COMBing Through Time

3D Models & Digital Object-Based Learning

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Abstract

This thesis aims to assess the importance on the use of digital object-based learning (OBL) for public outreach initiatives in archaeology, focusing on a case study involving an Iron Age comb. The goals were to create a virtual learning environment with interactive 3D models, integrate storytelling elements into the virtual learning environment, and a pilot study setup. This thesis is based on the theoretical framework of digital object-based learning and expands previous studies based on the use of interactive 3D applications for public outreach within archaeology. The questions this thesis addressed were:

- In what manner(s) can 3D models be used to enhance engagement and understanding of archaeological artefacts among the general public compared to traditional static displays?
- In what way(s) do contextual storytelling elements enrich public outreach and educational value of interactive 3D models showcasing archaeological artefacts?
- What challenges and limitations are associated with implementing digital OBL approaches, for public outreach aimed at engaging audiences with archaeology?

To answer the questions, I defined a research design. Several processes were used to create the virtual learning environment in 3DHOP. These processes consisted of an acquisition to create the 3D models of the Iron Age Comb. Processing the 3D model of the comb to divide the comb into individual parts. Post-processing to map the textures of the comb on the 3D models. Finally, the online presentation was created by combining the interactive 3D models and storytelling elements. The results are the creation of a virtual learning environment as an experimental way of creating interactive 3D models with information about an Iron Age comb. These results are preliminary and encouraging. However, the assessment of the efficacy of the virtual learning environment was not possible within the thesis time frame and a proposition for a pilot study has been provided.

Keywords: Digital Object-Based Learning (OBL), Public Outreach, Digital Archaeology, (3D) Visualisation, Blender, 3DHOP.

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Anne Hagemeier, May 2024.

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1. Introduction

> "*The ability to move between the two, three and four dimensions structures imagination and analysis, enabling scientists to vary the complexity of each visualization as its function changes during the process of discovery and communication*." (Gooding, 2008, p.1).

Museums have been using different methods for teaching about history, one of these methods is object-based learning. This teaching method involves engaging the senses - smell, sight, touch, taste, and hearing - to try to enhance learning and foster a deeper connection with history (Chatterjee and Hannan, 2015, 5; Museum.nl, n.d.; livrustkammaren.se, n.d.; The Tube, n.d.). By using the senses, museums aim to make learning about history more captivating, exciting, and interactive. Besides museums, schools and universities have also used this method for centuries. However, the COVID-19 restrictions put a pause on this application.

Globally, educational institutions had to quickly shift to online learning as a result of the COVID-19 pandemic (Kustiawan *et al*., 2022, 729). In response academic institutions began digitising materials for online teaching, like at Lund University with the Dynamic Collections Project (i.e. www.darklab.lu.se, n.d., Callieri *et al*., 2023; Ekengren *et al*., 2021). In disciplines like archaeology, where the tactile and visual examination of remains is vital to knowledge, innovative solutions and methodologies, universities were forced to find ways to incorporate object-based learning in online teaching. Despite the attention that the digital approach to object-based learning (or digital OBL) has generated, more research is needed to critically evaluate digitally-based educational strategies, particularly in public outreach in archaeology.

Yet, as universities adapted to the demands of online learning, a question arises: can the integration of 3D models for digitally-based educational learning extend beyond academia and serve as a tool for public outreach? Considering the difficulties in including various groups of people in education pursuits it is critical to investigate new methods for distributing information about archaeology and archaeological artefacts (De Groot, 2017, 10).

1.1 Aims and Research Questions

This thesis aims to analyse the possibility of using digital OBL for archaeological public outreach initiatives aimed at the general public; to provide them with an immersive experience that not only showcases the physical attributes of the artefact but also contextualises it within the historical and cultural narratives through theoretical and practical exploration.

The goal is threefold: firstly, to develop a storytelling application using an interactive 3D model of an archaeological artefact to foster a deeper understanding of archaeological artefacts and appreciation among the general public. Secondly, to explore the application of contextual storytelling within this 3D model to convey the historical significance of the artefact, by integrating narrative elements such as historical background, cultural significance, and archaeological context directly into the digital experience. The idea is that this approach provides users with a holistic understanding of the artefact and its place within broader historical narratives. Lastly, to provide a setup for the evaluation of the efficacy of the virtual learning environment a pilot study will be setup.

To conduct this research, I aim to address the following research questions:

1. In what manner(s) can 3D models be used to enhance engagement and understanding of archaeological artefacts among the general public compared to traditional static displays?
2. In what way(s) do contextual storytelling elements enrich public outreach and educational value of interactive 3D models showcasing archaeological artefacts?
3. What challenges and limitations are associated with implementing digital OBL approaches, for public outreach aimed at engaging audiences with archaeology?

By addressing these questions, this study seeks to get a better understanding of how digital OBL using 3D models might enhance public outreach in archaeology; to create a virtual learning environment that provides users with an immersive experience to allow them to enjoy and learn from contextual storytelling, changing how archaeology is brought to the public.

1.2 Theoretical Framework

This chapter describes the underpinning theoretical framework of this study. Theoretical aspects that combine archaeology and its digital components, specifically 3D models, with an object-based learning approach have been explored and are presented below.

1.2.1 Digital Archaeology

In the mid-20th century digital archaeology became extremely popular and computers became tools to aid archaeological research and began to lay the groundwork for further integration into archaeological practice by its usefulness for statistical analysis and data management (Morgan, 2022, 214-215). In the following years, the development and usage of GIS[1] revolutionised spatial analysis and mapping which transformed the way archaeologists started to study landscapes and settlements. By the 1990s, advancements in 3D scanning and modelling opened new opportunities for creating detailed digital reconstructions of artefacts and sites. After the initial enthusiastic approach, scholars began to critically examine the theoretical implications of digital technologies on archaeological practice and interpretation (Perry and Taylor, 2018, 14-16). This critical engagement was a reaction to the use of digital tools within archaeology as it was thought it would not contribute to the archaeological field from a theoretical standpoint (Morgan, 2022, 224-225). However, a recent contribution made by Perry and Taylor (2018) demonstrates how digital archaeology contributes to "archaeology" from a theoretical standpoint.

There has been, and still is, a digital shift in archaeology due to the quick development of digital archaeology, causing archaeology to be undertaken differently (Morgan, 2022, 216). Digital archaeology does not just simplify archaeological work; it also reshapes the field through changes in its practice, methods, communication, and visualisation, and it entails employing digital technologies and methods to construct more refined interpretations of the past, such as digital databases, open access sharing, GIS, and 3D modelling (Morgan, 2022, 223-225). This all generated an increase in support for digital methodologies and tools, allowing archaeologists to investigate new possibilities and apply technologies to new research goals and concerns (Tanasi, 2020, 22-25).

The Importance of Digital Archaeology

In today's Western world, archaeology can barely be conducted without the use of digital methods as (Robotic) Total Stations, GPS, and computers have become essential for excavations, enabling meticulous documentation and interpretation of archaeological sites (i.e., Evans and Daly, 2006; De Reu, 2014, Dell'Unto and Landeschi 2022). Digital archaeology also plays an important role in

[1] Geographic Information System.

theoretical advancement, reshaping archaeological paradigms through the influence of digital tools, revealing new insights and methodologies that combine traditional archaeological methods with technology to discover and preserve our heritage (Zubrow, 2006, 9).

Furthermore, in a recent article, Colleen Morgan points out that digital archaeology is crucial in public outreach because it enhances engagement, accessibility, and education about archaeological research and heritage, as well as reaching a broader audience through digital tools and platforms and making archaeological information more available, interactive, and engaging (Morgan, 2022). As Morgan states, using digital technologies enables the creation of virtual tours, 3D reconstructions, online exhibitions, and educational resources that allow the public to explore archaeological sites and artefacts anywhere in the world and at their own pace (Morgan, 2022, 224). Moreover, Morgan notes that digital archaeology facilitates public involvement and collaboration in research projects, empowering participation in the interpretation and preservation of their heritage (Morgan, 2022, 224).

Moreover, the expansion of digital platforms facilitates the dissemination of archaeological discoveries, fostering global collaboration among researchers (Morgan, 2022 214). These digital platforms make it possible to efficiently manage extensive datasets, allowing for more in-depth research and interpretation of archaeological data (Zubrow, 2006, 21-22). Additionally, digital methods also contribute significantly to preserving archaeological heritage by providing detailed documenting and virtual replicas, reducing the risks associated with physical handling and potential damage of archaeological artefacts (Zubrow, 2006, 11, 21). This elaborate reconstruction of archaeological sites and artefacts offers immersive experiences for scholars and the public, enhancing accessibility and engagement with cultural heritage (Zubrow, 2006, 20-23).

By drawing upon these theoretical insights, examples of public outreach, and engagement that can inform the development of the virtual learning environment using 3D visualisation (para. 1.2.2) and digital OBL (para. 1.2.3) I will try and design a storytelling application that can help foster a deeper understanding and appreciation of archaeological artefacts among the general public.

1.2.2 Three-dimensional Visualisation (3D Visualisation)

The contemporary use of digital visualisation technology witnessed relevant development and has become an important sub-discipline of archaeology, which is constantly evolving (Opgenhaffen, 2021, 353, 368). Furthermore, virtual archaeology is also emerging, which uses advanced 3D techniques to visualise archaeological remains (Opgenhaffen, 2021, 370). However, it is important to have a critical approach when using these technologies based on defined goals and purposes (Opgenhaffen, 2021, 365-372).

Regarding 3D visualisation, VR and 3D modelling have likewise been applied in archaeology for over three decades (Hermon and Nikodem, 2008, 1). However, the use of 3D visualisation has largely been focused on communicational aspects, such as for internet platforms or museum installations (Petrelli, 2019, 1). While many discussions have centred on their communicational uses and technological advancements, their role in scientific research has been underestimated (Petrelli, 2019, 2). On account of this, there is a need for more archaeological reports showcasing the new research results obtained through these technologies (Petrelli, 2019, 11). Take Petrelli (2019), for example, in his article on the use of 3D reconstructions as part of a visit to heritage sites (Petrelli, 2019, 11).

The Importance of 3D Visualisation and its application

The evolution of 3D visualisation plays an important role in archaeology, offering an opportunity for representing and understanding archaeological data in a dynamic and interactive way, as it provides a multifaceted approach, aiding in various aspects of archaeological endeavours (Opgenhaffen, 2021, 369, 372). Firstly, it enhances understanding by carefully representing archaeological artefacts, fostering a deeper insight into the past through the exploration, spatial relationships and complex data visualisation (Opgenhaffen, 2021, 269). Secondly, 3D visualisation also facilitates reconstruction and interpretation efforts, allowing researchers to recreate ancient environments and objects, thus enriching our understanding of past societies, landscapes, etc. (Moitinho de Almeida and Barceló, 2012, 384). Lastly, these visualisations serve as powerful tools for communication and public engagement, making archaeological discoveries accessible to broader audiences and effectively conveying historical narratives (Opgenhaffen, 2021, 365).

Within the archaeology field, it is important to make archaeological data more accessible and engaging for both researchers and the public, so by introducing the concept of archaeological artefacts as dynamic 3D models and virtually promoting their use through computer simulation, researchers aim to enable scientific hypotheses and public engagement with archaeological heritage (Moitinho de Almeida and Barceló, 2012, 386). By providing clear visualisation and visual reconstruction of how artefacts looked and were used in the past, archaeologists seek to bridge the gap between academic research and public understanding. This approach not only enhances the study of social activities and working processes in archaeology, but also opens opportunities for public outreach and education regarding archaeological heritage (Moitinho de Almeida and Barcel', 2012, 384).

By creating 3D models of artefacts and integrating storytelling elements, educators can provide virtual reconstruction that allows for detailed exploration from various angles (Chatterjee and Hannan, 2015, 71). The incorporation of storytelling narratives contextualises the artefacts, offering historical and cultural insights, and making them more relatable and memorable for the public (Chatterjee and Hannan, 2015, 8). Through these interactive experiences, users can actively engage with the archaeological artefacts, deciphering inscriptions, reconstructing broken pieces, and participating in historical scenarios. Ultimately, this approach enhances engagement, fosters a deeper understanding of archaeological artefacts, and promotes appreciation for our shared cultural heritage (Chatterjee and Hannan, 2015, 112-114).

Despite the costs associated with immersive content like VR, the availability of affordable VR devices like Sony PlayStation VR and Oculus Rift presents opportunities for wider engagement (Petrelli, 2019, 1). It is important that the faithful reconstruction of historical elements remains carefully depicted, and the potential for multiple uses of 3D virtual reconstructions underscores their value in enhancing visitor experiences and disseminating complex historical information (Hermon and Nikodem, 2008, 1).

All aspects are important as in the context of this thesis, a virtual learning environment with multiple 3D models was made (para. 2.2). Keeping this aspect in mind helps ensure that the virtual learning environment can be used for its intended goals of both engaging the public and effectively disseminating information about an archaeological artefact.

1.2.3 (Digital) Object-Based Learning

Object-based learning is an educational approach that uses physical objects or artefacts as the focus point for learning activities (Chatterjee and Hannan, 2015, 8). This method works well for improving students' critical thinking, empathy, and observational abilities, as it uses active learning that teaches the various viewpoints and stories that are present in the objects they examine. Furthermore, object-based learning functions as a stimulant for research-based exercises, dialogues, and practical applications (Chatterjee and Hannan, 2015, 9). So, students can draw links between abstract concepts and practical applications by looking at, evaluating, and understanding objects. However, in academic fields like art, history, and archaeology there is a focus on the use of historical texts and there is a strong favour to incorporate the interaction with primary materials (artefacts) for students at an early stage in their studies (Chatterjee and Hannan, 2015, 112-114).

