methods in Human-Computer Interaction* (2 ed.). Morgan Kaufmann, Cambridge, MA.

[21] Yanhong Li, Meng Liang, Julian Preissing, Nadine Bachl, Michelle Melina Dutoit, Thomas Weber, Sven Mayer, and Heinrich Hussmann. 2022. A Meta-Analysis of Tangible Learning Studies from the TEI Conference. In *Proceedings of the Sixteenth International Conference on Tangible,*

Embedded, and Embodied Interaction (Daejeon, Republic of Korea) *(TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 7, 17 pages. https://doi.org/10.1145/3490149.3501313

[22] Sonia Livingstone and Leslie Haddon. 2009. What are the best ways to interview children? https://www.lse.ac.uk/media-and-communications/assets/documents/research/eu-kids-online/toolkit/frequently-asked-questions/FAQ-15.pdf. EU Kids Online, Department of Media and Communications, London School of Economics and Political Science.

[23] Joyce Ma, Lisa Sindorf, Isaac Liao, and Jennifer Frazier. 2015. Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 33–40. https://doi.org/10.1145/2677199.2680555

[24] Danica Mast, Joost Broekens, Sanne I. de Vries, and Fons J. Verbeek. 2023. Participation Patterns of Interactive Playful Museum Exhibits: Evaluating the Participant Journey Map through Situated Observations. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23)*. Association for Computing Machinery, New York, NY, USA, 1861–1885. https://doi.org/10.1145/3563657.3595985

[25] Despina Michael-Grigoriou, Nectarios Pelekanos, Isabelle Chrysanthou, Panagiotis Zaharias, Loukia Hadjigavriel, and Yiorgos Chrysanthou. 2010. Comparative Study of Interactive Systems in a Museum. Springer Berlin Heidelberg, 250–261. https://doi.org/10.1007/978-3-642-16873-4_19

[26] Moesgaard Museum. 2024. Om Moesgaard Museum. https://www.moesgaardmuseum.dk/media/6007/formidlingsstrategi-2019.pdf Accessed: 25 January 2025.

[27] Jakob Nielsen. 1993. *Usability Engineering*. Morgan Kaufmann, San Francisco, CA.

[28] Polina Nikolaou. 2024. Museums and the Post-Digital: Revisiting Challenges in the Digital Transformation of Museums. *Heritage* 7, 3 (2024), 1784–1800. https://doi.org/10.3390/heritage7030084

[29] Heather L. O'Brien, Paul Cairns, and Mark Hall. 2018. A practical approach to measuring user engagement with the refined user engagement scale (UES) and new UES short form. *International Journal of Human-Computer Studies* 112 (2018), 28–39. https://doi.org/10.1016/j.ijhcs.2018.01.004

[30] Eva Pietroni. 2025. Multisensory Museums, Hybrid Realities, Narration, and Technological Innovation: A Discussion Around New Perspectives in Experience Design and Sense of Authenticity. *Heritage* 8, 4 (2025). https://doi.org/10.3390/heritage8040130

[31] Renaissance East of England. 2008. Evaluation Toolkit for Museum Practitioners. https://visitors.org.uk/wp-content/uploads/2014/08/ShareSE_Evaltoolkit.pdf. Published through SHARE Museums East.

[32] Yvonne Rogers, Helen Sharp, and Jenny Preece. 2011. *Interaction Design: Beyond Human-Computer Interaction* (3 ed.). Wiley, Chichester, UK.

[33] Marc Satkowski and Julian Mendez. 2023. Fantastic Hybrid User Interfaces and How to Define Them . In *2023 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE Computer Society, Los Alamitos, CA, USA, 247–250. https://doi.org/10.1109/ISMAR-Adjunct60411.2023.00057

[34] Mette Muxoll Schou and Anders Sundnes Løvlie. 2020. The Diary of Niels: Affective engagement through tangible interaction with museum artifacts. *CoRR* abs/2011.11375 (2020). arXiv:2011.11375 https://arxiv.org/abs/2011.11375

[35] ScienceDirect. 2013. Tangible User Interfaces. https://www.sciencedirect.com/topics/computer-science/tangible-user-interfaces. Accessed: 2025-06-06.

