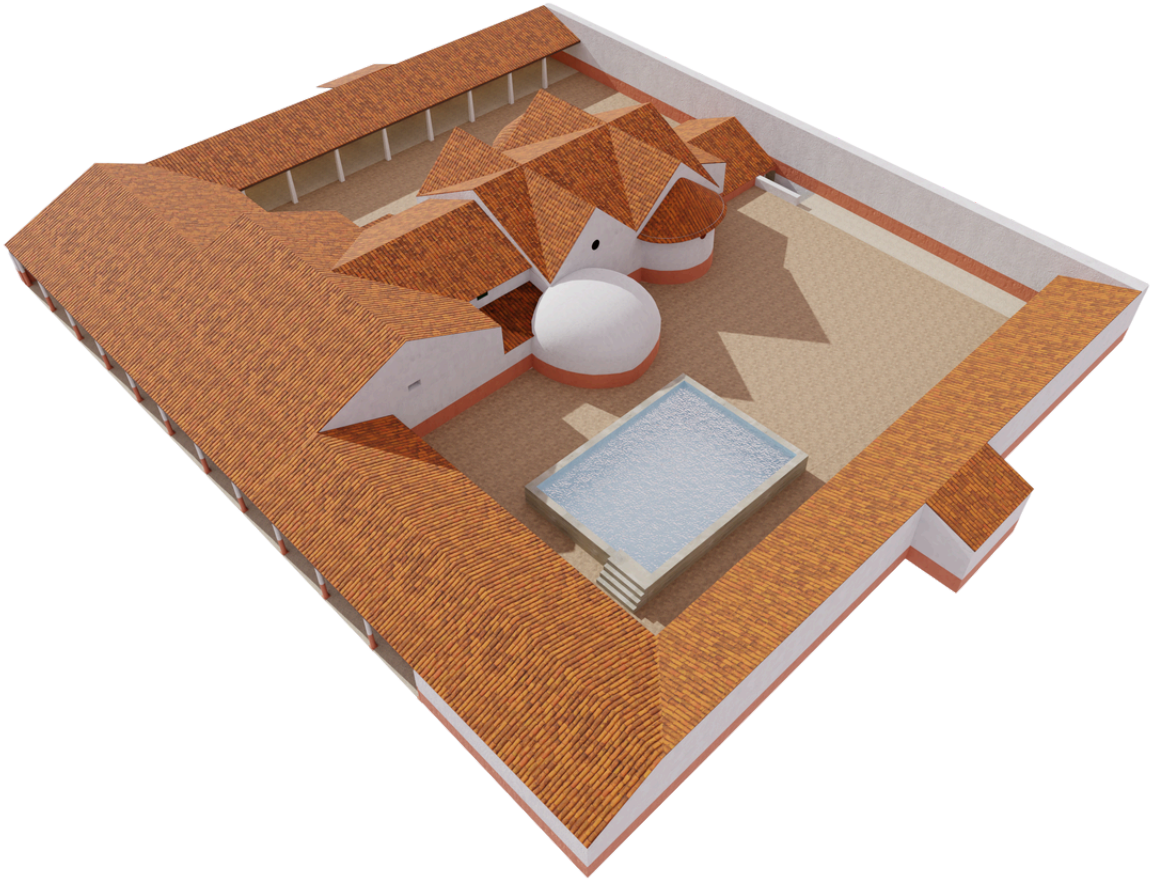
# The Bathhouse of Coriovallum

## A Virtual Reconstruction as a Foundation for a VR Educational Environment



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*I hereby declare that this dissertation is an original piece of work, written by myself alone. Any information and ideas from other sources are acknowledged fully in the text and notes.*

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# TABLE OF CONTENTS

TABLE OF CONTENTS ..... 1

1. PROJECT DATASHEET ..... 2

2. INTRODUCTION AND BACKGROUND ..... 3

3. AIMS AND JUSTIFICATION ..... 3

4. RESEARCH DESIGN ..... 5
   - 4.1 Approach ..... 5
   - 4.2 Theoretical Framework ..... 6
   - 4.3 Methodology ..... 12
   - 4.4 Sources ..... 13

5. WORKFLOW AND MODELLING PROCESS ..... 18
   - 5.1 Process description ..... 18
   - 5.2 Output ..... 31

6. RESULTS ..... 33

7. DISCUSSION AND CONCLUSION ..... 39

## 1. PROJECT DATASHEET

| | |
|---|---|
| Project Title | The Bathhouse of Coriovallum: A Virtual Reconstruction as a Foundation for a VR Educational Environment |
| Project duration, date (From – To) | 01-01-2025 – 15-08-2025 |
| Author | Merleau Neuféglise |
| Execution | University of Amsterdam |
| Scientific advisors | Chiara Piccoli |
| Delivered product(s) | - A 3D model of a virtual reconstruction of the bathhouse of Coriovallum in phase 3<br>- Eighth output renders of the reconstruction and three renders showing the uncertainty index of the reconstruction<br>- A screencast of a VR educational environment concept named 'CoriovallumVR'<br>- Thesis report documenting the reconstruction process and theoretical framework |
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## 2. INTRODUCTION AND BACKGROUND

The Roman bathhouse in Coriovallum (Heerlen) is the best-preserved Roman building in the Netherlands. It was first excavated in 1940-41, and the results were published in 1948 by A.E. van Griffen and W. Glasbergen. The 40 x 14m main building features four bathing areas (*apodyterium, frigidarium, tepidarium* and *caldarium*) and a later-built *laconicum,* which was attached to the west side of the main building. The main structure was built around 70 C.E., during either the last years of Nero's, or the first years of Vespasian's reign. On either side of the main building, large *palaestrae* surrounded by roofed porticoes were built in the late first century. The whole complex at this time went from a surface area of 500m2 to 2000m2.[1] In later phases, the bathhouse was restructured until it fell into decline in the late fourth or early fifth century, with the fall of the Western Roman Empire in 476 AD likely meaning the end of the bathhouse.[2]

In 1977, the *Thermenmuseum* was opened on top of the remains of the bathhouse. Since Van Griffen and Glasbergen's publication, no scientific publications about the bathhouse have been published. In 2013, serious damage to the monument was identified in 150 places.[3] This led to a new archaeological study being launched in 2016, of which the report was published in 2020 by the Cultural Heritage Agency of the Netherlands. The excavation was academically led and published by Karen Jeneson of the Thermenmuseum with Wouter Vos as co-editor.