Having proximity to the artefacts themselves can provide a better view than texts alone, working with objects can provide a visual aspect to the texts, viewing the objects from all sides and feeling the material (haptics) (Chatterjee and Hannan, 2015, 61). However, a haptic approach within object-based learning comes with some difficulties, as we want to provide an object-based learning experience, this requires the students to handle artefacts, in this case, archaeological artefacts (Chatterjee and Hannan, 2015, 61). Some of these artefacts are extremely fragile, and precious, or need to undergo conservation to be able to be used and, sometimes, artefacts are not available (Chatterjee and Hannan, 2015, 109). Luckily, alternative methods can be used for students to work with these artefacts, like drawing, and 3D and virtual modelling (Chatterjee and Hannan, 2015, 112-114).

Next to traditional object-based learning, digital OBL has become more popular during the COVID-19 pandemic and involves using digital resources and objects to enhance the learning experience, providing interactive and engaging opportunities for students to explore and understand various concepts (Tanabashi, 2022, 733-735). This period highlighted the importance of alternative methods of learning, such as digital alternatives and incorporating digital OBL strategies to adapt to the changing educational landscape during the pandemic.

This thesis will focus on these digital aspects of employing digital OBL approaches. In this study, I refer to a specific part of digital OBL, which is based on 3D and virtual modelling (Chatterjee and Hannan, 2015, 70). There are different ways to integrate digital OBL regarding 3D and virtual modelling, a prominent example of this is to let the students make the 3D models themselves which allows the students to see and work with the original artefact(s) and use techniques like photogrammetry and scanning to create a virtual representation of the original artefact(s). It involves the creation of digital representations of real objects, which can be explored, manipulated, and interacted with in virtual environments (Chatterjee and Hannan, 2015, 112). Using digital programmes can sometimes be easier than physically handling the original artefacts to avoid alteration and degradation. It is important to educate the students about the theoretical underpinning of digital OBL, so it would be a combination of text and a "hands-on" approach. Furthermore, the creation of a 3D model, including the theoretical underpinning, can give students extra insights regarding the importance of 3D models, their potential uses and applications.

The Importance of Digital Object-Based Learning

During the COVID-19 pandemic, the importance of digital OBL became even more pronounced as traditional in-person teaching methods were disrupted as universities and alike had to close their doors. Educators and institutions turned to digital tools and resources to facilitate remote learning and provide students with alternative ways to engage with course material, and this shift towards digital OBL during the pandemic underscored the adaptability and effectiveness of incorporating digital resources in education (Tanabashi, 2022, 733-735).

Educators have leveraged digital tools and resources to create interactive and dynamic learning experiences for students due to this shift to online learning which has highlighted the importance of artefacts in maintaining engagement, facilitating collaboration, and supporting diverse learning styles (Reitan, Waage, and Habib, 2022, 1-2). Additionally, artefacts have played a role in bridging the gap between technology and community-building in education, fostering connections and collaboration among students and educators (Reitan, Waage, and Habib, 2022, 14).

Furthermore, digital OBL holds significant value for public outreach within archaeology due to its ability to provide interactive and immersive (educational) experiences, and by digitalising archaeological artefacts, individuals can engage with cultural heritage in ways that were previously inaccessible (Morgan, 2022, 224-225). Through digital platforms, such as virtual museums or interactive websites, the public can explore artefacts in detail, uncovering their historical significance and cultural context (Mointinho de Almeida and Barceló, 2012, 394). This approach makes for a deeper understanding of archaeology and promotes inclusivity by making archaeological knowledge available to a wider audience regardless of geographic location or physical access to archaeological sites (Morgan, 2022, 224-225). Additionally, digital OBL encourages active participation and research-based learning, empowering individuals to develop critical thinking skills as they analyse and interpret archaeological materials (Tanabashi, 2022, 733-735). Overall, using digital technologies for OBL enhances public engagement with archaeology, facilitating a more immersive and enriching learning experience for diverse audiences.

Altogether, the use of digital OBL can help enhance public outreach efforts by creating open access to archaeological knowledge, promoting cultural heritage awareness, and fostering meaningful interactions between archaeologists and the general public (De Groot, 2017, 5). As the Icomos Charter for the Protection and Management of the Archaeological Heritage, Article 7 (1990) states:

> "The presentation of the archaeological heritage to the general public is an essential method of promoting an understanding of the origins and development of modern societies. At the same time it is the most important means of promoting an understanding of the need for its protection.
>
> Presentation and information should be conceived as a popular interpretation of the current state of knowledge, and it must therefore be revised frequently. It should take account of the multifaceted approaches to an understanding of the past.
>
> Reconstructions serve two important functions: experimental research and interpretation. They should, however, be carried out with great caution, so as to avoid disturbing any surviving archaeological evidence, and they should take account of evidence from all sources in order to achieve authenticity. Where possible and appropriate, reconstructions should not be built immediately on the archaeological remains, and should be identified as such." (ICAHM, 1990, Article 7).

In this thesis, as mentioned before, the aim is to provide a way to enhance public outreach initiatives, focused on public outreach by exploring the potential of incorporating 3D models, storytelling elements, and digital OBL approaches as an educational approach for the presentation and dissemination of artefacts by creating a virtual learning environment.

1.3 State of the Art

There is a wealth of research on digital teaching and learning in higher education and it generally divides learning into three types: face-to-face, hybrid (mix of face-to-face and online), and online (Reitan, Waage, and Habib, 2022, 2). Due to COVID-19, an abrupt shift from face-to-face to online teaching has exposed a need for pedagogical content knowledge among teaching staff regarding online learning (Rapanta *et al.*, 2020, 924). Research regarding online teaching and learning and digital object-based learning has been conducted and some contributions relevant to this study are presented below.

Online Teaching and Learning

Reitan, Waage, and Habib (2022) conducted research in 2021 focusing on understanding how educators adapted, shaped, and transformed teaching and learning practices during the COVID-19 pandemic and beyond. The study involved collecting empirical data through semi-structured interviews with teaching staff at the Metropolitan University in Oslo, Norway (Reitan, Waage, and Habib, 2022, 5), that explored the challenges and opportunities arising from pandemic-induced changes in digital teaching and learning, as well as their implications for post-pandemic educational practices with a focus on the pedagogical ones, not on artefacts (Reitan, Waage, and Habib, 2020, 6).

The results of the research by Reitan, Waage, and Hadid, highlighted the utilisation of primary artefacts like digital tools, learning paths, and virtual bulletin boards, to facilitate learning activities both in and outside the classroom. Along with secondary artefacts such as self-help guides, they played a crucial role in enhancing the teaching process and ensuring preparedness for online sessions (Reitan, Waage, and Habib, 2022, 6-8). Additionally, tertiary artefacts, including institutional policies, educational technologies, and community practices shape the learning environment (Reitan, Waage, and Habib, 2022, 9). Furthermore, the research underscores the need for flexibility and creativity in adapting to changing educational landscapes, particularly during and beyond pandemic times (Reitan, Waage, Habib, 2022, 14).

Similarly, Rapanta *et al*. (2020) focused on online university teaching during and after the COVID-19 crisis, drawing insight from four pedagogy experts from different parts of the world, namely Switzerland, Canada, Australia, and the North of Spain. These experts were selected based on their expertise and experience in online teaching and learning, with a particular emphasis on innovation in online education (Rapanta *et al.*, 2020, 926). The research methodology employed in the study involved heuristic research methods. So, rather than following strict protocols or predefined procedures, heuristic methods prioritise generating insight and understanding through the process of discovery and experimentation, which allows for flexibility and adaptability in problem-solving. The participants in the study also functioned as co-researchers, contributing their experiences and insights to the research process (Rapanta *et al.*, 2020, 940). Rapanta *et al.* (2020) aimed to provide valuable recommendations for non-expert university teachers based on expert insights, contributing to the discourse on innovative online education practices.

Digital Object-Based Learning

Digital OBL is a fairly new educational approach, and because of this, not a lot of research has been conducted. Research done so far seems promising; however, it is essential to continue to explore its effectiveness, impact, and potential for enhancing educational and public experiences. Some short-term studies have been conducted by researchers such as Tanabashi (2021) and Ekengren *et al.* (2021), whose works are highlighted below.

Tanabashi's (2021) pilot study focuses on the use of old Nishiki-e (traditional Japanese woodblock prints) as a learning tool for contemporary digital OBL in STEAM[2] education (Tanabashi, 2021, 219, 221). Tanabashi discusses the historical significance of Nishiki-e and how they can be integrated into modern educational practices to enhance interdisciplinary learning experiences (Tanabashi, 2021, 220). The study explores the potential of using these traditional artworks to bridge the gap between art and technology in educational settings, emphasising the importance of cultural heritage in STEAM education (Tanabashi, 2021, 219). The results of this study show that digital OBL enhanced the students' engagement and yielded positive results, indicating its potential for broader implications (Tanabashi, 2021, 221). Tanabashi (2021) demonstrates the value of digital OBL in enhancing STEAM education and promoting interdisciplinary collaboration, suggesting its potential to address future challenges in diversity and inclusion within the field.

Another recent study based on using digital OBL approaches by the use of digital tools is the Dynamic Collections at Lund University (Ekengren *et al.* in 2021). This project focuses on utilising 3D technology to enhance the engagement with archaeological collections for students, researchers, and scholars (Ekengren *et al.*, 2021, 337). It is an online platform that offers various tools and functionalities to interact with 3D models, such as searching and interacting with 3D models, database integration functionalities, the possibility to create personal collections, and perpetual access. The system aims to expand the collection management to include more ways to enrich the structure and work with the collected objects (Ekengren *et al.*, 2021, 348-350). The project seeks to enhance the learning experience by enabling users to interact with archaeological artefacts in a virtual environment, fostering a deeper understanding of material culture and heritage studies (Ekengren *et al.*, 2021, 338, 343).

[2] Science, Technology, Engineering, the Arts and Mathematics.

The experiments conducted during this study, a Stone and Bronze Age exam during COVID-19, also allowed the researchers involved in the project to identify some pitfalls. During the examinations, 3D models of selected artefacts were represented and used to ask questions to the students (Ekengren *et al.*, 2021, 346). One of the issues identified was a time restriction, employed to lower the chances of cheating. Another hurdle was that the students who took these exams were new to the university and had limited experience using this platform. Lastly, the pandemic itself was a cause of extra anxiety and stress that may have naturally affected the students' performance (Ekengren *et al.*, 2021, 346). Notwithstanding the limitations, this study proved successful in many aspects. This way of using 3D models in teaching complements the traditional methods when physical access is limited. However, 3D models cannot fully replace the tactile experience of physical objects (Ekengren *et al.*, 2021, 350). Yet, 3D models offer unique benefits, like accessibility, detailed analysis tools, and comparison with metadata. Additionally, 3D models can enhance students' understanding when using both physical artefacts and 3D models, making 3D models valuable tools in archaeological education (Ekengren *et al.*, 2021, 350).

In conclusion, it is evident that the way of teaching and learning in higher education has transformed, particularly by the challenges posted by the COVID-19 pandemic. The studies discussed highlight the adaptation, innovation, and exploration of digital teaching methodologies in the realms of online teaching and digital OBL.

Moving forward, it is important to continue exploring and enhancing these approaches, addressing challenges such as knowledge gaps, technological limitations, and the need for inclusive and engaging educational experiences. The studies presented offer valuable insight into the potential of digital tools and platforms to enhance learning outcomes, foster interdisciplinary collaboration, and promote cultural heritage preservation in educational settings.

1.4 Analytical Framework

Previous studies on online learning and digital OBL approaches have primarily focused on the use of digital OBL in higher education settings, particularly in response to the COVID-19 pandemic, which necessitated the shift to online learning platforms. While these studies have explored the effectiveness of digital OBL for teaching archaeological concepts and material culture to students, more research is needed to assess and understand its potential for public outreach in archaeology.

The methodological approach in this thesis is based on the theoretical framework of object-based learning (para. 1.2) and previous research (para. 1.3) and tries to expand this by applying it to public outreach. It lays the groundwork for further research in this emerging field, as digital OBL is still relatively new in its application. By utilising standard pillars of digital OBL, such as immersive storytelling and interactive platforms, this thesis proposes a framework and pilot study setup for a virtual learning environment that can engage diverse audiences (ch. 3). Moreover, this approach allows to reuse objects from the Dynamic Collections at Lund University, to build novel narratives around these objects, thus providing an innovative way of presenting the archaeological artefacts to the general public. Furthermore, such an interactive virtual approach to present and explain the information in an engaging way, follows Icomos Charter for the Protection and Management of the Archaeological Heritage, Article 7.

Moreover, the use of 3D models not only enhances accessibility to archaeological artefacts, but also addresses practical challenges, such as fragility or unavailability of the original archaeological artefacts. This technology enables a detailed exploration of artefacts, illustrating their construction, function, and cultural significance, thereby fostering a deeper understanding among the general public. This thesis contributes to advancing existing research on digital OBL; it also redirects object-based learning approaches focused on public outreach efforts in archaeology.

It showcases the potential of immersive storytelling applications to captivate and educate the public about archaeological artefacts and their cultural significance. By leveraging the Dynamic Collections and software tools, the thesis lays the groundwork for further analyses and research endeavours. Through the integration of meta- and paradata from the Dynamic Collections, it provides a rich data model that can be further explored, contributing to the ongoing refinement of best practices and strategies for employing digital OBL in various public outreach contexts.

The virtual learning environment has been created in 3DHOP. This is an open web-based environment that can be customised to present 3D models and create storytelling elements. It was decided to use 3DHOP as it is highly customisable which is crucial when creating narratives, furthermore, it allows online publication of high-resolution 3D meshes (Potenziani *et al.*, 2015, 135). There are other web-based platforms where 3D models can be presented, like Sketchfab. However, Sketchfab is less customisable, and you lose control of the 3D models' properties (Sketchfab, n.d.). This is not a problem when working with 3DHOP. As this thesis was aimed to enhance the presentation and engagement of artefacts to the general public, it was important to create my visualisation of how I wanted the virtual learning environment to look. Additionally, I wanted to be able to add multiple 3D models, text, and images which can be done when using 3DHOP.