[36] Orit Shaer and Eva Hornecker. 2009. Tangible User Interfaces: Past, Present, and Future Directions. *Foundations and Trends in Human-Computer Interaction* 3 (01 2009), 1–137. https://doi.org/10.1561/1100000026

[37] Amanda Strawhacker, Amanda Sullivan, and Marina Umaschi Bers. 2013. TUI, GUI, HUI: is a bimodal interface truly worth the sum of its parts?. In *Proceedings of the 12th International Conference on Interaction Design and Children* (New York, New York, USA) *(IDC '13)*. Association for Computing Machinery, New York, NY, USA, 309–312. https://doi.org/10.1145/2485760.2485825

[38] Britt M. ten Voorde. 2023. Exploring Engagement in Science Museums : A Comparative Study of Static and Interactive Exhibitions. http://essay.utwente.nl/95172/

[39] Zhiyu Wang. 2022. The Impact of Emotional Interaction Design on Museum Displays. *Journal of Humanities, Arts and Social Science* 6 (11 2022), 522–529. https://doi.org/10.26855/jhass.2022.12.004

[40] Abdelrahman Zaky, Johannes Zagermann, Harald Reiterer, and Tiare Feuchtner. 2023. Opportunities and Challenges of Hybrid User Interfaces for Optimization of Mixed Reality Interfaces. In *2023 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE, 215–219. https://doi.org/10.1109/ISMAR-Adjunct60411.2023.00050

[41] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704

Appendices

A The Commander's Tent Usability Problems

To identify specific usability issues and areas for improvement, we used Jacob Nielsen's usability severity rating scale [27].

- **Cosmetic Problems (Severity 1):**
  - *Projection misalignment:* The projection slightly missed the table, resulting in parts of the projection being displayed on the floor.
- **Minor Usability Problems (Severity 2):**
  - *Lack of back buttons:* The interface did not include back buttons to navigate to previous states.
  - *Token activation inconsistency:* Although there were three tokens, only one could be active at a time. Archers, even when inactive, sometimes appeared on the team according to the selected formation.
- **Major Usability Problems (Severity 3):**
  - *Token interaction confusion:* It was not initially clear that only one token could be active at a time and that the same token needed to be moved to the other field to select a formation.
  - *Lack of audio feedback:* The game lacked audio, which could have enhanced the feedback and immersion.
  - *Initial learning curve:* It was unclear how to interact with the table at first. It took some time to realise how it worked, including the meaning of red rings under the tokens, which indicated either incorrect placement or unsuitable units for a battle.

Our evaluation of *The Commanders's Tent* identified several usability issues that present opportunities for improvement. Cosmetic problems, such as misaligned projections, highlighted minor accessibility and visual challenges. Minor usability problems included the lack of back buttons for navigation and inconsistencies in the activation of tokens, which occasionally led to confusion during gameplay. More significant issues, such as unclear interaction mechanics, the absence of audio feedback, and a steep initial learning curve, limited the overall accessibility and engagement of the installation.

B First Iteration - Interview Questions

INTERVIEW

Introduktion

Som en del af denne undersøgelse vil vi gerne spørge, om vi må filme og optage lyd under din deltagelse. Optagelserne vil udelukkende blive brugt til analyse og dokumentation i forbindelse med vores projekt. Alle deltagere vil blive anonymiseret i den endelige rapport og præsentation, og ingen personlige oplysninger vil blive delt offentligt.

Evaluering af oplevelse

1. Hvordan var din samlede oplevelse som hærfører?
2. Var spillet sjovt og engagerende? Hvorfor/hvorfor ikke?
3. Lærte du om datidens krigsførelse og strategi gennem spillet?