In this thesis project, I will create a virtual reconstruction of the bathhouse of Coriovallum in its third phase. This phase stretches from the late first century to the mid third century and sees the bathhouse at its height. The next section will discuss the aims I'm trying to achieve with the virtual reconstruction of the bathhouse of Coriovallum in more depth.

## 3. AIMS AND JUSTIFICATION

This thesis project has two aims: firstly, to create a virtual reconstruction of the bathhouse of Coriovallum based on extensive previous research and comparative materials, and secondly, to explore how the virtual reconstruction could be utilised as an educational tool.

The first aim of this thesis, to produce a scientifically grounded virtual reconstruction of the bathhouse, is based on the extensive excavation report 'Roman bathing in Coriovallum' by K. Jeneson and W.K. Vos; the interpretation of the remaining foundations and comparisons with more intact bathhouses (as found in Pompeii and Herculaneum); and the remains and interpretations of other contemporary bathhouses from the North-Western Roman empire. The process and underlying decision-making of the reconstruction process will be covered in depth in the fifth section of this report, 'Workflow and Modelling Process'.

Creating a 3D reconstruction has multiple benefits. First, it allows for the visualisation of archaeological remains and thus provides a way to express data, interpretations, and uncertainties in three dimensions.[4] This is especially helpful for complex structures like Coriovallum, where foundational remains alone can be difficult to interpret, especially for people not trained to do so. A 3D model can offer specialists, students and visitors a

[1] K. Jeneson and W.K. Vos (2020) 179
[2] Ibidem 187
[3] Ibidem 11
[4] S. Hermon (2008) 37

concrete idea of what such a building might have looked like. Additionally, as the amount of archaeological data continues to grow, visualising this information spatially can support its interpretation and communication.[5] Lastly, research in cognitive psychology has shown a positive relationship between visual tools and the comprehension of information, which underlines the potential of the model as an educational tool.[6]

Part of the final output of this project consists of fully textured renders of the virtual reconstruction that demonstrate the full potential of the model, providing a semi-realistic impression of the bathhouse and showing how a VR educational environment based on this model could look. These renders are intended not only to showcase the model in an appealing way but also to serve as a proof of concept for its use in a VR educational environment used by museums.

This brings me to the second aim of this project: to explore how the digital reconstruction could be developed into a VR educational environment that is immersive and engaging for museum audiences, and could be made easily accessible through a desktop-based version as well. This version would feature lower-quality visuals but would be accessible in classrooms or at home.

In this context, Virtual Reality (VR) refers to the use of interactive 3D environments that allow users to explore a digital reconstruction in an immersive or semi-immersive way. When referring to educational tools within such a virtual environment, I will use the term ‘VR educational environment’. A fully immersive and interactive VR educational environment with a head-mounted display could be developed for museums. However, a less intensive desktop-based VR setting (D-VR), accessible via a web browser, could also be produced to ensure broad accessibility while still enabling interaction with the model.

The full realisation of such a VR educational environment lies beyond the scope of this thesis. Therefore, I produced a theoretical framework on which a VR educational environment can be built in future projects and a screencast of a guided walk-through in the software used to create the model. This screencast demonstrates how the envisioned environment could function by simulating a user navigating through the bathhouse and interacting with informational signs. A link to this video is provided in section 5.3 ‘Output’ of this thesis project. The demonstration illustrates how a more accessible, web-based version of the VR educational environment could look, while the final output renders present higher-quality visuals that show how a VR educational environment in a museum could potentially look. A future project could fully realise such an environment, built around the reconstruction of the Coriovallum bathhouse. For clarity, I refer to this potential project, as demonstrated in this thesis, as *CoriovallumVR*.

While the use of immersive 3D environments may allow users to actively engage with archaeological content, rather than passively consume it, the impact of this approach is not assessed here. Instead, this project investigates its possibilities, which I will elaborate on in the next section.

[5] Ibidem 38
[6] Ibidem 37

# 4. RESEARCH DESIGN

In this section, the research design of the project will be discussed. The section consists of four parts. In the first part, I outline the approach of this thesis project. In the second part, 'Theoretical Framework for Educational Design', the theoretical basis for the VR educational experience will be laid out. The third part, 'Methodology', describes the methods I've used to produce the virtual reconstruction and the demonstration of the VR educational environment. And lastly, 'Sources' will describe and list all sources used in the production of the virtual reconstruction, as well as the sources for the theoretical framework of the VR educational environment.

## 4.1 Approach

Since this project has two aims — building the virtual reconstruction and laying the foundation for the VR educational environment — the approach is also twofold.

For the virtual reconstruction, the main source of information is the report 'Roman bathing in Coriovallum' by K. Jeneson and W.K. Vos (2020). This is an extensive report with up-to-date data and interpretations about the archaeological remains of the bathhouse, which forms a reliable basis for a virtual reconstruction. While the report describes and analyses the bathhouse in great detail, some parts are left to the imagination. Therefore, I will look at similar structures for reference, including the bathhouses found in Pompeii and Herculaneum, as well as Reihentyp bathhouses from the North-Western Roman Empire, such as the one found in Weißenburg.

To translate this archaeological data into a 3D model, I will use Blender (version 3.6.17) as the modelling tool. Blender is an open-source 3D software widely adopted in academic and professional heritage visualisation projects because of its accessibility and flexibility. Texturing, lighting and rendering for final output images will also be done in Blender.

To keep the scope of the project manageable, I will keep the model of the bathhouse between an LoD of 2 and 3, while adding some more details in the form of objects and textures to enhance the immersion of the educational demonstration. While higher details in the building would be better for immersion as well, this requires a lot of interpretation. General shapes, such as walls and roofs, have a higher level of certainty than small details.

The output of this thesis will consist of: (1) this scientific report, including the reconstruction workflow and the theoretical foundation on which a future VR educational environment can be built; (2) eight rendered images showcasing the 3D reconstruction of the bathhouse of Coriovallum and three renders showcasing the certainty index of the model; (3) a screencast demonstration of the VR educational environment CoriovallumVR captured within Blender; and finally (4) the blender file containing the 3D model of the reconstructed bathhouse of Coriovallum.