By using a 3D representation of an object from the Dynamic Collections at Lund University, this thesis aims to address the identified gap of not applying digital OBL approaches for public outreach within archaeology. This application was designed and developed as an outreach interactive application around a 3D representation of an archaeological object. To create a deeper engagement of the general public, an interactive storytelling layout was defined and applied to this digital representation.

Based on personal interest and its accessibility, an Iron Age comb was chosen as the study object. After the selection, I analysed the 3D, made available on the Dynamic Collections website in 2021, and studied its characteristics. The dataset of these 3D models had been made available to me by Danilo Marco Campanaro from Lund University, currently responsible for the 3D data within the Dynamic Collections Project.

The 3D acquisition was made using a structured-light scanner (para. 2.2.1). Data processing and data-post-process represented a crucial part of my study, and it was crucial to look at how the 3D model could be used and what aspects I wanted to use for the virtual learning environment. This process consisted of visualising the different parts of the comb and dividing the original 3D model of the comb (para. 2.2.2), further post-processing of all these 3D models was needed to achieve the defined goals.

The 3D models of all the different parts of the comb were further post-processed to visualise the texture on all the components of the comb, to give the user a full picture of what the comb looked like (para. 2.2.3). These 3D models with texture were then exported and compressed to a suitable format for its online publication. All 3D models were then used to create a contextual story to provide the best possible information to the users (para. 2.2.4). This way, not only the physical features of the object are shown, but there is also a story attached to it. This can create a better understanding and appreciation of archaeology among the general public.

Lastly, it is important to note that the methods used for this thesis can be applied to all artefacts, thus demonstrating that is possible to find innovative ways to make archaeology more immersive and interesting to the public by using interactive approaches.

2. Materials and Methods

2.1 Iron Age Comb

To achieve the goals of my study, I selected an Iron Age comb, which is an archaeological object from the collections currently used at the Department of Archaeology and Ancient History at Lund University. The comb (DC265_LUHM2905,1) is part of the *Historiska Museet vid Lund Universitet* (Lund University Historical Museum), and it is also part of the Dynamic Collections Project, which makes it available online.

Starting in 2020, several archaeological objects from the Historical Museum collection were implemented in the Dynamic Collection platform in response to COVID-19 and used in online teaching (Ekengren *et al.*, 2021). Meta- and paradata enriched the digital objects in the collection.

The comb was analysed by F. Ekengren and scanned by D. Dininno in May 2021 (models.darklab.lu.se, 2021). The meta- and paradata of the comb are available on the website. An overview of the comb data-scheme can be seen in appx. 1.

2.1.1 The Iron Age Comb

The comb is from the Early Iron Age, more specifically the *Folkvandringstid* (Migration Period) which is from ca. 400 - 550 AD (historiska.se, n.d.). It is made of horn and consists of three layers. The two outer layers, grip plates, are triangular shapes and in between these two grip plates are four toothed plates and it is all held together by iron rivets (Tuohy, 1999, 18). The decorations on the two grip plates consist of concentric circles and linear lines (fig. 1 and 2) (models.darklab.lu.se, 2021).

Figure 1. Front of the Iron Age Comb.

Figure 2. Back of the Iron Age Comb.

Unfortunately, not a lot is known regarding the archaeological context of the comb. It is known that it was found on a farm in Källby, Lund, in Grave 1. Two books, both written by Märta Strömberg[3] (1961) have information about the place where the comb was found. However, this information is very limited.

Strömberg (1961) mentions: “In Grave 1 there was a three-layer comb with an approximately triangular top part, dotted circle decoration and coarse teeth that become shorter at the ends” (Strömberg, 1961, 102). In another book, Strömberg (1961) mentions that it is a destroyed grave with many artefacts, like a double-edged sword, a ring, a buckle, a knife, a folding knife, leather scraps, and decorated fittings from the bridle, and a horse skeleton. However, Strömberg believes it is unlikely that the horse skeleton originally belonged to the grave, given the grave inventory (Strömberg, 1961, 46).

More so, it is unsure of why the comb was found in this grave. As the grave was destroyed, the original context was also destroyed. This means that the excavators were unable to determine why the grave content was found the way it was. However, combs were important during the Iron Age, as hairstyles were not just about looking clean, the hair of an individual also hinted at status, job and where someone came from (Aufleger, 1996, 642).

After archival research, I was able to fine one study done by Brynja (1998) that shows different types of combs, including Iron Age combs, found in the region *Mälardalen* in Sweden (Brynja, 1998). As Iron Age combs are mentioned in this study by Brynja, this information has been used to catalogue the comb used for this thesis.

In Brynja’s (1998) study, the comb used in this thesis falls into Group 1: “Older compound comb” (Brynja, 1998, 18). These combs typically have a short, arched grip part with a rounder or slightly angled dorsal line, characteristics that match the comb in this study (Brynja, 1998, 18). Additionally, the length of the grip plates (around 8.2 cm) aligns with the average size (8.5 cm) of older compound combs (Brynja, 1998, 18). The grip plates are identified as type C: “Angled back” (Brynja, 1998, 19), and the iron rivets connecting them are arranged in a regular zig-zag pattern (Brynja, 1998, 20). Unlike in Brynja’s study, where combs have either three or five toothed disks, this comb has four toothed disks (tine planes) (Brynja, 1998, 20). The cross-section of the central rail supporting the grip plates corresponds to type C: “Wedge-shaped section without ledge” (Brynja, 1998, 20) and type A:3: “Thin central rail cross-section, no edges, flat sides and straight horizontal upper sides” (Brynja, 1998, 21). Moreover, the comb features decorations such as edge-following lines and concentric circles (Brynja, 1998, 18), which were common during the Iron Age (Tuohy, 1999, 18).

[3] Märta Strömberg was a Swedish archaeologist and researcher at Lund University (Sydsvenskan, 2012).

2.2 Creating the virtual learning environment

To create a virtual learning environment, I developed a flowchart based on five stages:

1. acquisition;
2. data processing;
3. data post-processing;
4. online presentation.

To accomplish my tasks, I used specific software for every step. This flowchart is illustrated below:

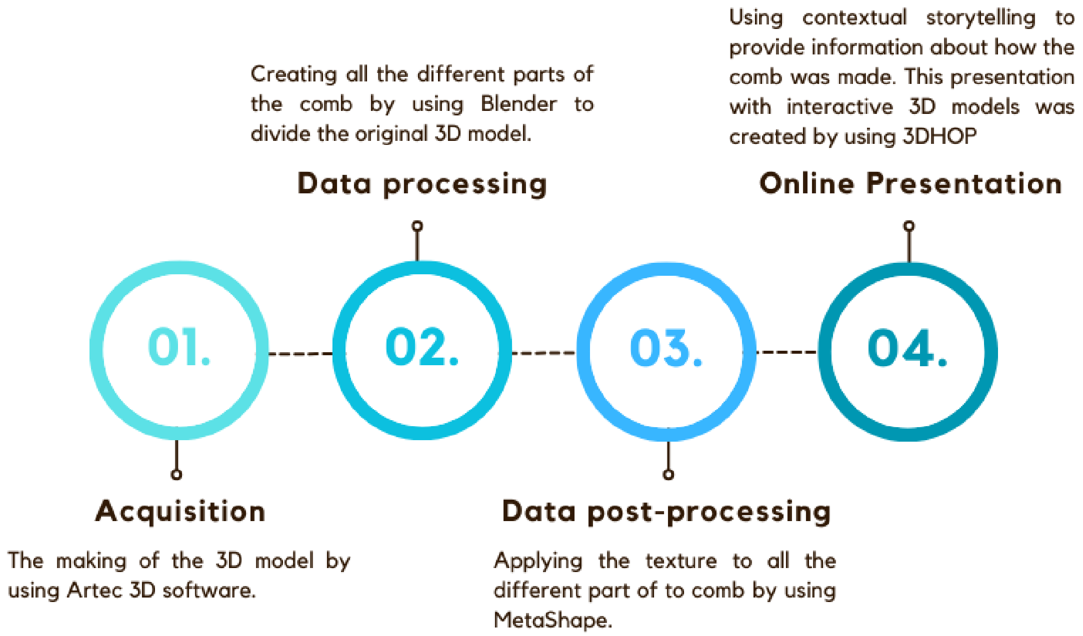

Figure 3. Flowchart of the creation of the virtual learning environment.

2.2.1 Acquisition

The 3D model of the selected Iron Age comb represents one of the main components of this project. This 3D model was made available in 2021 on the Dynamic Collections website at Lund University. However, for this thesis, it is important to describe the process of making this 3D model.

Artec 3D has made handheld and portable 3D scanners since 2007. The 3D scanners are high-quality and easy to use. Furthermore, the 3D software is made as user-friendly as possible (www.artec3d.com, n.d.). The specific scanner used for the creation of the 3D model of the Iron Age comb was the Spider Scanner (models.darklab.lu.se, 2021). Based on blue light technology, the Artec Spider Scanner is a high-resolution 3D scanner. It is ideal for capturing fine details or small objects in high-resolution, with bright colour and consistent accuracy. With the ability to export the finished 3D models to CAD or the Artec 3D software, it is a perfect 3D scanner for high-resolution scanning of things like moulding components, coins, and more archaeological artefacts (Professional 3D scanning solutions | Artec3D, n.d.).

Processing the data

The Spider scanner was used to make three scans of the Iron Age comb in 2021 by D. Dininno. After these scans were made, the scans were processed to remove unnecessary data, i.e. automatically created geometry between the comb teeth which are not part of the original comb. After this process, the scans were aligned, a mesh was created, and a texture was applied to it. The texture was produced simultaneously when the comb was scanned. This texture is a .mtl file which contains the information about the coordinates and file path of the outer texture.

A mesh simplification was likely done to size down the polygons, depending on the purpose for which the 3D model was created. Setting the parameters is important as the 3D models should not be too big to have any difficulties being displayed online, but still have geometrical details. In this case, the 3D model had to work fast and easily in online streaming for students and teachers using the website.

2.2.2 Data Processing

The 3D model was used as the starting point to create multiple 3D models, consisting of all the different parts of the comb. These 3D models were conceived for being part of the interactive 3D virtual learning environment.

To create the different 3D components of the comb, I used the software Blender was used. It is a free and open-source software that can be used for 3D modelling, animation, and rendering (Blender Foundation, 2019). Using Blender I was able to divide the 3D model into different pieces:

- two grip plates;
- four tine plates (plates with the comb teeth);
- seven rivets.

Processing the data

To isolate these 3D components of the comb in Blender, different steps have been taken. First, the 3D model of the comb was imported into Blender in the .obj file format.

After the model was loaded into Blender, the original model was copied so that one original model was present as a reference. The copy was used as the base for isolating the different pieces mentioned above. This was done by adding a “plane” (fig. 4). This is a square that is mouldable to fit the spaces where the parts of the original artefact are glued together. Once this “plane” was placed along these lines, the “plane” was converted into a 3D solid plane by changing its “width” to 0.001 cm. The different parts of the comb were then separated to divide the comb into all its parts (fig. 7).

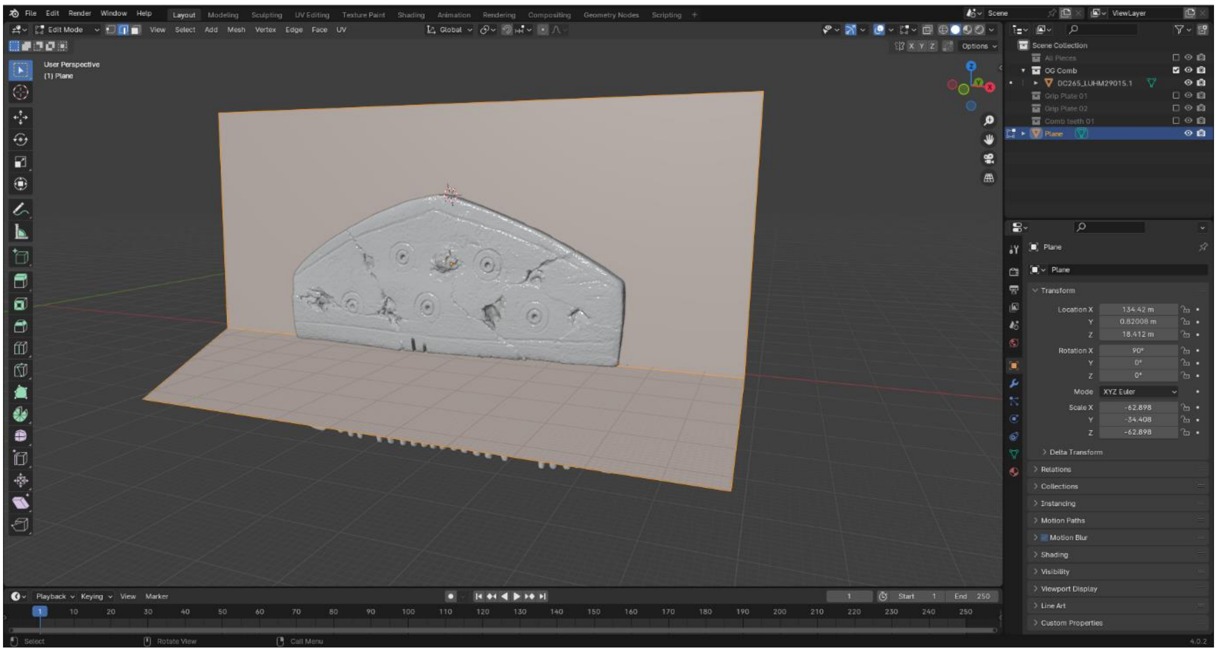

Figure 4. Placing the ‘plane’ correctly to cut the different parts.