Evaluering af design og gameplay

4. Var reglerne og mekanikkerne nemme at forstå?
5. Føltes det naturligt at bruge tokens sammen med den digitale skærm?
6. Hvilken form for interaktion kunne du bedst lide? Tokens eller skærm?
7. Følte du, at dine valg som hærfører havde en betydning for slagets udfald?
8. Gav spillet dig en fornemmelse af, hvordan forskellige formationer og strategier kan bruges i kamp?

Evaluering af sociale aspekter

9. Hvordan var det at spille mod en anden person?

10. Snakkede I om spillet eller strategi undervejs?

Evaluering af læringsmål og kontekst

11. Hvordan synes du, spillet passer til en museumsudstilling?

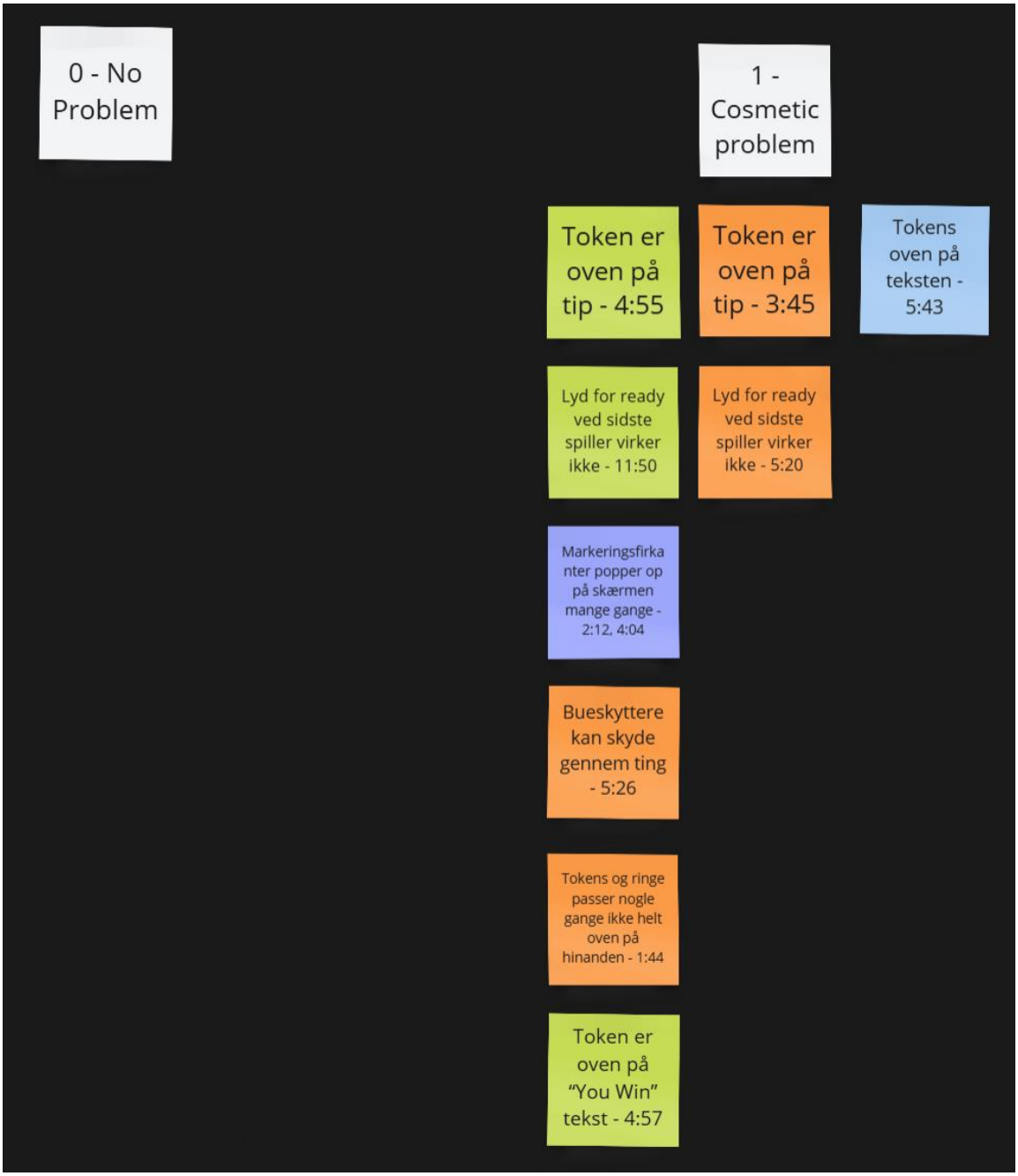
12. Gav spillet dig en følelse af at være en del af en historisk kontekst?