The eight renders showing the virtual reconstruction will be fully textured and rendered through the realistic engine 'Cycles', to show the full potential of the model. Three renders textured with colours indicating levels of certainty and rendered in the engine 'Eevee' will also be included to ensure transparency in the output of this thesis project.

## 4.2 Theoretical Framework

In this section, the theoretical framework of this thesis is outlined. I will briefly discuss transparency in virtual reconstructions and the use of VR in education, and I will provide a recommended structure and layout for a potential VR educational environment. The aim is to create a foundation, rooted in learning theory, on which future projects can build.

Transparency in virtual reconstructions

Transparency in virtual reconstructions is a longstanding problem. Peer review, as we know it in academic texts, is much more difficult to apply to a 3D reconstruction that is not intellectually transparent. A parallel for this would be to present only the conclusion of an article, without its sources or the thought processes behind it.[7] A flashy-looking reconstruction is often assumed to be correct by the lay public. Therefore, it is incredibly important that the thought process and source material behind a reconstruction are easily accessible and that the uncertainties of a reconstruction are made apparent.

For this reason, the 'London Charter' was developed by a group of virtual archaeologists in 2006. The goal of the London Charter is to establish internationally recognised principles for the use of computer-based visualisations.[8] It emphasises the need for clear documentation of aims, sources, interpretive processes, and long-term sustainability of digital assets. Later, the 'Seville Principles' were developed with a more specific focus on the challenges within archaeology itself. They stress the importance of intellectual transparency, data longevity, and public accessibility.[9] Not only did these principles make the London Charter more applicable within archaeology, they also put virtual archaeology on the map as a mature discipline that is founded on scientific and shared methods.[10]

In this thesis, these principles are applied in the following ways. First of all, the text in this thesis was written along a template of the 4D Research Lab (4DRL) of the University of Amsterdam. The template was developed to ensure that 3D visualisation projects are executed and documented to academic standards that adhere to the London Charter and the Seville Principles.[11] The ideals and main principles of these documents are implemented into the template itself.

Secondly, I will colour-code different parts of the Coriovallum bathhouse to indicate varying levels of certainty within my reconstruction. This approach makes information on uncertainty immediately accessible, allowing viewers to grasp it directly in the model rather than reading through the entire thesis. To do this, I will make use of the 'Degrees of Certainty' offered by the 4DRL.[12] This will ensure that the colours used are standardised. The Degrees of Certainty presented by the 4DRL consist of 6 classes ranging from 'certain' to 'very uncertain'.

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[7] C. Piccoli (2018) 67, comparison originally made by H. Denard's lecture 'The London Charter'.
[8] https://londoncharter.org/ (accessed on 07-08-2025)
[9] ICOMOS Spain, *Principles of Seville: International Principles of Virtual Archaeology* (Seville 2017) https://icomos.es/wp-content/uploads/2020/06/Seville-Principles-IN-ES-FR.pdf.
[10] F. Gabellone (2015) 78
[11] 4D Research Lab, *Template for 3D Visualisation Projects and Reports* (2020) https://4dresearchlab.nl/template-for-3d-visualisation-projects-and-reports/.
[12] 4D Research Lab, *Degrees of Certainty for Reconstructions* (2020) https://4dresearchlab.nl/degrees-of-certainty-for-reconstructions/.

Lastly, an effective way to ensure transparency about uncertainties in a model is to present multiple reconstruction hypotheses. This approach is far more feasible in virtual reconstructions than in physical restorations, where interventions can be irreversible, as illustrated by the controversial reconstruction of the Palace of Knossos in Crete, for example.[13] In contrast, virtual environments allow hypotheses to be tested and compared without causing permanent alterations. Besides being a highly transparent way of showing uncertainty, it also demonstrates the different thought processes that went into the reconstruction, aligning with the London Charter's principle that alternative hypotheses should be documented and made accessible to users.[14] While I would have liked to include more alternative hypotheses, within the scope of this thesis, this was only possible for the roof covering the caldarium and tepidarium. A rough version of two barrel roofs was modelled, which can be toggled on and off within Blender.

VR in education

As stated before, a VR-based learning environment does not necessarily require a Head Mounted Display (HMD). VR can be divided into two categories: desktop VR (D-VR) and immersive VR (I-VR), the former requiring just a screen and the latter requiring a headset.[15]

The effectiveness of VR in education has been researched, though the field is far from fully mapped. A literature review by A. Hamilton et al. (2020) covered 29 publications on the pedagogical effect of I-VR compared to other (less immersive) pedagogical methods.[16] While most of the studies found a significant advantage in the use of I-VR, they focused on scientific topics such as biology and physics and did not examine information retention.[17] Such literature reviews show us that studies about the use of VR within the humanities are underrepresented.[18] J. Waagen et al (2024) argue that even though a favourable argument for the use of VR in the humanities could be formed, the best way to utilise it for optimal learning is not yet clear and requires more study.[19] This is why the rest of this section aims to define an appropriate theoretical framework for CoriovallumVR. This can be used for a potential future project featuring the virtual reconstruction of the bathhouse of Coriovallum, but can also be applied to any other VR educational environment.

Educational methods

Any educational tool needs to build its foundation in theory. Two main perspectives within educational theory are behaviourism, which focuses on learning as changes in observable behaviour shaped by reinforcement, and constructivism, which sees learning as building on prior knowledge through experience. This thesis draws on constructivist approaches to explore methods relevant to VR education, including Experiential Learning Theory, the 5E Instructional Model, and the Cognitive Theory of Multimedia Learning.

[13] C. Piccoli (2018) 73
[14] H. Denard in *Paradata and Transparency in Virtual Heritage* (2012) 77
[15] Ibidem, 3
[16] Ibidem
[17] Ibidem, 1
[18] Hamilton, *et al.* (2021), S. Kavanagh, *et al.* (2017), J. Radianti, *et al.* (2020)
[19] Waagen, *et al.* (2024)

**Experiential Learning Theory**

D. A. Kolb published his book 'Experiential Learning' in 1984, popularising the term but building on ideas of Lewin, Dewey and Piaget, placing it firmly in the constructivist approach.[20] By identifying the common characteristics of the learning models of his predecessors, Kolb aims to define the nature of experiential learning.