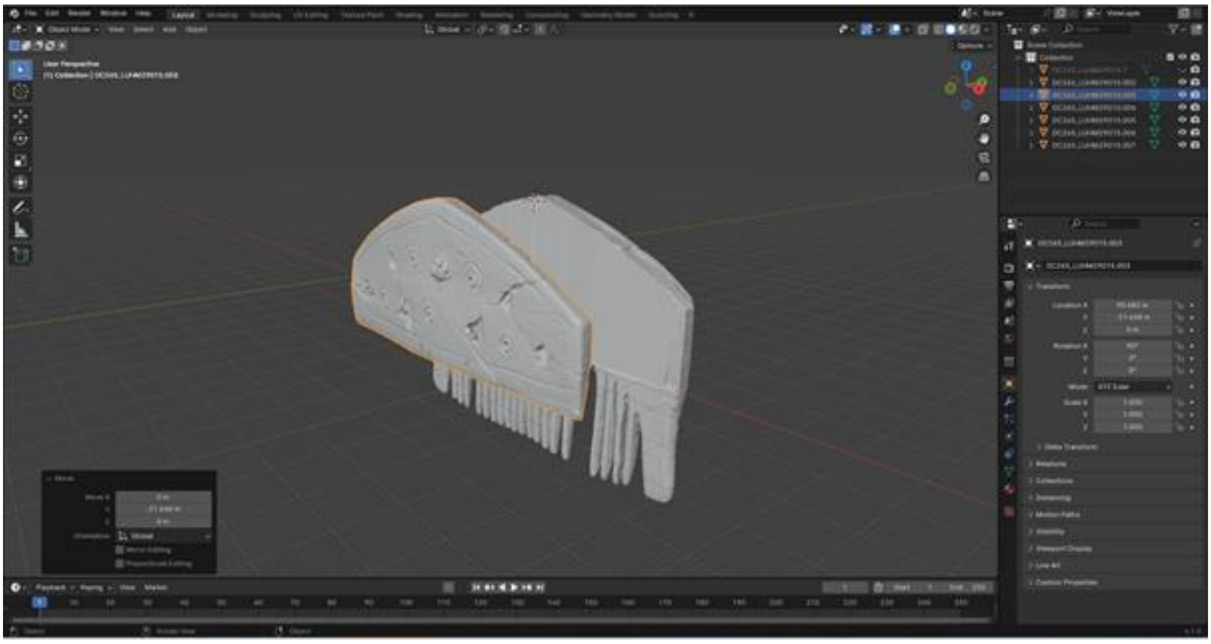

Figure 5. A part of the comb has been cut into a grip plate.

After the comb pieces were isolated, the texture was applied to the outer surface (fig. 6). The outer texture of the original artefacts was created when it was scanned with the Spider Scanner. This information is necessary to correctly apply the texture on a 3D model. In this instance, this file was part of the data provided by D.M. Campanaro, so I did not have to create this file myself.

As mentioned above, the comb components are currently glued together, meaning that the texture on the not visible parts of the comb as not been scanned. Therefore, I decided to create the inner texture myself (fig. 7). I made it as similar as possible to the outer texture as possible. However, it should be made clear that this inner texture is my own interpretation. The settings that I used to create the inner texture can be found in appx. 2.

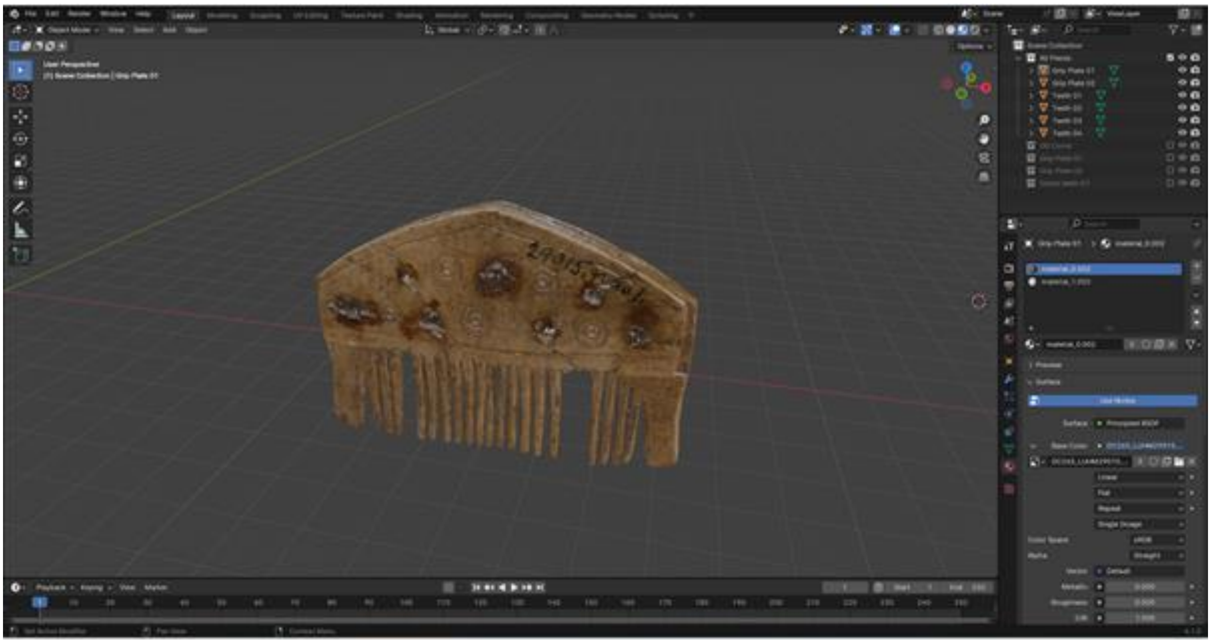

Figure 6. The outside texture of the comb applied to the parts.

Figure 7. The comb in all the parts, incl. the inner- & outer texture.

Then, I worked on another problematic component of the comb, the rivets (fig. 8). It was difficult as all the original rivets were rusty or gone. This caused some problems, but I decided to still create rivets to provide the best way to showcase all the parts of the comb. Also, I needed to have the rivets to give the best explanation to the users regarding the aspect of how the comb was made. The rivets were created with the “cylinder” tool and placed in the same position as the original rivets would have been. In total, there are seven rivets in this comb, thus I created seven “cylinders” were created.

In order to render the rivets as similar as possible to the original ones and with a round surface, some more processing was necessary: to improve the cylinders made in Blender (fig. 9), I applied two modifiers: “Edge Split” and “Subdivision Surface”. These two modifiers combined smoothened the surface of the sides (fig. 10). This was done to create a more realistic rivet, as these had no sharp edges. Furthermore, this rounded-out surface is a better base to apply the texture.

The texture of the rivets has been created with a PBR CG[4] Texture called: Hammered and Oxidized Metal Plate Texture (Metal 0009) (www.texturecan.com, n.d.). As the original texture of the rivets is completely oxidised and rusty, it was difficult to make the rivets have this exact texture, therefore, I chose to try and replicate the presumably iron texture the rivets might have had (fig. 11). It is uncertain if this was the original texture of the rivets, but it indicates a plausible texture to the users.

The interactive 3D models were made with authenticity in mind; however, the inner texture and rivets were created by me, and this is integrated into the virtual learning environment. This means that some parts of the 3D models are not completely authentic, but as the original comb is glued together and underwent preservation, this was the better alternative as opposed to trying to see the inner texture of the original comb by altering it. The rivets were completely rusty, due to the natural degradation of the metal. The rivets were determined as made of iron; thus, an iron-like texture was applied.

[4] Physically Based Rendering Computer Graphics.

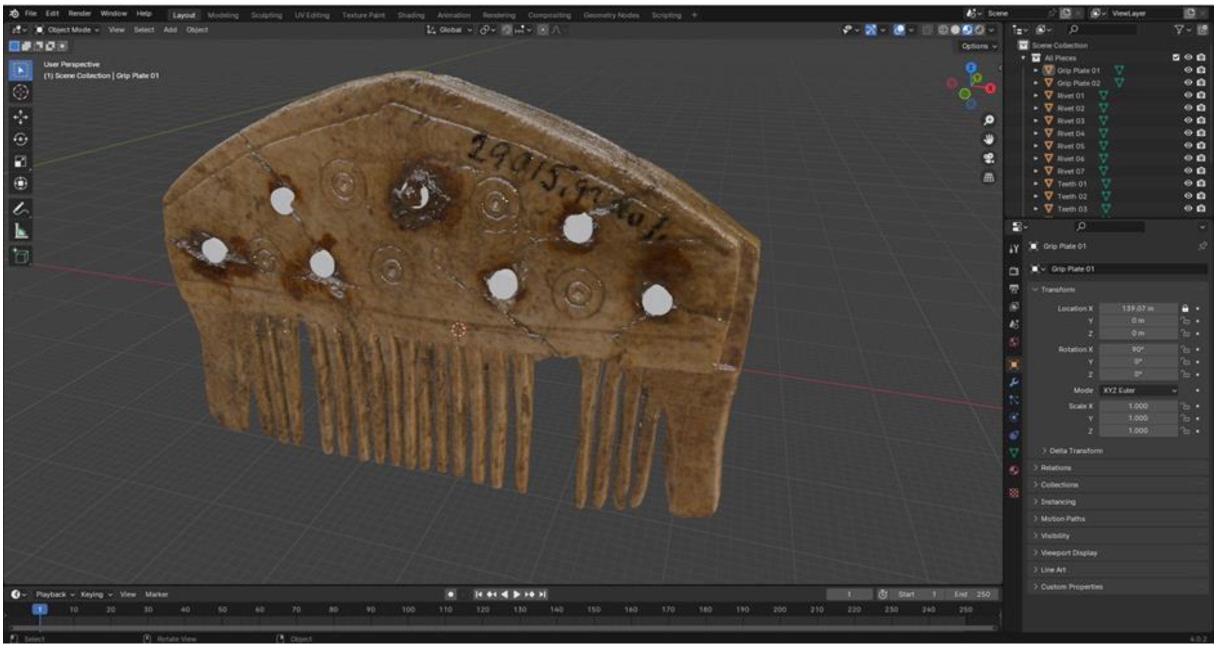

Figure 8. Rivets placed within the 3D model of the comb.

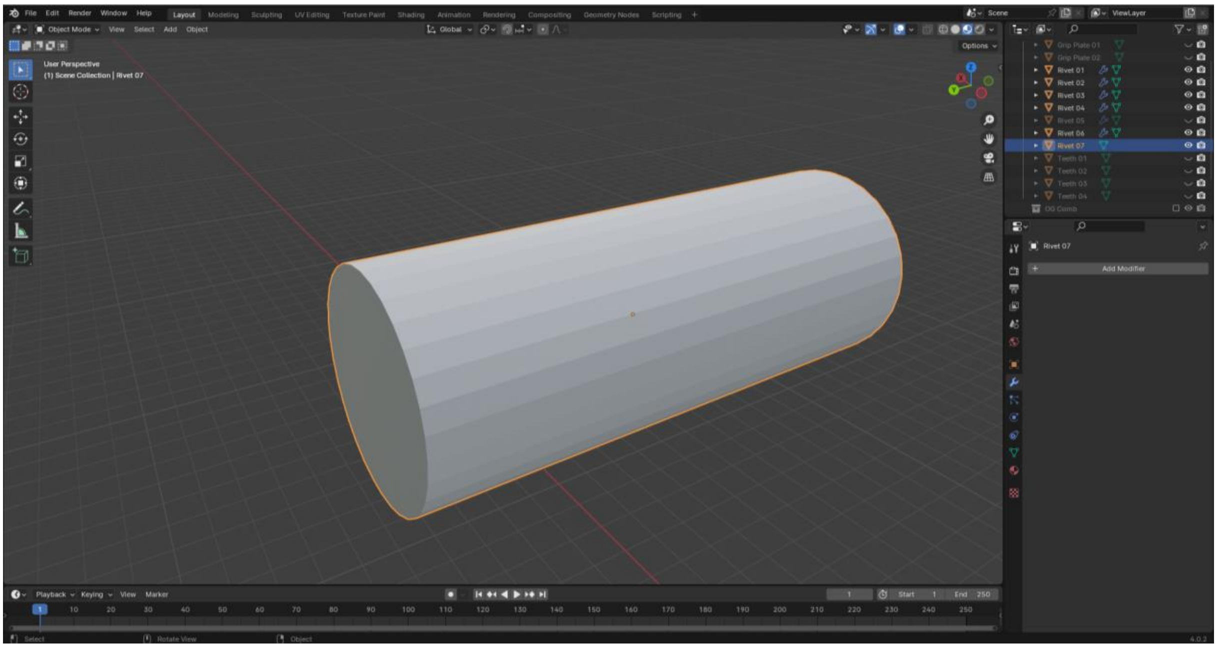

Figure 9. A rivet without rounded edges.

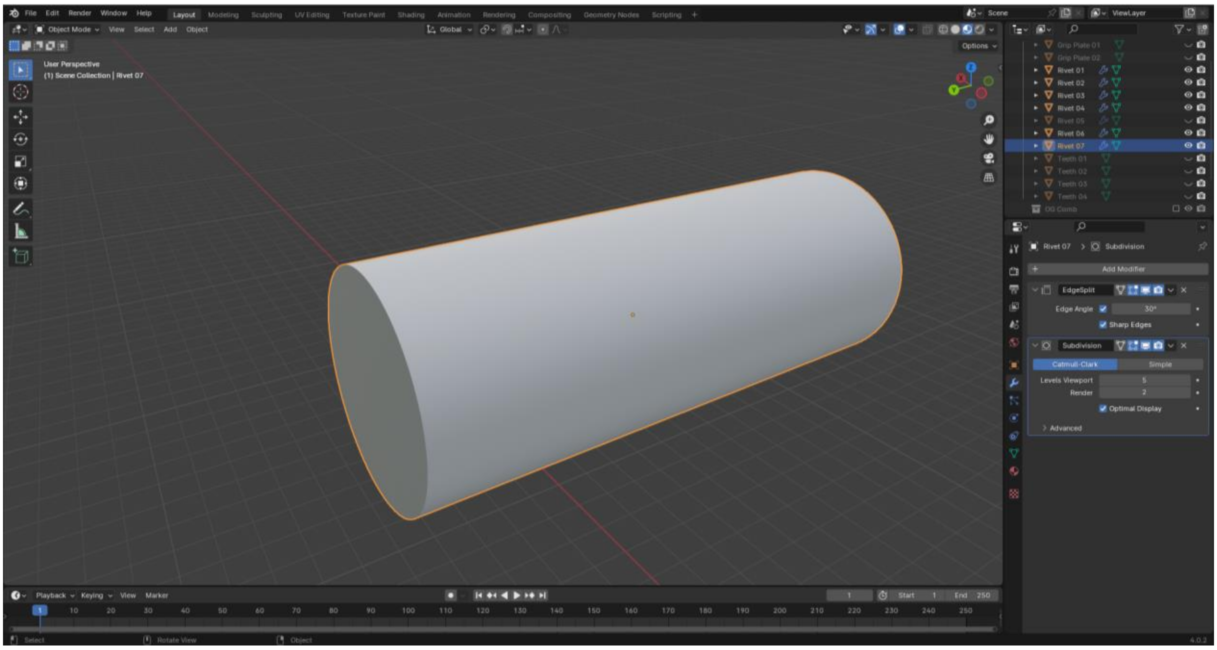

Figure 10. A rivet with rounded edges.