Afsluttende refleksion

13. Hvad fungerede godt i spillet, og hvad kunne forbedres? (Åbent spørgsmål)

14. Synes du, spillet balancerede godt mellem underholdning og læring?

C First Iteration - Usability Problems




2 - Minor problem
Formationer kan starte inde i hinanden - 5:29
Formationer kan starte inde i hinanden - 2:02
Units spawner oven i hinanden - 6:14
Units kan starte inde i objekter - 6:19
Units kan starte inde i objekter - 6:48
Ved ikke, at de skal flytte deres token, når de starter ny runde - 2:55
Units placeres direkte efter reset, hvis man ikke fjerner tokens - 4:01 (1 person)
Kan placere token helt op til midter linjen - 4:19
Kan placere på modstanderens side - 4:09 (1 person)
Ramte change map knap, uden at klikke den - 5:04 (1 person)
Læser ikke tips - 3:44 (begge)
Var ikke klar over at unit count bliver vist i toppen - 12:25 (1 person)
Placering af token i symbol - 2:44
Kan ikke klikke change map - 5:34
Halstørklæder og tøj kan tæller som touch - 2:26


3 - Major problem
Prøvet at placere units for tæt på hinanden - 12:57
Prøver at spawne units oven i andre - 6:48
Kan ikke spawne units tæt på andre - (no timestamp provided)
Spawner for tæt på - 4:01
Spawner ikke units, for tæt - 6:54
Prøver at spawne for tæt på units - 11:32
Placering af units for tæt på andre - 6:39
Lader ikke statuen blive - 2:41 (1 person)
Troede man kunne flytte dem - 2:49 (1 person)
Lader ikke statuen blive - 1:52 (1 person)
Fjerner sin satte token og forsøger at sætte den andre steder - 1:08
Flytter sin token rundt, selvom den er placeret - 1:00
Flytter hesten og ødelægger rækkefølgen - 4:09
Tror at man kan rykke units bagefter - 8:07
Kan ikke spawne units - 7:45, 8:53
Kan ikke spawne units - 1:18
Kan ikke spawne units med sin token - 1:06, 1:45, 4:10
Token skulle placeres 2 gange for at registrere - 5:18 (1 person)
Skal genplacerer token på for den register den - 1:02
Kan ikke placere token - 4:26 (1 person)
Har svært ved at skifte formation - 4:02
Kan ikke skifte formation - 1:48
Kan ikke skifte formation - 4:46
Kan ikke skifte formation - 5:19
Units går i stå - 6:54
Units går i stå - 5:33
Units angriber ikke - 11:47
Units går i stå - 10:15
Satte forkerte token ned - 1:50
Kan ikke klikke ready - 3:07 (1 person)
Formation knapper overlapper - 11:48 (1 person)
Kan ikke klikke reset field - 2:08 (1 person)
Formation knapper overlapper - 5:11 (1 person)
4 - Usability catastrophe
Kan slet ikke spawne units - 1:38

D First Iteration - Thematic Analysis

D.0.1 Usability

This is one of the two overall themes that cover multiple categories. This theme revolves around the general usability of the prototype.

(C1) Learning Curve

In terms of intuitiveness, participants generally felt that the game mechanics were straightforward and easy to understand. One participant said, "Yes. It was fairly straightforward." (P9), while another added, "It's fairly intuitive." (P1). Mechanics and gameplay clarity were also acknowledged, with one participant sharing, "Yes, I think so. (About whether the mechanics were easy to understand.)" (P5). These comments indicate that the game succeeded in providing an accessible experience, allowing participants to engage with the mechanics without significant confusion or frustration.