As the name of the theory suggests, it sees learning as something that is achieved through experience. It assumes that ideas are not fixed thoughts but are formed and reformed through these experiences.[21] This also has educational implications. While it is tempting to see the learner's mind as a blank piece of paper on which we can write, this is not the case, Kolb says.[22] Everyone enters a learning situation with ideas that are already formed. Besides implanting new ideas, it is therefore also the educator's role to dispose of and modify old ones. New ideas that are integrated into a person's existing knowledge tend to become very stable parts of their conception of the world.[23]

However, this integration process can also lead to resistance or distortion. When experiences challenge deeply held assumptions, learners may reject or misinterpret the new information to preserve existing beliefs.[24] This is why, without proper guidance and an appropriately shaped learning experience, there is the risk of reinforcing prior misconceptions rather than transforming them. Drawing on Kolb's Experiential Learning Theory, which emphasises active, experience-based learning, the CoriovallumVR environment will be structured using the 5E model.

**5E Instructional Model**

The 5E Instructional Model is a teaching and learning approach that builds on other instructional models, such as the Atkin and Karplus Learning Cycle. It was developed by the Biological Sciences Curriculum Study in 1987 and consists of five phases: engagement, exploration, explanation, elaboration, and evaluation. This cycle offers multiple opportunities for learners to connect prior knowledge with new concepts through active engagement.[25]

This thesis does not aim to evaluate the pedagogical impact of the 5E model, as this would require user testing beyond its scope. Instead, the model serves as a guiding framework for structuring a VR educational environment, offering a clear, research-based approach to designing engagement and exploration.[26] I will use the 5E model to describe the ideal way to build CoriovallumVR. This description can be used as an example and functions as a foundation that can be built on in future projects. Some elements of this description will also be implemented in the screencast demonstration.

While the 5E model was developed for classroom teachers, it lends itself well to the organisation and structuring of a VR educational environment. While research on the implementation of this model in VR learning is limited, one study by G. Güven *et al.* (2025) examined the effect of VR integrated into the 5E learning model on a 7th-grade science course.[27] The study concludes that the implementation of VR into the 5E learning model enhanced students' academic achievements. They state that 'the principles of active learning emphasised in the constructivist approach can become more effective when

[20] Kolb (1984)
[21] Ibidem, 26
[22] Ibidem, 28
[23] Ibidem
[24] Ibidem, 30-31
[25] Ruiz-Martín, *et al.* (2022) 1
[26] Ibidem, 6-7
[27] Güven, *et al.* (2025) 15

combined with immersive technology'.[28] Especially the 'engage' and 'explore' phases of the 5E model benefited from the virtual environment.

In the following section, I will outline the five phases of the 5E model, explain their pedagogical function, and describe how they could be applied to the VR educational environment I'm proposing and demonstrating in this thesis.

*Engagement*

Engagement, the first phase of the 5E model, is about activating prior knowledge of the student, so that they can build on it in later stages. This is an essential part of the processing and retention of new information. Since students might not spontaneously bring their prior knowledge from their long-term memory to their 'working memory', where it needs to be for information to be manipulated, it can be beneficial to prompt this knowledge by, for example, asking questions and guiding the student in their thought process.[29]

To implement the engagement phase into CoriovallumVR, the visitor could start in front of the portico of the bathhouse. The columned walkway would serve as an initial visual cue to activate the visitors' prior knowledge of the Roman world. To strengthen this cue, information can be given in the form of a pop-up text posing an invitation accompanied by some brief questions to spark curiosity: 'Step into a Roman bathhouse. How did it function, and what was it like to be a visitor some 2,000 years ago?' In front of the visitor, a sign giving information about the bathhouse of Coriovallum can be placed to further activate prior knowledge of the subject. Meanwhile, ambient Roman street sounds can be implemented to enhance immersion.

*Exploration*

The exploration phase invites visitors to actively investigate. Instead of receiving structured information right away, visitors are given the opportunity to interact, observe, and generate their own ideas. This is also a phase where visitors could share observations and discuss their interpretations if the experience allows for multiple visitors at once.[30] The exploration phase is important for the process of conceptual change because it provides visitors with a chance to check their prior knowledge against what they perceive, and form new explanations grounded in their understanding.[31]

The implementation of this phase for CoriovallumVR would be quite intuitive. After the initial engagement, the visitor would be able to roam freely through the model and focus on whatever grabs their interest. The role of the teacher in this phase, Ruiz-Martín *et al.* say, is to facilitate guidance and scaffolds for the students' thinking.[32] In the case of CoriovallumVR, the 'teacher' takes the form of the narrative techniques implemented into the VR educational environment. This could come in the form of a 'recommended' route that visitors can follow if they are confused about what to do or would like some more guidance. Ideally, the virtual environment would include interactive objects that invite interaction without necessarily involving text. An example of this would be the ability to add wood to the oven in the *praefurnium,* which would result in the sound of a flame blazing up. If this sparks enough interest, visitors can get more information by clicking a button near the oven that will tell them about the *hypocaustum*, which they can then go see as well.

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[28] Güven, *et al.* (2025) 15
[29] Ruiz-Martín, *et al.* (2022) 2-4
[30] Ibidem, 4-5
[31] Ibidem
[32] Ruiz-Martín, *et al.* (2022) 4

*Explanation*
The explanation phase comes when the visitor understands the necessity of new information and its relevance to the exploration. This phase formalises the concepts that were grasped in the exploration stage and helps visitors organise new knowledge in a way that benefits memorisation.[33]

This stage would be intertwined with the exploration phase in CoriovallumVR. Visitors would go in and out of the explanation phase as they walk around and decide they would like information on certain aspects of the bathhouse. Explanations could take the shape of signs containing information that could ideally be listened to as well.