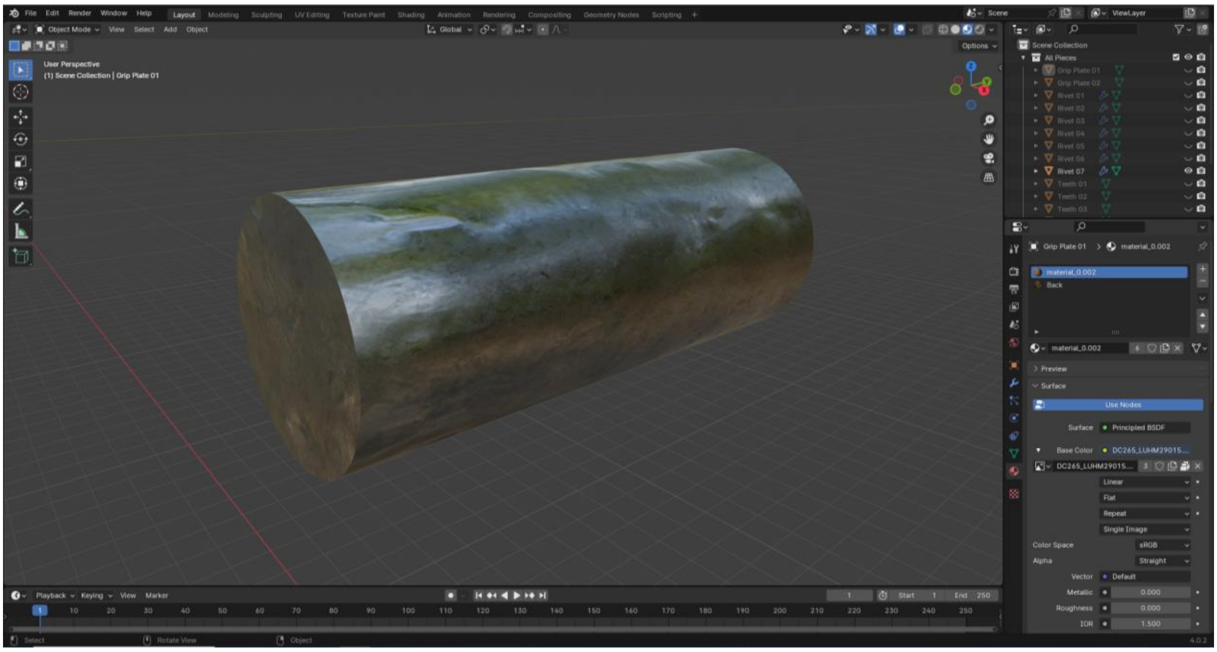

Figure 11. A rivet with the texture applied.

Once the parts were finished, they were exported as .ply files and texture files were also exported as .png files. All these files were used for further processing in the software MeshLab.

2.2.3 Data post-processing

Once all the different 3D models were created and exported, the texture needed to be applied again. This post-processing had to be done to map the texture to the 3D models in the correct way.

The texture is an important component to recreate the most authentic representation possible for the public. To ensure that the public gets the best possible image of an artefact, its 3D representation must contain a texture. While this model contains all the geometrical details of the Iron Age comb, there is nothing else on it and the public does not get an accurate picture of the artefact.

To map this texture correctly, I used the software MeshLab. MeshLab is an open-source platform used to work with and improve 3D triangular meshes. It has several features, such as mesh editing, cleaning, inspecting, rendering, texturing and converting. It makes models ready for 3D printing and makes the processing of data produced by 3D digitisation easier (www.meshlab.net, n.d.).

Processing the data

The .ply files were opened in Meshlab (fig. 12) and the texture was applied using “Convert PerVertex UV into PerWedge UV” and then the texture file was applied using “Set Texture” (fig. 13). Once the texture was applied, the file was exported again as a .ply file.

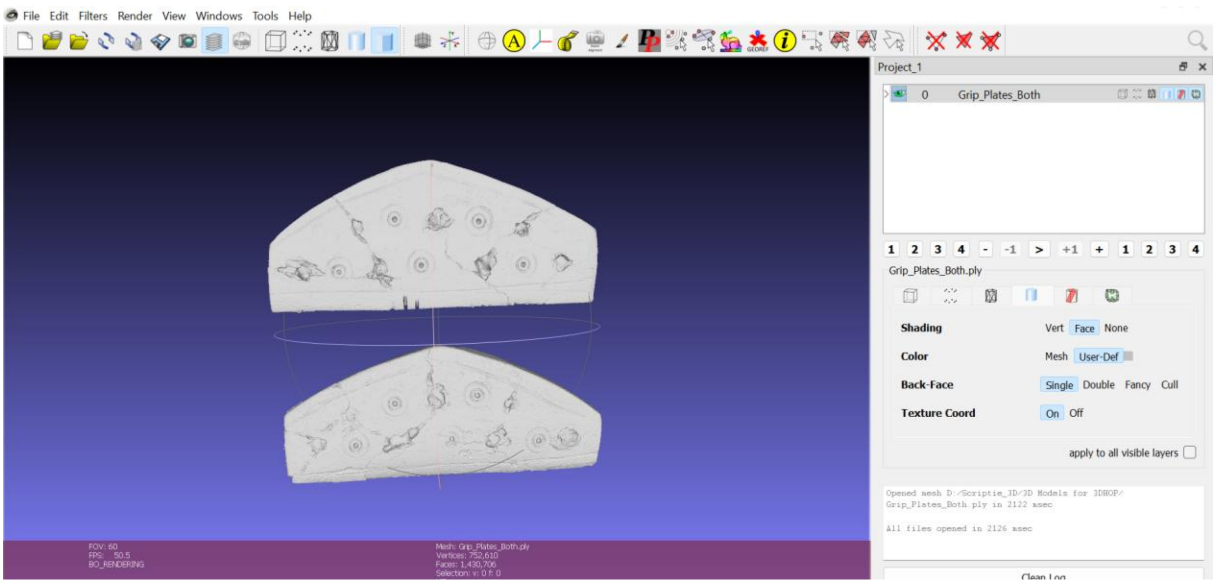

Figure 12. The grip plates in MeshLab without texture.

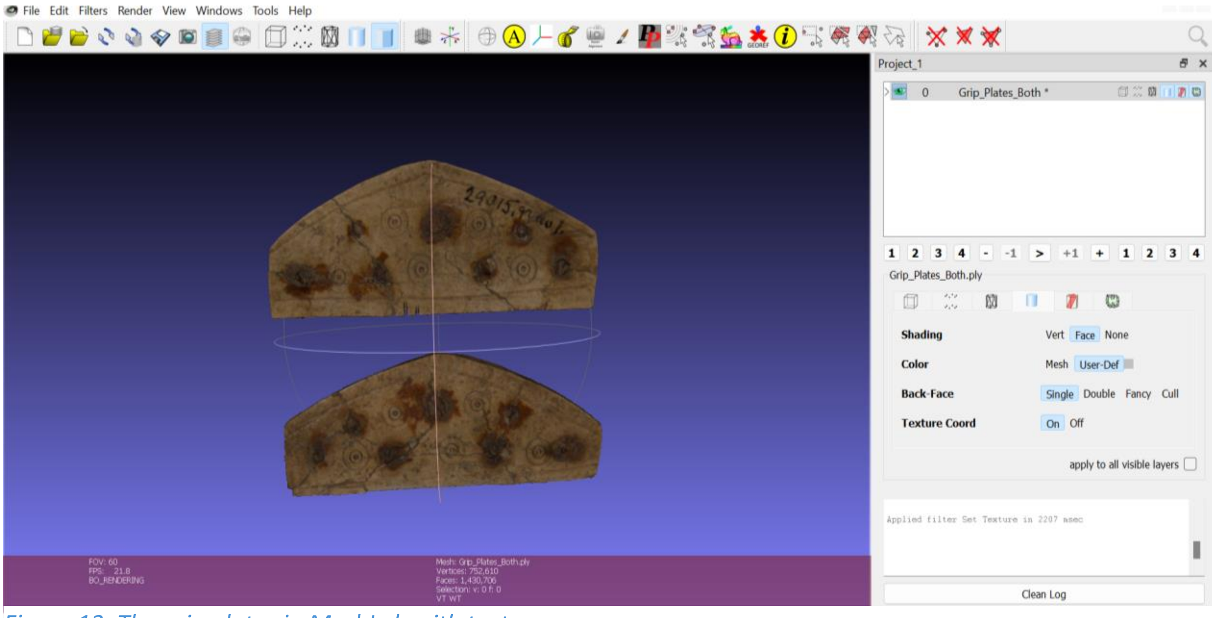

Figure 13. The grip plates in MeshLab with texture.

2.2.4 Online Presentation

The last step of the process is to create an online presentation of the comb used to design and create the virtual learning environment. Making it available online was important as I wanted to create a virtual learning environment that is easily accessible and available for everyone who has an internet connection. Making it accessible online creates a wider public outreach and makes it more inclusive offering everyone around the world the chance to learn and interact with cultural heritage.

To make such an online presentation, I used 3DHOP. 3DHOP[5] is an open-sourceHTLM framework to create dynamic online presentations of high-resolution 3D models with a focus on cultural heritage. With 3DHOP, 3D models can be interactively visualised right within a typical web page. 3DHOP operates within web browsers without the need for plug-ins or other extra components. It only requires some space on a web server and no specialised server or server-side processing (3dhop.net/, n.d.; Potenziani *et al*., 2015, 129).

Using 3DHOP is a fast and easy way for users to interact and learn about the object. The users are able to interact with the 3D model and the attached information (Potenziani *et al.*, 2015, 129). Regarding the information, the users get a better overview of this comb from the Iron Age, getting to know why combs were important during this. Furthermore, the users can see the different 3D models to get an insight into how combs were made during the Iron Age. An overview of the information used can be found below.

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[5] 3D Heritage Online Presenter (3dhop.net/, n.d.)

Presentation design

The content of this paragraph described the design of a flowchart for creating the virtual learning environment in 3DHOP can be found below, which illustrates the workflow from the production of the 3D models to its online presentation.

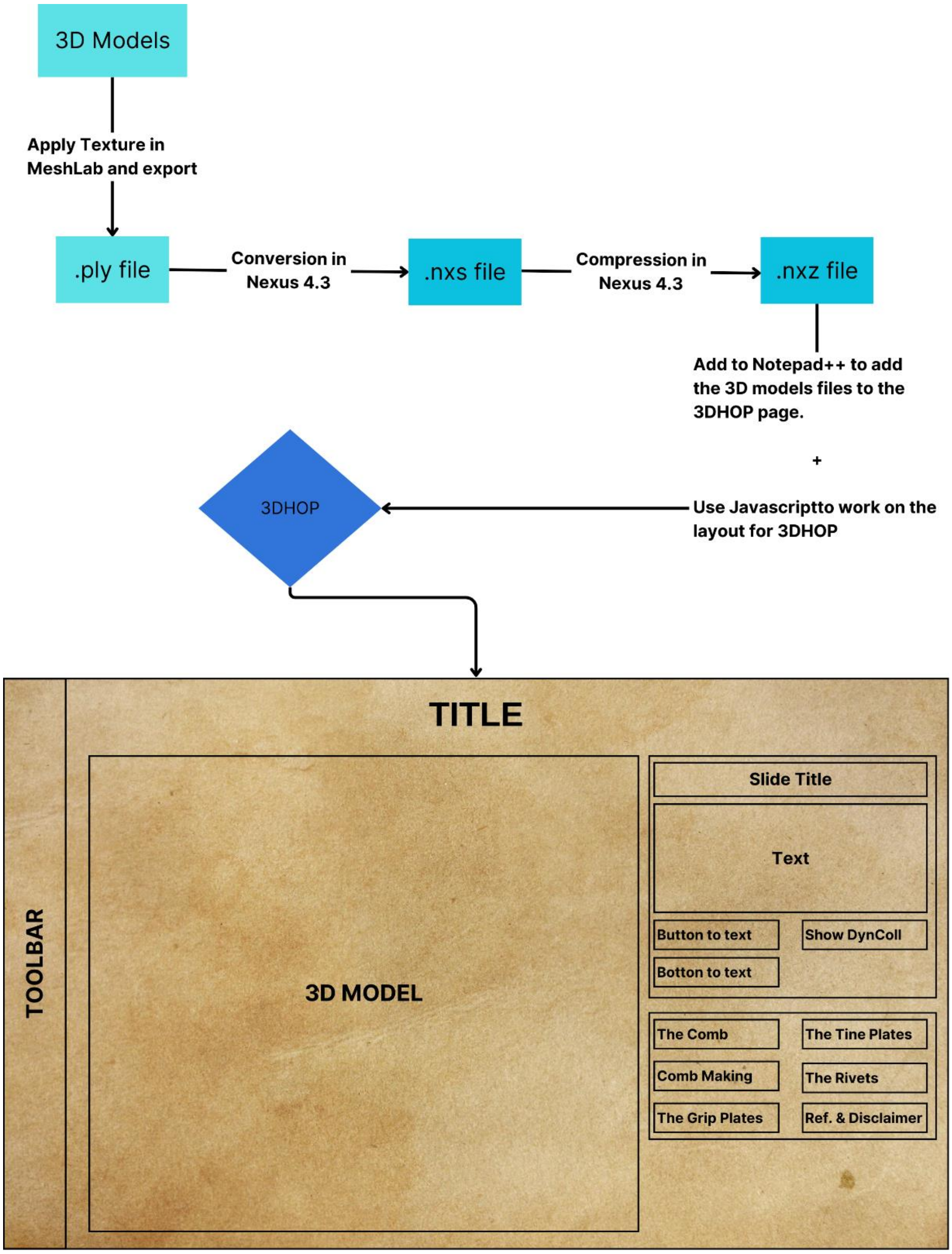

Figure 14. Flowchart representing the workflow structure used to create the virtual learning environment in 3DHOP.