(C2) Interaction

In this theme, participants compared their experiences with using tangible tokens versus intangible interactions on a screen. The interviews revealed strong preferences for tangible tokens due to their tactile and engaging nature. Several participants highlighted the added layer of immersion and strategic thinking enabled by tokens. One participant mentioned, *"It was definitely more fun to place the figures than to click with your hand."* (P5). Another participant noted the sense of narrative and strategy evoked by tokens: *"Yes, it was actually cool. It's like in Game of Thrones when they sit and plan their war, they also move the figures."* (P10). When asked if the tokens provided immersion, one participant responded, *"Yes, I think so."* (P4).

One participant commented on the hybrid interaction: *"Is it natural with a hybrid? I think so. In some ways, it feels a bit cooler to just play."* (P2). Another participant mentioned that having both tangible and intangible interaction made them more engaged: *"It makes me more engaged."* (P6).

Overall, the preference leaned towards tokens and hybrid interaction rather than intangible interaction, with participants associating them with higher user engagement, immersion, and enjoyment. The physicality of tokens appeared to create a more satisfying and contextually rich experience.

(C3) Control

Participants discussed their experiences with control in the game and how their choices influenced the outcomes of battles. When talking about control, one participant reflected on how troop placement felt meaningful, yet uncertain: "Yes, I felt that. I don't remember how much of it had to do with where I placed my troops, but I assume they are equally strong. So when I lost, it was probably because someone had placed theirs better." (P9). Another participant expressed a clear frustration about the lack of control and clarity: "Yes, I think there was a need for more control to feel it more..." (P2).

When discussing whether choices had any significant impact on the outcome of the game, one participant simply stated: "No." (P2). Another elaborated further: "Not particularly." (P1). These statements suggest a feeling that their decisions did not have the intended influence or that the results

were driven more by randomness than by participants' actions.

On the topic of control, one participant explained the challenge of understanding the consequences of their actions: "Yes, I think it was a bit difficult to see how you placed them. What effect they had on how the battle ended." (P10). This highlights uncertainty about the consequences of their choices and placements.

These reflections highlight a fundamental challenge with the game's control system, participants experienced a lack of clarity and transparency regarding how their actions influenced the outcomes. This created a sense of uncertainty, which, in some cases, led to frustration and a feeling of diminished control.

(C4) Visibility Issues

Participants discussed the challenges of maintaining strategic secrecy while playing on a shared touchscreen. Both participants could see each other's placements, which reduced unpredictability and made counter-strategies too easy. One participant noted, "But then it's just a problem that the opponent places their square, and you position your point against it, and then you can just change it." (P10). Another added, "It could be fun if you couldn't see what the other person was doing." (P10).

There were also concerns about giving away too much information during play. One participant said, "I wouldn't want to give away too much to the opponent." (P9). Another highlighted a flaw in the system, "I also think it's the thing where you can just wait until your opponent has positioned their team, and then just counter it to be sure to win." (P1).

These comments suggest that the shared visibility limited the excitement and unpredictability of strategic planning.

(C5) Improvements

Participants shared a variety of suggestions for improving the game, focusing on flexibility in placement and rotation, the integration of historical elements, and broader gameplay enhancements.

One recurring theme was the desire for greater flexibility in how units were placed and rotated. Some participants felt constrained by the rigid placement system and suggested improvements that would allow for smoother, more strategic positioning. As one participant noted, "It would be cool if we could rotate them. So they only have one direction, then pull them that way." (P1). Another reflected on the frustration of static positioning, saying, "My men are getting wrecked over there. It would be kind of cool to be able to rotate them." (P2). Flexibility in placement was also highlighted as an area for improvement, with one participant suggesting, "Yes, it would be cool if you could do it so that they didn't have to place themselves in a specific order." (P1). Additionally, another participant pointed out the need for better situational awareness during placement, commenting, "You would expect that if you wanted to change the spearman's position, you could just move him somewhere else. Even after you had placed him." (P9). Another participant proposed a more dynamic approach to placement, saying, "Maybe here it's easier to move them afterwards. Now it was like, you change everything, or you remove everything and set them again. It would be cool to just drag and drop some of the ones you've placed." (P11). These reflections indicate a need for greater adaptability in both placement mechanics and the ability to adjust strategies mid-game.