*Elaboration*
The fourth phase, elaboration, provides opportunities for visitors to transfer their new knowledge to different contexts. This 'extended practice' with the newly acquired knowledge is essential to learning anything new, especially if the goal is for that knowledge to be retained.[34]

In CoriovallumVR, this phase would be implemented through comparisons and questions that could be woven into the exploration and explanation phases. For example, when something in the reconstruction is based on remains found in Pompeii or Herculaneum, comparative images should be shown together with an explanatory text. Questions underneath would invite reflection: *What do these differences reveal about the region of this bathhouse?*

*Evaluation*
Evaluation, the final phase of the 5E model, assesses the acquired knowledge through an activity. This part not only tests knowledge, but it also plays an important role in the learning process. Cognitive psychologists have shown that retrieving information from long-term memory is a very effective way of learning, and while it often takes the shape of a final test in the classroom, it is recommended to integrate the evaluation phase throughout the whole learning sequence.[35]

In the CoriovallumVR, the evaluation phase would be implemented through swift, quiz-like questions throughout the bathhouse. However, tests can be stressful for people, which in turn can harm memory and learning.[36] Therefore, the visitor should pick from a multiple-choice answer and immediately get feedback, keeping the stakes of the questions low. At the end of the tour, visitors could scan a QR code, which allows them to download a summary sheet containing information they've learned so they can keep retrieving it, even though the experience has ended. Ideally, this would be personalised based on which aspects the visitor explored longest or marked as interesting.

**Cognitive Theory of Multimedia Learning**
While the 5E model provides the theoretical framework for CoriovallumVR, the Cognitive Theory of Multimedia Learning (CTML) will support the choice of a spoken narration.

CTML was popularised and largely defined by the works of R. E Mayer.[37] It aims to explain how people learn from words and graphics and how combining the two can lead to

[33] Ruiz-Martín, *et al.* (2022) 5
[34] Ibidem
[35] Ibidem, 5-6
[36] Ibidem, 6
[37] Mayer & Fiorella (2021)

deeper, more meaningful learning.[38] However, Mayer stresses, 'simply adding pictures to words does not guarantee an improvement in learning… all multimedia presentations are not equally effective'.[39] While the theory has evolved through the years, the main principles have remained the same.

First is the assumption that people process information through *dual channels*: one for visual input and one for auditory input. Second, both channels have *limited capacities*, meaning we can only take in and process so much at once. Third, it outlines how information moves through different memory systems through *active processing*: starting in sensory memory, then into working memory, and finally (if learning happens) into long-term memory.[40]

Within CoriovallumVR, the dual-channel assumption could be applied by adding audio guides, which would play alongside visual features. While visitors listen to an explanation, they could also be looking at the relevant part of the bathhouse, which engages both auditory and visual channels without overloading either one. This could help guide attention and support information structuring, encouraging visitors to actively process what they're seeing and hearing. In doing so, it could increase the chance that the experience will lead to meaningful learning and that the information will be stored in the visitor's long-term memory.

Conclusion

As discussed earlier, this section aimed to lay the groundwork for a possible VR educational environment. By examining how VR can function as a learning space and connecting this to established educational theory, I have outlined key principles that could guide the design of such an environment, whether for CoriovallumVR or similar projects.

The constructivist approach, particularly as developed in Kolb's Experiential Learning Theory, emphasised the importance of active, experience-based learning. The 5E Instructional Model provided a clear structure that could guide visitors through CoriovallumVR in a way that promotes engagement, exploration, understanding, and retention. Finally, the Cognitive Theory of Multimedia Learning supports a design choice of audio narration combined with visual information to reduce cognitive overload and encourage deeper learning. Together, these theories form the foundation on which a VR educational environment like CoriovallumVR can be built. This foundation can be used in future projects and will be partially implemented into the screencast demonstration that is part of the output of this thesis.

[38] Mayer (2024)
[39] Mayer (2021) 57
[40] Ibidem

## 4.3 Methodology

The 3D model of the bathhouse of Coriovallum created for this thesis was made using a combination of virtual reconstruction and virtual restoration. The difference between these two is that a reconstruction recreates entire structures, objects or environments that no longer exist, while a restoration fills in missing parts of a partially surviving object or structure. Most of the superstructure of the Coriovallum bathhouse is gone, and the remains mainly consist of foundations.

Due to the preserved foundations, the overall layout of the building is known, along with information on the sizes of the rooms and pools, the thickness of the walls and columns, and other features identifiable from the floor plan. Elements such as wall heights, roof structures, and other parts of the superstructure that have not survived were more difficult to reconstruct. For these elements, I relied on a combination of archaeological interpretations presented in the 2020 excavation report and comparisons with similar, better-preserved bathhouses, such as those in Herculaneum and Pompeii.

Other parts of the structure were developed through a process of trial and error combined with structural reasoning. Working closely with the model made it possible to experiment with different configurations and see which ones were most plausible. For instance, the roofs of the apodyterium and the northern portico would logically have been interconnected. Initially, it was difficult to imagine a structure that linked them convincingly, but after testing many alternatives, I found a solution that made structural sense. In this way, some design solutions emerged naturally throughout the modelling process, as the “puzzle pieces” began to fit together.

The modelling process started by copying the base geometry from the site plan, then adding the structural features, applying the textures, and lastly, applying lighting for the final renders. Thorough reasoning on the choices made during the reconstruction process can be found in section 5.2 ‘Process description’.

## 4.4 Sources

This project drew from a range of sources, covering archaeological evidence, academic literature, and earlier visualisations. The selection includes works that informed the foundation of the VR educational environment, as well as sources used for the aims, justification, and modelling approach for the Coriovallum bathhouse reconstruction.

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Images

**Image 1**: K. Jeneson and W.K. Vos (2020) 19
**Image 2:** CyArk. *Weissenburg Reconstruction*. 2018. Digital reconstruction. Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Cyark_Weissenburg_Reconstruction.jpg (accessed August 10, 2025).
**Image 3:** Heese, Klaus. *North End of the Vaulted Caldarium in VI.1/7, Herculaneum*. April 2013. Photograph. Herculaneum.uk. https://herculaneum.uk/Ins%206/Herculaneum%206%2001%20p3.htm (accessed August 3, 2025).
**Image 4** Irving, J. *Italia: Wandering Herculaneum*. July 26, 2024. Photograph. Wandering Jana. https://wanderingjana.com/2024/07/26/update250-italy-wandering-herculaneum/ (accessed June 30, 2025).

Additional images used in signs for VR educational environment demonstration:
**Image** fragment of column: K. Jeneson and W.K. Vos (2020) 154
**Image** boilers: K. Jeneson and W.K. Vos (2020) 94

Previous reconstructions

Two previous reconstructions of the Coriovallum bathhouse informed, but did not determine, the approach taken in this project. The first is a digital reconstruction commissioned by the Thermenmuseum Heerlen (now *Het Romeins Museum*) and produced externally by Remi Kooij of Submedia. This model was based primarily on the 2020 excavation report.