The flowchart gives an overview of the different processes that were necessary to create the virtual learning environment for the public. The virtual learning environment layout has been divided into different sections (fig. 15).

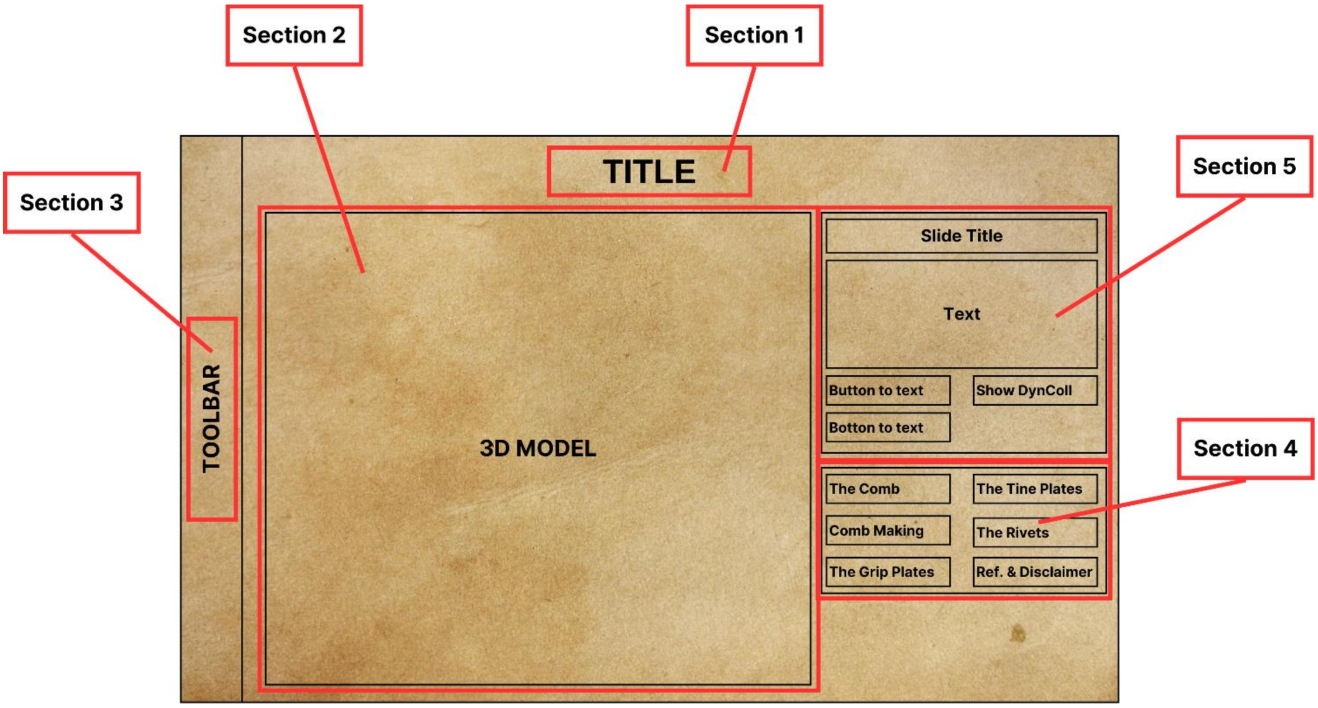

Figure 15. Annotated schematic planning of the 3DHOP learning environment output Section 1: title of the slide; section 2: 3D canvas, where; section 3: toolbar to interact with the 3D model; section 4: interactive buttons to access the other slides; section 5: narrative, the story that supports the user experience.

The different sections of the 3DHOP environment have been designed considering the best interactive 3D environment to enhance and engage public outreach among the general public.

The online presentation is set up in such a way that multiple 3D models and other visual components such as pictures viewed with text. The title (section 1) informs you about the content. The complete 3D model of the comb is placed in the 3D canvas on the left side (section 2). Different tools can be used to interact with the model (section 3). On the right lower side, is a box with different buttons that will allow users to visit different slides that show the different parts of the comb individually. These different parts are also interactive 3D models (section 4). The right upper box provides information about the comb the user is viewing in the form of text and images (section 5). Each slide is built based on a storytelling design (para. 2.3).

The storytelling design makes it very interactive, and users can look at what they think is interesting to explore and read about. This makes the more personal, as every user can take their own path.

Each slide is designed in HTML files where I specify the 3D models that I want to be visualised on each slide (fig. 16 and 17) and the text window to pop-up. More information about 3DHOP can be found on the following website: https://vcg.isti.cnr.it/3dhop/howto.php.

```
<script type="text/javascript">
var presenter = null;

function setup3dhop() {
    presenter = new Presenter("draw-canvas");

    presenter.setScene({
        meshes: {
            "OG_Comb" : { url: "models/DC265_LUHM29015.1.nxz" }
        },
        modelInstances : {
            "model_1" : {
                mesh  : "OG_Comb",
                color : [0.8, 0.7, 0.75]
            }
        },
        trackball: {
            type : TurntablePanTrackball,
            trackOptions : {
                startPhi: 35.0,
                startTheta: 15.0,
                startDistance: 2.5,
                minMaxPhi: [-180, 180],
                minMaxTheta: [-30.0, 70.0],
                minMaxDist: [0.5, 3.0]
            }
        }
    });
```

Figure 16. JavaScript[6] coding for adding the original 3D model of the comb to virtual learning environment.

Figure 17. The visualisation of the JavaScript coding of the parameters set in the HTML page in 3DHOP.

[6] JavaScript is a common coding language to make webpages interactive (Javascript, 2016).

More coding had to be done to create the virtual learning environment that I designed (para. 2.3) and the virtual learning environment can be visited using the following link: https://models.darklab.lu.se/dig_excav/TheCombStory/Home.html.

2.3 The Comb Story

A storyboard was designed to make a sound story, combining the content of the comb with the 3D visual aspects. Using a storyboard allowed me to create an overview of everything that needed to be done to create an interactive digital application for the general public. This online application was made to function on a tablet and laptop. I wanted to make it as user-friendly and accessible as possible so that everyone can easily engage with the comb story.

The storyboard is based on several 'slides' that were lately created in 3DHOP. These slides are the different 3DHOP pages, built in html format files and are presented below.

2.3.1 Slide 0: The Comb (Homepage)

The first slide, or the homepage, is the landing slide that will be opened when entering the virtual learning environment in 3DHOP. The first slide contains the original 3D model made by D. Dininno in May 2021. This was a deliberate choice, as this is where the users will get the first impression of the virtual learning environment. Furthermore, to give a context of what this virtual learning environment is about, it was necessary to use the full 3D model of the comb to grab users' attention and whereafter the users can choose their own path to explore the story.

The slide presents the fully interactive 3D models on the main part of the screen (fig. 18). On the right lower side of the screen there will be a box with some archaeological information about the comb itself, such as provenience and characteristics (fig. 19).

Figure 18. The Homepage of the virtual learning environment.

This Iron Age comb is from the *Folkvandringstid* or Migration Period, which is from 400 to 550 AD.

Archaeological context

Categorisation

The comb was found in a destroyed grave back in the early 20th century in Källby, Lund. Unfortunately, not a lot is known about this specific grave.

The grave founds were a sword, knives, leather straps, a ring, fitting from a decorated bridle, this comb and a horse skeleton.

As the grave was destroyed before the excavation, it is not certain if the horse skeleton was originally part of the grave.

This comb is considered as a type called: "Older composed comb".

These comb have short, arched grip plates. The length of the comb is around 8.3 cm and the zig-zag pattern of the rivets all fit within the categorisation of this type of comb.

The decoration on this comb - concentric circles - are common for the Iron Age period.

Figure 19. Text for slide 0. The "Archaeological context" and "Categorisation" are two buttons that open the text with the corresponding-coloured text box.

The 3D model used for this slide can be seen from all sides and can be interacted with using different tools, like zooming in/out, taking measurements, light control and more. This was done as this is the only 3D model of the complete comb and I wanted to give the users the ability to fully interact with the model. To create more engagement with the artefacts and give the users the ability to fully explore the model to try enhancing their appreciation for the artefact.

2.3.2 Slide 1: Comb Making

In this slide, I chose to explain the way combs were made during the Iron Age, describing the material used to make them, so I provided information about why bone materials were used and their symbolic meaning. I also created two buttons below this text, each opening a new text box. The information in the other text boxes is connected to either the "Making of the comb" or "Different parts of the comb" (fig. 20).

Users are also provided with two figures in the textboxes, one of the craftsmen working with bone and one displaying the different parts of the comb (fig. 21). Both these figures and the 3D model of the complete were added to provide a visual component to these text descriptions.

Figure 20. The Comb Making slide of the virtual learning environment.

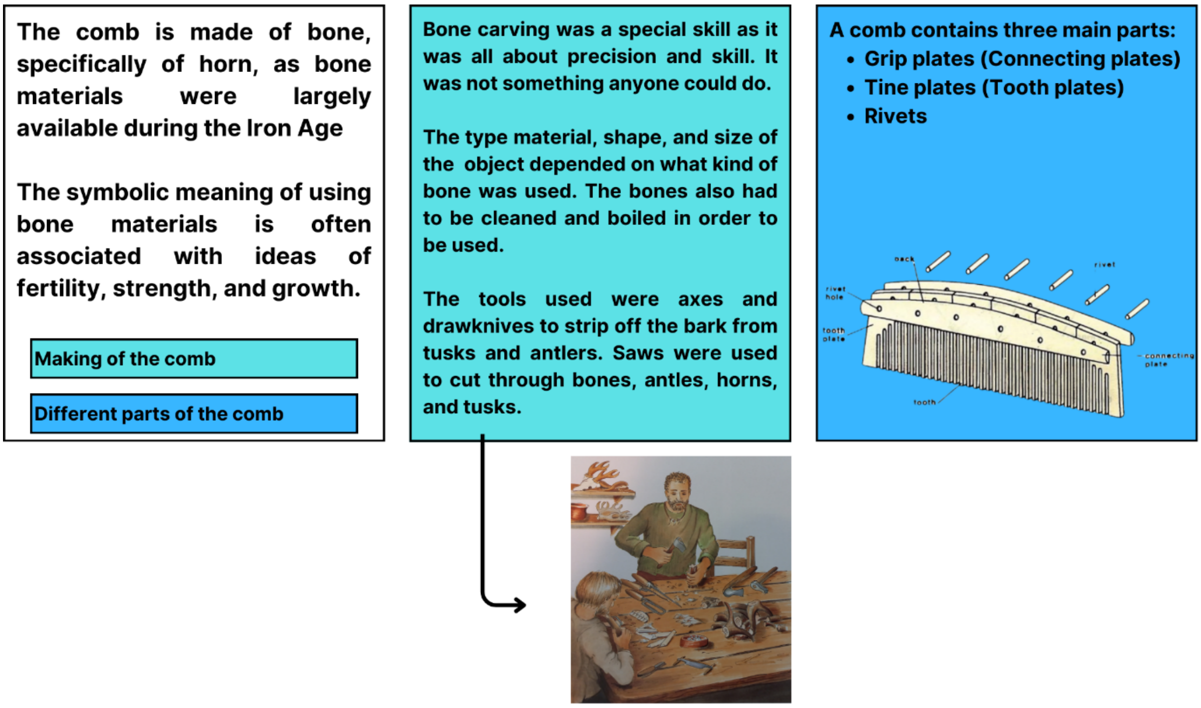

Figure 21. Text for slide 1. The "Making of the comb" and "Different parts of the comb" are two buttons that open the text with the corresponding-coloured text box with images.

This thesis highlights the importance of enhancement and engagement of archaeological artefacts for the general public, which is why I wanted to provide the user with an overview of how combs were made. This comb-making concept can be hard to grasp as not many people study ancient combs. To make it more inclusive, it is important to explain every little thing, even if it may seem logical to some individuals.

2.3.3 Slide 2: Grip Plates

For this slide, I displayed the 3D grip plates of the comb in an interactive environment (fig. 22). This model can be tilted; however, the backs of the grip plates are not available in this model. This was done because I wanted to keep the focus on the decoration of the comb. As I wanted to keep the focus on the decoration, I added all the available 3DHOP tools so that users can take measurements of the decorations. Furthermore, the information attached to this slide regards the grip plates, the making of the decoration and the concentric circles (fig. 23). This information describes to the users what they are seeing when first opening this slide. The users are then given the choice to click on "Making of the decorations" or "Concentric circles". Both buttons open different text boxes.

The "Making of the decorations" provides the user with how craftsmen made the specific decorations that can be found on the comb. This information is most likely something new for the users and can maybe spark new interest in how craftsmen from the Iron Age used different tools. The "Concentric circles" provides information about the symbolism of the decoration. The symbolism is an important aspect as this views the beliefs of the Iron Age to answer the question of why these specific concentric circles were used.

Figure 22. The Grip Plates slide of the virtual learning environment.

The grip plates are two triangular shaped plates. Each side features five concentric cirles and two thin lines tracing the edges of the plates.