D.0.2 Engagement

This is the second theme of the two overall themes that cover multiple categories. This theme revolves around overall engagement with the prototype.

(C6) Expectations

In this theme, participants discussed the overall expectations, focusing on the horses and archers. Several participants felt that the horses were not functioning as expected, with one participant saying, *"The horses were too weak. You feel like they should be strong, especially since they are such large figures. There should be impact with them."* (P9). This comment reflects frustration about the perceived lack of power or impact for such prominent figures in the game. Another participant mentioned, *"Horses. I thought they would be really good."* (P10), highlighting expectations that were not met.

Regarding the archers, one participant observed, *"It turned out that the bowmen don't really move, they just stand there."* (P2), indicating that the archers felt static and lacked dynamic movement, which could have impacted their overall utility and balance within the game. Another participant commented on the effectiveness of the archers, saying, *"What are my archers doing? They can't even take down a horse."* (P5), which indicated frustration that it took too many arrows to kill a mounted rider. This created a sense of imbalance, as participants may have expected archers to be more effective at handling mounted units.

(C7) Immersiveness

Participants shared their appreciation for different aspects of the game, focusing on design, intuitiveness, and overall enjoyment. One participant commented on the visual appeal of the maps, saying, "I actually thought the maps were very cute. Especially with the rain and the music." (P2). Another highlighted the game's audio effects: "The sound effects, when you turned it on and closed it in and things like that, were really cool. It was satisfying, also with the background sound that's here now." (P3). The atmosphere created by the combination of visuals and audio was also praised, with one participant saying, "I really liked the atmosphere. The atmosphere in here with the music and such." (P10). These reflections suggest that the game's audiovisual elements played a significant role in creating an immersive and pleasant experience.

(C8) Multiplayer

In this section, participants discussed their experiences with the multiplayer aspect of the game. One participant expressed how competition created an engaging dynamic: "We want to beat each other. That's probably how it's supposed to be." (P6). Another participant noted that the game felt more meaningful when playing against another person: "I was much more invested, there were higher stakes because I really wanted to win." (P9). A third participant added their preference for familiar opponents, saying: "I would rather play with one of my friends, but it could also be fun enough to play against a stranger." (P3).

Communication between participants varied significantly. One participant described the experience as fairly quiet: "We actually did it mostly in silence, I would say." (P2). However, another participant highlighted how the game allowed for playful banter and victory celebrations: "[Yes,] it's mostly because we can, like, gloat." (P1).

These differences in participants' interaction suggest that the multiplayer element had room for both

quiet focus and expressive moments of triumph, catering to different styles of competitive play.

(C9) Entertainment

Participants expressed their enjoyment of the game, with one saying, ”I thought it was cool. It was, without a doubt.” (P4), and another reflecting, ”I thought it was really fun. It’s a bit disappointing that I lost, but it was very fun.” (P5). The interactive nature of the experience was also highlighted: ”Also just the fact that it’s interactive. Yes. That’s cool. Both for kids, but also for adults, for that matter.” (P3). One participant summarised the unique appeal of the game with: ”There was a lot of novelty to it.” (P7). These remarks indicate that the game successfully delivered an engaging experience, appealing to a broad audience through its interactivity, novelty, and fun gameplay.

E Pilot Questions

Pilot Test Spørgsmål

1. Var det intuitivt?
2. Er der noget forvirrende?
3. Hvordan var oplevelsen?
4. Følte du, at du havde kontrol over figurer?
5. Var der for få eller for mange figurer?
6. Følte du dine valg påvirkede spillet?
7. Er der noget du vil ændre ved spillets længde eller tempo?
8. Hvad syntes du om kampen?
9. Hvad kunne forbedre spillet?
10. Hvad med designet?