The second is an older physical scale model (maquette), also held by the Thermenmuseum, which was constructed before the most recent excavations and reflects the interpretations available at that time. Its design incorporates assumptions that have since been revised in light of newer archaeological evidence.

While I occasionally consulted both reconstructions for comparison and inspiration, my main references were the excavation report and comparative analysis, to avoid uncritical repetition of earlier interpretative choices. As a result, my reconstruction diverges from previous examples in several notable ways, including the cross-gabled roof over the caldarium and tepidarium, and the use of pillars rather than columns in the palaestrae.

Specialists

Karen Jeneson, who led the most recent excavation of the Coriovallum bathhouse, agreed to be interviewed for this thesis, providing valuable information and feedback on the site.

Imported textures, models and sounds

**Imported textures:**

- Plaster's main building (colours manually changed)
  Matvey Sheyanov, *Plaster* (PBR material, BlenderKit 2025)
  https://www.blenderkit.com.
- Concrete as ‘Opus signinum’
  Chroma 3D, Concrete (4K PBR texture, BlenderKit 2025) https://www.blenderkit.com.

- Dirt ground
  Matheus Godoi, Dirt Ground Material (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Ground natatio
  Textures Can, Limestone Tiles (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Floor apodyterium
  Matheus Godoi, Sand Ground Material (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Wood
  Texture used: SubVis Creative, Wood (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
  Andrey Livintsov, Wood (PBR material, BlenderKit 2025) https://www.blenderkit.com.
- Pottery clay
  chroma 3D, Procedural Curved Pottery Clay (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
  chroma 3D, Procedural Pottery Clay (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
  D.R. Rodriguez, Dry Clay (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Alabastra
  Tiago Musumeci, Ceramic Tile Fishscale Blue (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
  Tiago Musumeci, Ceramic Tile Fishscale Green (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
  Tiago Musumeci, Ceramic Tile Fishscale Orange (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Natatio plaster and plaster wall praefurnium
  Free poly, Plaster Grey (PBR material, BlenderKit 2025) https://www.blenderkit.com
  ydd 3D, Simple Blue Plaster (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Water
  Dustin Wann, Water (procedural material, BlenderKit 2025)
  https://www.blenderkit.com
  Soran Mohammadi, Realistic Water (procedural material, BlenderKit 2025)
  https://www.blenderkit.com
- Cement
  Mikhail Zabolotny, Cement (PBR material, BlenderKit 2025)
  https://www.blenderkit.com
- Doors
  Dimitrios Savva, Wooden Garage Door (PBR material, Poly Haven 2025)
  https://polyhaven.com

**Imported models:**

- Fish statue apodyterium
  Model: Erik Rülücke, *Fish Statue* (3D model, BlenderKit 2025)
  https://www.blenderkit.com
- Fire praefurnium
  Model: Matthew Ames, *Animated Fire Sprite* (3D model, BlenderKit 2025)
  https://www.blenderkit.com
- Wood praefurnium furnus
  Model: REAL SCANS, *Firewood* (3D model, BlenderKit 2025)
  https://www.blenderkit.com
- Wood stacks praefurnium
  Model: Volodymyr Shmorhun, *Log Rack* (3D model, BlenderKit 2025)
  https://www.blenderkit.com
- Wooden table tepidarium
  ydd 3D, *Wooden Table* (3D model, BlenderKit 2025) https://www.blenderkit.com
- Wooden bench caldarium
  Waldemar Dad, *Bench* (3D model, BlenderKit 2025) https://www.blenderkit.com

**Imported sounds CoriovallumVR:**

- ranjit_foley, Indian Village ambience (audio file, Pixabay 2025) https://pixabay.com
- Kunal_Acharjee, People talking from Distant (audio file, Pixabay 2025)
  https://pixabay.com
- freesound_community, medieval_village_atmosphere (audio file, Pixabay 2025)
  https://pixabay.com
- freesound_community, 'Touching the Water' (sound effect, Pixabay 2025)
  https://pixabay.com/sound-effects/touching-the-water-123994
- freesound_community, 'Pool Water' (sound effect, Pixabay 2025)
  https://pixabay.com/sound-effects/pool-water-43182
- MaxHammarbäck, 'Fire Sound Effect' (sound effect, Pixabay 2025)
  https://pixabay.com/sound-effects/fire-sound-effect-42150

# 5. WORKFLOW AND MODELLING PROCESS

## 5.1 Process description

***Disclaimer measurements**: all measurements were, where possible, calculated in Roman feet (pes/pedes), with a conversion of 1 pes = 0.3 m used for convenience (rounded from the commonly accepted value of c. 0.296 m).*

***Disclaimer slope elevation:** The reconstruction does not include the natural slope of the site as described in the excavation report. The undisturbed soil within and around the complex varied in elevation, with an estimated difference of up to 2 m between the southeast and northwest corners immediately before construction.[41] These variations resulted from both natural topography and human intervention, such as partial raising of the ground in the west palaestra and excavation in the east palaestra. For this model, the terrain has been kept level to simplify the modelling process and maintain focus on the educational research aim.*

**Starting:**
A map of the bathhouse in its third phase from the excavation report (2020) was imported into Blender and was scaled to its true size. [42] After this, I outlined the walls on the map to have a base from which to work.

**Caldarium and tepidarium**
The first part of the bathhouse that was reconstructed was the caldarium, as it is part of the central building. The first question that arose was what the roof would have looked like. This has been visualised in different ways. Reconstruction drawings of Coriovallum made by Frits Peutz show the bathhouse with a saddle roof (image 1), whereas reconstructions of similar bathhouses, such as the one in Weissenburg (image 2), show the bathhouse with a vaulted roof.