Making of the decorations

Concentric circles

Creating comb decorations was a simple process using just a few tools.

Craftsmen achieved the linear designs using sharply pointed instruments.

For the concentric circles, or dot-and-double-circle, craftsmen would have most likely used a centre-bit to make the dot. The two circles surrounding the dot were likely created using a double 'footed' tool.

Concentric circles, or dot-and-double-circle, carefully crafted by artisans, hold deep meaning.

Concentric circles were thought to symbolise celestial and religious concepts, representing the cosmos and perhaps linking the stars and sun.

The circular shape, connecting endlessly, also adds to their symbolism of eternity and continuity.

Figure 23. Text for slide 2. The "Making of the decorations" and "Concentric circles" are two buttons that open the text with the corresponding-coloured text box.

2.3.4 Slide 3: Tine Plates

This slide displays the interactive 3D model of the tine plates (fig. 24) and text (fig. 25). The information about the tine plates provides the user with basic information about the function. There is also a button with “Making of the comb teeth” which allows users to access more information explaining how craftsmen made the comb teeth of the tine plates.

The interactive 3D model can be viewed in a 360-degree view. All the sides are visible to the users. This was done so that the user can inspect the comb teeth from all sides if they are interested in doing so. These users are also able to measure the comb teeth.

A note on this model is that I created the texture (inner texture) of the tine plates myself. I did not create the texture of the comb teeth which was provided by the 3D model made by D. Dininno. I decided to create the inner texture otherwise this part of the 3D model would not have given realistic colour information, thus not providing the user with a complete view of the tine plates. It is important to note that the texture that I created is not the original one, but it offers the user a more realistic view of the tine plates.

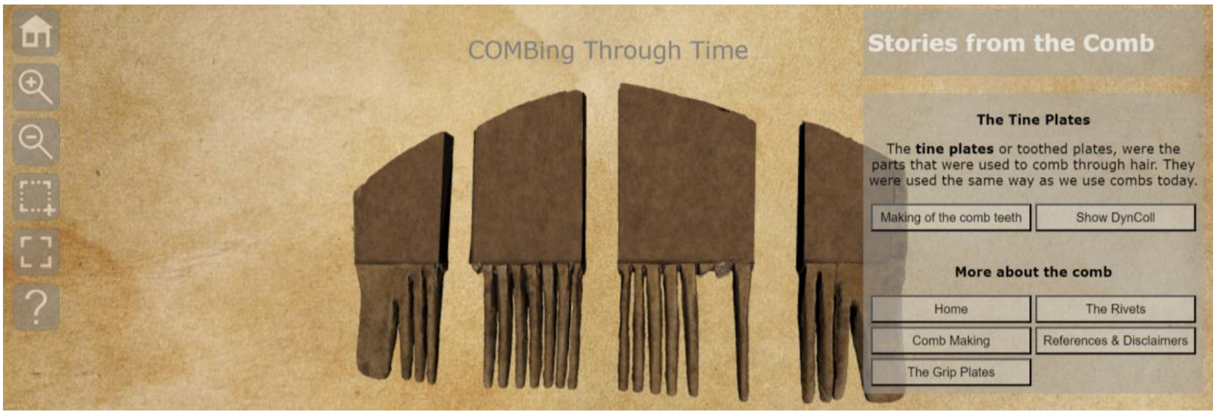

Figure 24. The Tine Plates slide of the virtual learning environment.

The tine plates, or toothed plates, were the parts that were used to comb through hair. They were used the same way as we use combs today.

Making of the comb teeth

Craftsmen joined the toothed plates and grip plates before creating and sharpening the comb teeth using saws and knives.

The teeth are cut to be similar in thickness, and they are individually shaped and cleaned.

After tapering the tips of the teeth, the comb is polished to finish the process.

Figure 25. Text for slide 3. The “Making of the comb teeth” is a button to open the corresponding-coloured text box.

2.3.5 Slide 4: Rivets

This is the last slide containing a 3D model, displaying the rivets (fig. 26). To provide the user with a comprehensive visualisation of the comb, I had to create rivets myself. For this reason, it is important to inform the users that the rivets they explore are the results of my interpretation. The interactive 3D model can be viewed in 360 degrees.

The text that I provided gives the information about the function and how these rivets were placed within the comb itself (fig. 27). I did not provide the user with too in-depth information as I barely found any information that focused on the rivets. The rivets are an important part of the comb, but information about the decoration is often more interesting for the general public.

As I created the rivets myself, I decided to not provide the users with measurement tools, as the measurements are not of the original rivets (para. 2.3.6). Therefore, in order not to give a wrong representation of the original artefact, it was decided to leave these tools out of this specific interactive 3D model.

Figure 26. The Rivets slide of the virtual learning environment.

To ensure that the grip and tine plates stayed together.

Once the grip and tine plates were finished, they were carefully positioned together, likely held together with a clamp.

Once clamped together, rivet holes were made. Afterwards, the rivets, typically made of bronze or iron, were hammered into places. In this case, iron rivets were used.

Figure 27. Text for slide 4.

2.3.6 Slide 5: References & Disclaimer

This slide contains all the literature and disclaimers about the comb that I used while creating this virtual learning environment in 3DHOP (fig. 28 and 29). I added this to provide information about the sources that I used, and to show that I did not create all this information myself. It is important to consider to contribution of other researchers and give them the credit they deserve. Furthermore, I added a disclaimer regarding the creation of the virtual learning environment and the interpreted textures to provide the users with an overview of the authentic and interpreted aspects of the 3D model (fig. 29).

Figure 28. The References and Disclaimers slide of the virtual learning environment.

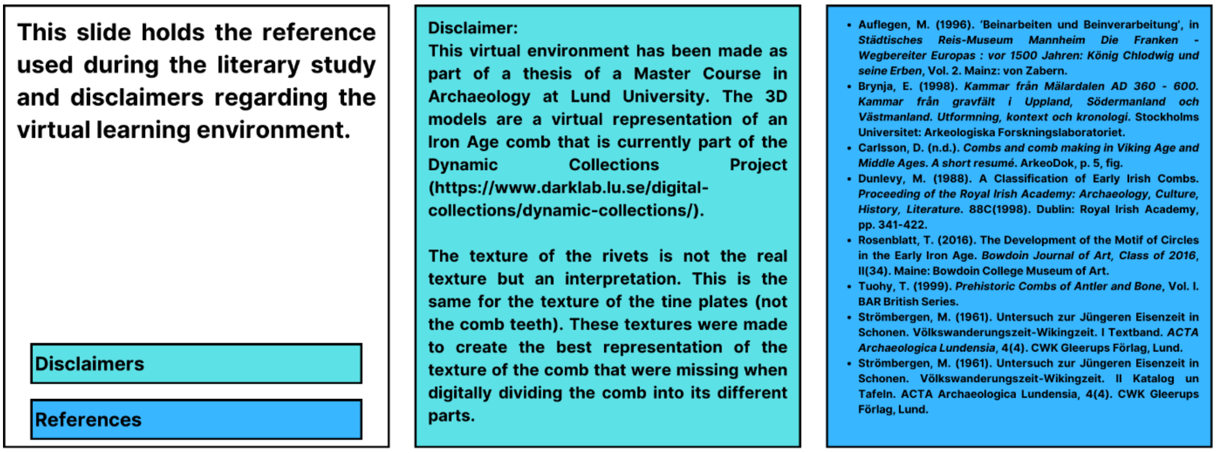

Figure 29. The references used for all the texts and a disclaimer.

3. Analysis (Pilot Study Setup)

As stated, the virtual learning environment could not be critically evaluated within the timeframe of this thesis. However, in order to evaluate the efficacy of the virtual learning environment with the integration of digital OBL, I hereby provide a setup for a pilot study. The idea of using a pilot study is to provide insight into the efficacy of whether a project is successful when implemented. The feedback of the users of the pilot study can reveal highlights and risks. These risks combined with the highlights generate new ideas and concepts to develop and improve the project.

As mentioned in para. 1.3, pilot studies regarding the efficacy of the use of digital OBL have been done, however; these studies were focused on the use in higher education settings and not on public outreach within archaeology. To address this identified gap this setup for a pilot study will be aimed at the general public, to generate as much feedback as possible and make it possible to modify the virtual learning environment accordingly (fig. 30). When focused on the general public, this pilot study can be conducted in museums itself, on museum website, or even social media. As I used an Iron Age comb that was originally part of the *Historika Museet vid Lund Universitet*, the virtual learning environment can be displayed in the museum itself and on the website of the museum.

When conducting a pilot study, it is important to have a clear understanding of the objectives, motive, content, platform, and guidelines/protocols. Adhering to this, the virtual learning environment can be made available to the public. These elements ensure that the virtual learning environment can be critically evaluated and assess the efficacy of the integration of digital OBL. The pilot study will enhance the aim of this thesis; to assess the use of digital OBL for public outreach within archaeology.

Objectives	Motive	Content	Platform	Guidelines/Protocols
• Evaluate the effectiveness of digital OBL in engaging the general public in archaeology. • Assess the level of understanding and retention of archaeological concepts among participants. • Gather feedback to improve the virtual learning environment for future public outreach efforts.	• Communicate the significance of archaeology and its relevance to contemporary society to inspire interest and participation among the general public. • Foster a sense of discovery and exploration by providing opportunities for a “hands-on” learning and interaction with archaeological artefacts • Emphasise the value of public engagement in preserving cultural heritage and advancing archaeological research.	• Curate engaging and informative content that covers various aspects of an archaeological artefact, including historical contexts and artefact analysis. • Incorporate multimedia elements, such as interactive simulations, virtual tours, and audio-visual elements to enhance learning experiences. • Ensure content accessibility and relevance to diverse audience interests.	• Select a user-friendly and accessible platform for hosting the virtual learning environment, considering factors such as navigation, compatibility across devices, and scalability. • Use interactive features and communication tools to facilitate participant engagement and collaboration. • Test the platform's functionality and security measure prior to the pilot study to mitigate technical issues.	• Establish clear instructions for navigating the virtual environment and accessing its features. • Provide guidelines for participants, including interaction with content, and feedback submission. • Implement protocols for data collections, privacy protection, and ethical consideration in research involving human participants. • Ensure an overview of bibliography and a disclaimer regarding the authenticity of the artefact.

Figure 30. Overview of a pilot-study setup to implement and critically evaluate the efficacy of a virtual learning environment.

Pilot studies are designed to determine the set of questions; data collection tools provide adequate feedback for the research intended to be conducted. The duration depends on the extent to which the purpose of the pilot study has been achieved, to have gathered enough feedback to evaluate the potentials and limitations. For this pilot study, a duration of three months should provide enough time to gather feedback and evaluate the potential highlights and risks. The feedback of the users' participation in the virtual learning environment can be done through surveys, interviews, and focus groups (fig. 31).

Surveys	Interview	Focus Groups
Design online surveys to collect quantitative and qualitative feedback from participants. Including questions about their overall experience, the content, ease of navigation, level of engagement, and suggestions for improvements. Surveys can be distributed before and after participants engage with the virtual learning environment to track changes in perception and understanding.	Conduct structured or semi-structured interviews with a subset of participants to delve deeper into their experiences. Explore their motivations for participating, their favourite aspects of the virtual learning environment, areas where they encountered challenges, and recommendations for enhancement.	Organise focus group discussion with small groups of participants to facilitate interactive dialogue and idea generation. Use prompts to stimulate conversation around key themes such as content, relevance, interactivity, user interface design, and the impart of digital OBL on learning outcomes. These focus groups enable participants to build on each other's responses and generate new ideas collaboratively.

Figure 31. Overview of setup to gather feedback for the pilot study.

The feedback can be collected and evaluated to create new strategies and enhancements of any potential risks (i.e. insufficient information, lack of immersivity and engagement, or unforeseen technical difficulties) when implementing the shift to a larger-scaled project. When building strategies for the potential risks, a re-evaluation can be done to determine whether these changes are manageable and fit within the aim and objectives.

A setup could be as follows: The comb will be exhibited to the user and questions regarding the comprehension of the object will be asked, i.e. What is it? How was it used? Do you have an idea of how it was made? What do you know about the material used? What do you know about the decoration of the comb? What do you think about a virtual application showcasing an archaeological artefact? The user will then experience the virtual learning environment, and afterwards, the same questions will be asked, including a question that asks the users for suggestions for improvements.

The pilot study setup in this chapter serves as a way to evaluate the effectiveness of integrating digital OBL into virtual learning environments for public outreach within archaeology. By collecting feedback on user participation through surveys, interviews and focus groups, limitations can be identified. This collected feedback can also provide ideas for new ideas and improvements within the virtual learning environment to fit the users' needs. This pilot study can provide a critical assessment of the use of digital OBL approaches to create a virtual learning environment that is engaging and enhances public outreach within archaeology.

4. Results

During the thesis, different methods have been used to create a virtual learning environment that incorporates digital OBL approaches and storytelling elements: https://models.darklab.lu.se/dig_excav/TheCombStory/Home.html. Due to time constraints, this has not been critically evaluated, but a pilot study setup has been provided to provide a clear framework for future analysis.

Virtual learning environment

The goals of the thesis regarding the creation of a virtual learning environment have been achieved through a workflow that involved the acquisition of the making of the 3D model, data processing to divide the 3D model into all its different parts, post-data processing to apply a texture to all the 3D models, and lastly the creation of the online presentation with storytelling elements.

During the creation of the virtual learning environment the Icomos Charter for the Protection and Management of the Archaeological Heritage, Article 7. Article 7 states several things, one of them being:

> "Presentation and information should be conceived as a popular interpretation of the current state of knowledge, and it must therefore be revised frequently. It should take account of the multifaceted approaches to an understanding of the past." (ICAHM, 1990, Article 7).

To follow this, digital OBL approaches were used, and multiple interactive 3D models were created of the Iron Age comb to tell different parts of the story, related to the specific elements of the comb. Having them sorted in different slides, allows the users to choose their own path. Furthermore, the information about the comb was written in an understandable way, ensuring that any user can understand what they are reading. This was done to reach a more diverse audience and to be inclusive. It is important that every user can understand the information given.