F Pre-cinema Questions

Comparative Questions

Spørgsmål: “Har du oplevet begge borde? Kan vi lige hurtigt stille nogle spørgsmål?”

Aldersgruppe: Barn, Teenager, Voksen

UES-SSF Dimension	Spørgsmål
Focused Attention(FA):	"Hvilket bord var mest fascinerende?” (optaget, opslugt)
Hvorfor?	
Perceived Usability (PU):	"Hvilket bord var nemmest at forstå?"
Hvorfor?	
Aesthetic Appeal (AE)	"Hvilket bord havde det bedste visuelle design"
Hvorfor?	
Reward (RW)	"Hvilket bord gav den bedste oplevelse?"
Hvorfor?	

G Post-cinema Questions

Post Cinema Questions

Spørgsmål: “Hej, fik i snakket med mine kollegaer? Kan vi lige hurtigt stille nogle sidste spørgsmål?”

Aldersgruppe: Barn, Teenager, Voksen

1. Hvilket bord passer bedst til den samlede oplevelse? Nu når I har været i biografen.
2. Hvilken af disse kategorier er mest grunden til dette?
    a. Indlevelsen
    b. Brugervenligheden
    c. Det visuelle
    d. Udbyttet af oplevelsen?
3. Hvorfor?

H Datalog Findings

Datalog Findings

- 86 total games, 172 sides in play
- Total interaction time was 1 hour 58 minutes and 16 seconds.
- Average interaction time was 1 minute and 22.5 seconds (82.5 seconds)
- Average view times for formations was 4.72 seconds
- Average time to build a formation was 14.25 seconds

- Blue won 34 games (39.5%)
- Red won 52 games (60.5%)
- Game was rigged for Blue 25 times (29.07%)
- Game was rigged for Red 25 times (29.07%)
- Rigged for none in 36 games (41.9%)
- Rigging didn't work 1 time (1.16%)
- Blue won 10 non-rigged games (27.8%)
- Red won 26 non-rigged games (72.2%)

- Both teams picked same formations in 19 games (22%)
- Blue won 2 times when both teams picked same formation (10.5%)
- Red won 17 times when both teams picked same formation (10.5%)

- Triple Line was viewed in 44 games (25.6%)
- Flanking was viewed in 70 games (40.7%)
- Wedge was viewed in 58 games (33.7%)
- Cavalry was viewed in 65 games (37.8%)
- Archer Line was viewed in 57 games (33.1%)

- Triple Line had an average view time of 5.57 sec
- Flanking had an average view time of 6.23 sec
- Wedge had an average view time of 5.68 sec
- Cavalry had an average view time of 4.5 sec
- Archer Line had an average view time of 6.93 sec

- Triple Line fought in 18 battles (10.5%)
- Flanking fought in 51 battles (29.6%)
- Wedge fought in 31 battles (18%)
- Cavalry fought in 39 battles (22.7%)
- Archer Line fought in 33 battles (19.2%)

- 5.32 seconds average misplacement time
- Longest misplaced marker - RedHorse 12 for 47 seconds
- 59 games had no marker misplacements (68.6%)
- 27 games had a marker misplacement (31.4%)
- 13 games had 1 marker misplacement (15.12%)
- 5 games had 2 marker misplacements (5.81%)
- 4 games had 3 marker misplacements (4.65%)

- 4 games had 4 marker misplacements (4.65%)
- 0 games had 5 marker misplacements (0%)
- 1 games had 6 marker misplacements (1.16%)
- In games where there was 1 marker misplaced, the average misplacement time was 2.08 seconds

- Shortest interaction time 37.29 seconds
- Longest interaction time 240.35 seconds
- Shortest formation build time 0 seconds
- Longest formation build time 159.9 seconds

- Most placed marker - BlueSpearman 2, was placed 86 times, and was placed in 52 games (60.47%)
- Least placed marker - BlueHorse, was placed 32 times, and was placed in 21 games (24.42%)