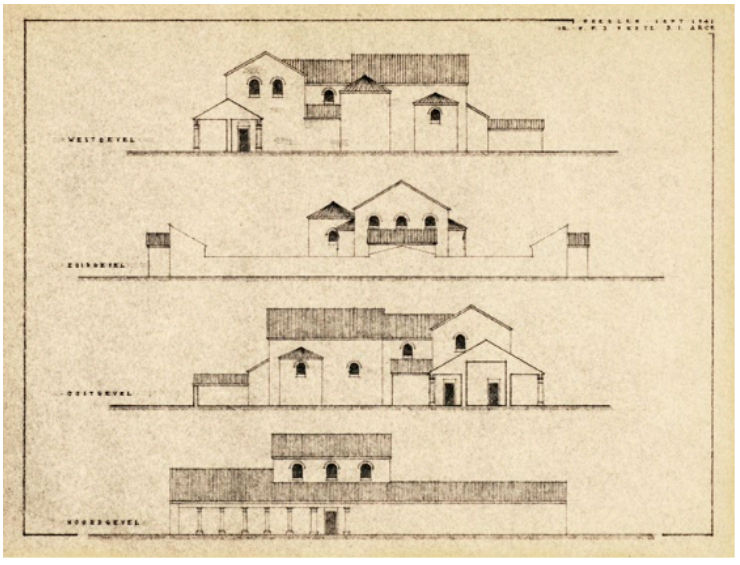

**Image 1**
Reconstruction drawings of the Coriovallum bathhouse by Frits Peutz showing views of different façades. The saddle roofs are visible here.

[41] K. Jeneson and W.K. Vos (2020) 70-72
[42] K. Jeneson and W.K. Vos (2020) 180



**Image 2:** A reconstruction of the Roman Baths in Weißenburg, Germany, displaying the vaulted roofs.

These types of barrel-vaulted ceilings that were also visible on the outside of the building certainly existed in Roman times. Examples of bathhouses with externally visible barrel vault roofs include the Hunting Baths in Lepcis Magna and the Terme Santa Venera in Pozzo ad Acireale.[43] However, none were preserved in the northwestern provinces of the empire.

I decided I would reconstruct a barrel-vaulted ceiling covered by a cross-gabled roof. This choice was based on the presence of corner reinforcements in both the tepidarium and caldarium, which are typically associated with vaulted ceilings.[44] Such vaults would have needed protection from the wet and cold climate of north-western Europe. A single saddle roof over the length of the building, as seen in Peutz's reconstructions, would not align properly over two parallel barrel vaults. Alternatively, placing two adjacent saddle roofs, as seen in the Thermenmuseum reconstruction (**Image 3**), would create a central gutter prone to water and leaf accumulation, increasing the risk of leakage. This is why I settled on a cross-gabled roof, which allows for effective water runoff on all sides.



**Image 3:** The Coriovallum bathhouse, digitally reconstructed by Submedia, commissioned by the *Thermenmuseum* Heerlen. The two adjacent saddle roofs are visible from this western perspective.

[43] K. Jeneson and W.K. Vos (2020) 81
[44] Ibidem, 81-82

Caldarium

The reconstructed caldarium features a barrel-vaulted ceiling that springs at a height of 3.3 m (11 pedes), with semi-domed apses on the east and west ends reaching an internal height of 4.8 m and an external height of 5.1 m.

The report (2020) states that the wall height of most caldaria ranges from 2.5 m in late republican baths to 4.5 m in later examples at Pompeii and Herculaneum.[45] To stay within these margins and I chose a wall height of 3.3 m (11 pedes). This more modest height helps conserve the heat more efficiently, which is especially important in regions with colder climates.

From there, I let the vaulted ceiling rise to a total height of 4.8 m (15 pedes) at the apex. I initially chose this height based on visual comparisons with similar barrel vaulted ceilings found in the surviving bathhouses, such as the Forum Baths in Pompeii, and then went for a rounded Roman measurement (15 pedes).[46] The vaulted ceiling terminates in two half-domes on the eastern and western sides (**image 3)**. After building it, I calculated the arc of embrasure to see if it would be a structurally plausible vault. This is done by treating the vault as a circle and calculating the angle of a line drawn between the spring points of the vault and the centre of the circle. This can be done by drawing this out in Blender (**image 4**), which resulted in an angle of 135°. In a study by Lynne C. Lancaster on Roman vaulted construction (2005), she states that barrel vaults used by Romans typically have an arc of embrasure of less than 180°, with barrel vaults at Trajan's market ranging from 104° to 170°, for example.[47] This places my 135° well between these margins.

Besides that, the vaulted ceiling has a free span of 4.56m. It is supported by reinforced corners that consist of 0.635 m-thick walls. This results in a span-to-support ratio of approximately 1:7.2 (free span divided by wall thickness). Lynne C. Lancaster identifies typical ratios for barrel vaults ranging from 1:4.8 to 1:10.9.[48] The ratio of the vaulted ceiling in the caldarium of 1:7.2, therefore, fits comfortably within the range provided by Lancaster. The caldarium terminates on both the east and west sides in semi-domed apses. These rise from the same springing height as the main vault (3.3 m) and reach the same internal height of 4.8 m.

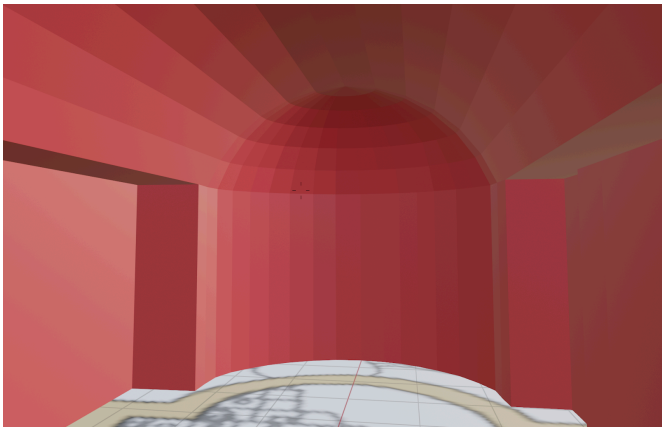

**Image 3**: Screenshot taken in Blender, showing the Eastern half dome inside the caldarium.

[45] K. Jeneson and W.K. Vos (2020) 82
[46] Carole Raddato, 'The Forum Baths in Pompeii' (photograph, World History Encyclopedia 2019) https://www.worldhistory.org/image/11292/the-forum-baths-in-pompeii/
[47] L. C. Lancaster (2005) 132
[48] L. C. Lancaster (2005) 133