Using 3D models also fits into another aspect of article 7:

> "Reconstructions serve two important functions: experimental research and interpretation. They should, however, be carried out with great caution, so as to avoid disturbing any surviving archaeological evidence, and they should take account of evidence from all sources in order to achieve authenticity. Where possible and appropriate, reconstructions should not be built immediately on the archaeological remains, and should be identified as such." (ICAHM, 1990, Article 7).

The creation of the virtual learning environment is an experimental way of creating interactive 3D models with information about the Iron Age comb. Furthermore, research was conducted to find information about the comb to create storytelling elements. Using a 3D model also contributes to preserving the original Iron Age comb, as it remains 'untouched' and is not physically altered. Using 3D models of the comb made that users can still explore all the different parts of the comb and learn about the comb.

Finally, this virtual learning environment represents a foundation that could be used for future research, to explore new ways of presenting archaeological artefacts to the general public and to try to find a way to reach the public and better understand archaeological artefacts, following ICAHM 1990, Article 7:

> "The presentation of the archaeological heritage to the general public is an essential method of promoting an understanding of the origins and development of modern societies. At the same time it is the most important means of promoting an understanding of the need for its protection." (ICAHM, 1990, Article 7).

Further testing could look at effectiveness and usability within a wider audience. It is important to use users from different backgrounds during these tests. Archaeology should be accessible to everyone, so the test should include users from different geographical places and educational backgrounds.

Pilot study setup

A setup for a pilot study has been provided and could be performed through e.g. *Historiska Museet vid Lund University* as the comb is part of the museum collection but stored at Lund University. During the pilot study at the museum feedback on users' experience can be collected to critically evaluate the efficacy of the virtual learning environment that was created. By involving the public in the tests, the researchers can identify shortcomings in the virtual learning environment.

With the knowledge of these shortcomings, the virtual learning environment can be refined and made more user-friendly and effective. This would allow users to assess whether the application of digital OBL approaches for public outreach is effective. This application ensured the creation of a virtual learning environment where interactive 3D models and storytelling elements come together, offering the user the feeling to 'handle' the objects themselves, to ensure a deeper understanding and appreciation of archaeological artefacts among the general public.

5. Discussion

The aim of this thesis was to analyse the significance of using digital OBL approaches for public outreach initiatives within archaeology. This aim was done with the general public as a target group, as previous research has conducted pilot studies regarding the use of digital OBL approaches in higher education. The goals were to create a virtual learning environment using storytelling elements which was chosen to give users an immersive experience. Another goal was to provide a pilot study set-up.

I chose a 3D model already available in the Dynamic Collections; for this reason, I did not work on the 3D acquisition. Because of this, I cannot assess the acquisition process itself. I chose this comb because I wanted to work with a 3D model for my thesis. I also wanted to work with a 3D model to be able to split it and view all the different parts. Choosing a complex object like a comb, composed of multiple parts, allowed me to explore 3D possibilities like splitting it and visualising all its different parts, to ensure that an interesting story could be told, to enhance the presentation of an 'ordinary' artefact, to deeply engage the general public with archaeological artefacts.

The creation of the virtual learning environment was done through various processes. In this virtual learning environment, storytelling elements are crucial to enrich the user experience and provide information concerning the making of the comb and aspects such as the decoration on the grip plates. The virtual learning environment is composed of four 3D models: one of which was created by D. Dininno in May 2021 and represents the entire comb. I created the other three 3D models. Creating these three models was fairly smooth sailing.

After isolating all the different parts composing the comb, I reused the texture from the original 3D model. Once this texture was applied, I realised that I had to make the texture for the inside of the comb myself. This process was long and allowed me to create a rendering that looked similar to the original texture of the comb. Once this texture was finished, I applied it to the comb.

In order to provide a realistic visual experience, I needed to consider that the output results are not the original artefacts. I am aware that this is a risk to publish something that is not deemed authentic, however, this is an opportunity for public outreach and to explain comb-making during the Iron Age. to make a difference in enhancing engagement and providing information about an archaeological artefact.

Building the storytelling was challenging because there was very little information about Iron Age combs and how they were made. Furthermore, there was also little information about the excavation and archaeological context where this comb had been found.

Regarding the information about the comb, I had to conduct a thorough literature search. After some intense research, I happened to find literature containing some information about the excavation and the context in which the comb was retrieved. This literature consisted of two small paragraphs spread over two books by Märta Strömberg, and this information was used to create storytelling elements about the comb itself. Further literature search also provided books about the explanation of comb-making techniques and about Iron Age comb types and characteristics. All this information has also been integrated into the storytelling elements in the virtual learning environment.

The creation of the virtual learning environment was also something that I struggled with; it took me a while to understand how I had to create the virtual learning environment using 3DHOP. As I never used JavaScript before, I had to learn this quickly in order to work on the virtual learning environment. Luckily, my supervisor had experience using this and she helped me during the process.

Regarding the pilot study setup, I realise that this is similar to the other mentioned pilot studies were done. However, the use of digital OBL is new and more assessments need to be conducted regarding its application. Feedback can, for example, show that the engagement of the virtual environment is not up to par for the public. In this instance, theories within museology could be used to improve engagement. The same goes for if the learning outcomes are lower than those of traditional object-based learning initiatives, in this case, theories within pedagogy could be reviewed to improve the learning outcomes.

The pilot study can also contribute to broadening the research- and theoretical field on the use of digital OBL approaches in a virtual learning environment for public outreach. Moreover, the feedback in this pilot study could also be incorporated into the feedback of the pilot studies done on digital OBL approaches within higher education, to provide a broader view of the needs of the users. This way, the theoretical framework regarding digital OBL can be expanded and can lead to new ideas and methods. The ultimate goal of the pilot study is to collect feedback and optimise the engagement and enhancement of archaeological artefacts for the general public within a virtual learning environment.

6. Conclusion

This thesis contributes to the current discussion on the potential of digital technologies to enhance engagement and learning in archaeology, as the aim was to examine the possibility of using digital OBL for archaeological outreach initiatives. The target group was the general public, as pilot studies regarding this application in higher education have been conducted. The focus on the general public is to provide them with an immersive experience that not only showcases the physical attributes of the artefact but also contextualises it within the historical and cultural narratives through theoretical and practical exploration.

With my work, I was able to address and answer the following research questions:

1. In what manner(s) can 3D models be used to enhance engagement and understanding of archaeological artefacts among the general public compared to traditional static displays?

My work explored the possibilities of using 3D models to enhance engagement and understanding of archaeological artefacts in different ways, by integrating them into digital objects-based learning (OBL) approaches. Digital OBL is a way of active learning, engaging multiple senses when interacting with the artefacts, and creating stimulants to enhance learning. By using this digital OBL haptic (hands-on) approach, I was able to use interactive 3D models to create immersive experiences that encourage active engagement.

With my work, I was able to create a 360-degree view of a 3D model of an artefact. Museums have a lot of artefacts, however, most of these are not completely visible. This 360-degree view allows users to explore the artefacts from all angles, and zoom in on details, and these artefacts could even be used in virtual reality. These interactive 3D models give the users a way to "digitally handle" the artefacts themselves.

Regarding traditional static displays, like using display cases, images and standard text plates tends to reduce interest. Museum visitors can often only look at an artefact and read some information. However, there is no active participation, interactive 3D models provide this active participation element, as users can move and interact with the 3D models. For example, users can click on details and get specific information. Interactive 3D models also allow users to explore objects based on their own interests, and take their own exploration path within the virtual platform. The way each user can focus on their own interest can provide a better connection with the artefact. This provides a sense of a personal experience, increases motivation, and engagement and creates a unique experience.

My thesis demonstrates that even if a 3D model can ensure a more immersive experience, it does not replace the use of the original artefacts. It should be seen as an additional means of ensuring that the public's attention is captured by using technology, such as interactive 3D models, it ensures that the users can take their own path, and follow their own interests. The users get the feeling that they have an artefact in their own hands, that they can look at and explore the artefact themselves. It should not become a replacement, but using interactive 3D models can be an extension of the traditional static presentation of artefacts.

2. In what way(s) do contextual storytelling elements enrich public outreach and educational value of interactive 3D models showcasing archaeological artefacts?

The use of contextual and storytelling elements, in my work, served as key components in enriching educational value and public outreach. Adding historical context, for example, allows users to understand the role of archaeological artefacts in an ancient society, and using videos or images also enhances user experience by providing more visual elements. Moreover, using contextual storytelling enables exploration of the cultural meaning of artefacts. Contextual storytelling also makes it possible to tell and explore individual stories related to the interactive 3D models of artefacts, such as the lives of ancient artisans, the journeys of traders or the experiences of ordinary people. Highlighting these personal stories was crucial that the user creates a personal connection with the past, allowing to create empathy and a sense of shared heritage.

Even if I did not assess this approach systematically, I believe that incorporating contextual storytelling elements into interactive 3D models of archaeological artefacts increases public outreach and educational value. By providing historical context, presenting cultural relevance and value, and engaging storytelling, personal interest can be motivated and enhance engagement. Furthermore, providing multisensory experiences can promote personal connections and critical thinking of interactive 3D models of artefacts when interacting with them to enhance the understanding and appreciation of archaeological artefacts.

3. What challenges and limitations are associated with implementing digital OBL approaches, for public outreach aimed at engaging audiences with archaeology?

My work proves that despite the positive aspects, digital OBL approaches can have limitations and challenges that need to be addressed. First, not every organisation/museum has the ability to use a platform that allows the creation of and can properly use digital OBL approaches. This can influence accessibility and public outreach. For example, consider geographical locations where internet connectivity is limited or non-existent. Furthermore, specialised techniques are also needed to create a virtual learning environment that implements digital OBL approaches. The creation of something like a virtual learning environment, as done in this thesis, takes time and effort, especially when the creator has never done this before. It is something that needs to be taught or explained to be used. Moreover, it is important to have elements like interactive 3D models for active participation, engagement, and motivation, this aspect also uses specific materials and techniques.

Additionally, it is important that the digital representation of the artefacts used is as authentic and accurate as possible. If the artefacts have inaccuracies, they can give a false image of the artefact, which can lead to spreading misinformation about the past, to avoid this, the techniques used to create the interactive 3D models used in digital OBL approaches must be carefully considered. Take my explanation of creating the inner texture for the 3D models and the rivets as an example. I explained why I did it and how it did it, providing a reasoning and I made sure this is part of the story. It should be made clear what is reliable and what is not. In addition, it should be considered whether the artefacts have cultural significance and sensitivity. There should be a clear look at what and why a 3D model for digital OBL approaches is being made for. This should include looking at the context on a religious and cultural level, to avoid offending a group of people or promoting stereotypes.

In conclusion, my thesis demonstrates that using digital OBL approaches offers different possibilities and can be successful for public outreach. However, my work also proved that it is important to be familiar with the limitations and challenges that it brings: addressing these limitations and challenges requires creative innovation and testing different virtual learning environments using digital OBL approaches. By taking these aspects into account, more inclusive and immersive virtual learning environments using digital OBL approaches can be created.

7. Future Research

For future research, it will be important to implement the pilot study, and a good start to analyse the effectiveness of the virtual learning environment. Thus, enough feedback can be collected to evaluate whether the integration of 3D models and contextual storytelling enhances and engages audiences. Moreover, it provides opportunities to improve certain aspects, e.g. accessibility, usability, and immersiveness.

After the pilot study has been evaluated, adjustments can be applied to refine the virtual learning environment. Furthermore, consideration can be given to audio-visual elements, to create a more multisensory experience while using the virtual learning environment, something that has been applied to (digital) OBL approaches as it enhances the learning experience. Adding audio narratives, ambient sounds, and music can also increase engagement and immersivity for the users. Furthermore, the use of audio narratives can also ensure a wider audience reach, for example, people with vision impairments or low vision. By adding audio elements, this group can still use the virtual learning environment.

In addition, a possible collaboration between the Dynamic Collections Project at Lund University and the 4D Research Lab at the University of Amsterdam could be considered. The 4D Research Lab strives to contribute to a more general methodology of 3D and VR modelling methods combined with more project-oriented methods (4D Research Lab, n.d.). Both the Dynamic Collections Project and the 4D Research Lab combine traditional learning methods and online learning, introducing the use of 3D technologies and their application. By collaborating more research could be done and students, researchers, and more groups could get involved in different projects, to get a better understanding of the potential of using 3D and VR approaches within education and public outreach.

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Appendix 1: Meta- and Paradata of the Comb.

LUHM29015.1 – code: DC265_LUHM29015.1

Metadata	
Museum	LUHM
Inventarienummer	29015.1
Plats	Lund
Materialkategori	Ben; Metall
Material	Horn; Järn
Encumbrance	10 x 7 x 3 cm
Kategori	Kam
Underkategori	Sammansatt enkelkam
Typ	Trelagskam med rekantig grepplatta
Period	Yngre järnålder
Underperiod	Folkvandringstid
Fyndplats	Källby gård, grav 1
Socken	Lund stad
Härad	Torna Härad
Landskap	Skåne
Typologiska referense	Thomas 1960
Metadata författare	F. Ekengren
Beskrivning	Trelagskam av horn bestående av fyra tandade plattor sammanhållna i en grepplatta av två trekantiga skållor. Båda sidorna av grepplattan är dekorerade med koncentriska cirklar och linjer som följer grepplattans kanter. Nitar av järn.*

Paradata	
3D Object ID	DC260_LUHM29015.1
Measure Unit	mm
Polygons	19564395
Textures	1
Digitization Method	Scan
Date	15/5/2021
3D Author	D. Dininno
Software Used	Artec Studio 14
Scans	3

*Three-layer horn comb consisting of four toothed plates held together in a grip plate by two triangular scales. Both sides of the grip plate are decorated with concentric circles and lines that follow the edges of the grip plate. Iron rivets.

Appendix 2: Settings of the Inner Texture of the Comb.