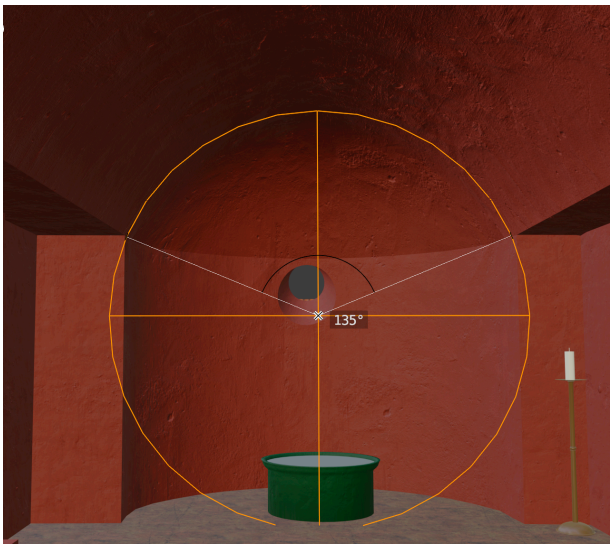


**Image 4**: Screenshot taken in Blender, showing the arc of embrasure drawn out.

Tepidarium

The tepidarium was constructed similarly to the caldarium, but without the apses on the eastern and western ends. I reused the barrel-vaulted ceiling from the caldarium and adapted it to fit the tepidarium's dimensions. This resulted in an arc of embrasure of about 147°. The free span of the tepidarium is approximately 4 m with a support thickness of about 0.7 m at the reinforced corners, yielding a span-to-support ratio of 1:5.7. This ratio, as well as the arc of embrasure, falls comfortably within the margins determined by Lancaster.

Tables were added that could have been used to lie on and receive massages. This is hypothetical, but treatments such as this were quite common in Roman bathhouses.[49]

Roof

As stated above, the barrel-vaulted ceilings would most likely have been protected from the cold and wet climate of northwestern Europe.[50] I decided on a reconstruction with a cross-gabled roof, as this ensures water runs off on all sides. I placed two roofs running east to west over the barrel-vaulted ceilings of the caldarium and the tepidarium, with quite a steep pitch (40°) to allow the vaults to fit comfortably underneath. A third roof running north to south was added in between to complete the cross-gabled form and was pitched at an angle of 28.5°. I worked with rafters during the modelling process. While they won't be visible in the final version, they helped ensure the roof construction fit together and would structurally make sense. The total height of the roof comes out to 6.8 m. The protruding apses at either end of the caldarium were separately covered with conical tiled roofs, integrated into the main structure to protect them from the wet climate.

[49] S. Gianfaldoni, *et al.* (2017)
[50] K. Jeneson and W.K. Vos (2020) 81

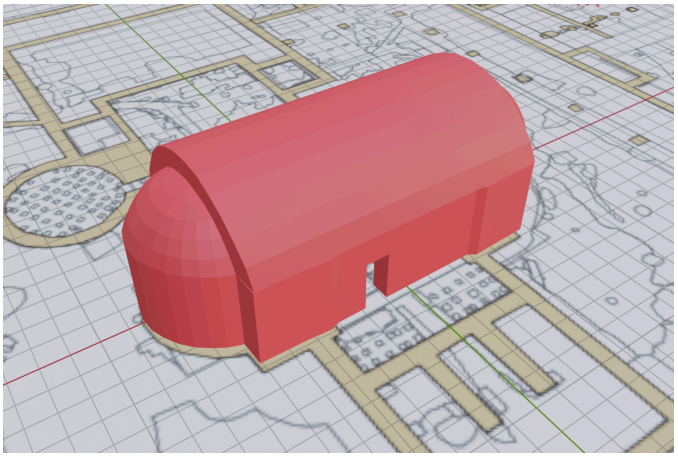

**Image 3**: Screenshot taken in Blender, showing the caldarium with a vaulted roof visible from the outside.

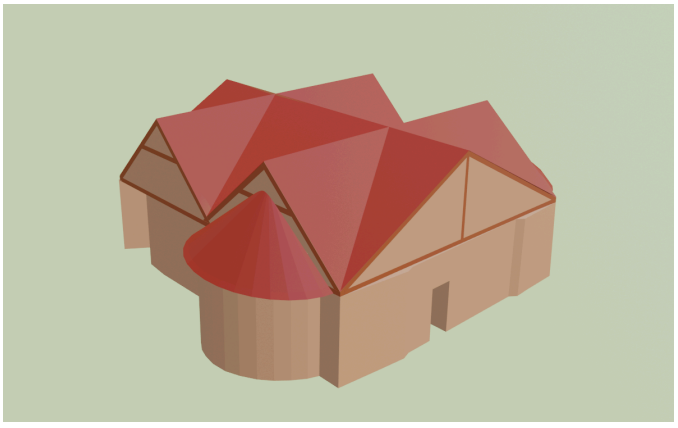

**Image 6:** Screenshot taken in Blender, showing the completed cross-gabled roof with visible rafters and the conical roofs over the apses.

Textures

The main textures used for the caldarium and tepidarium are stone floors and painted plaster walls. Although these walls would likely have been decorated more intricately, this level of detail falls outside the scope of the present thesis.[51]

**Frigidarium**

Since the frigidarium is a cold room, it does not need to conserve heat as much as the caldarium and tepidarium. Additionally, no reinforced corners were found here, suggesting that the space likely did not feature a vaulted ceiling. As a result, the roof could be pitched less steeply, with a 25° slope running in a north–south direction. The walls were made slightly higher at 4 m (13 pedes), bringing the total height of the structure to 6.1 m (20 pedes), including the roof. The room also includes two *piscinae* that project from the main structure as external niches.

Piscinae

I built the piscinae based on the measurements provided in the excavation report (2020).[52] A 35 cm ledge was placed in front of each to keep water from flowing over. Since these piscinae are small niches that project from the main structure, they don't need to be as high as the main building walls, but still need to be tall enough for someone to step into them comfortably without hitting their head. For this reason, I made them 6 pedes (1.8 m) high.

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51

52 K. Jeneson and W.K. Vos (2020) 87-89

While still relatively low, I added a curved ceiling that peaks at 8 pedes (2.4 m). This design was based on a bath niche in the Central Thermae of Herculaneum (**image 7**).



**Image 7:** Photograph of the north end of the vaulted caldarium in VI.1/7, Herculaneum.

The steps leading into the piscinae differ slightly between the eastern and western sides. The eastern piscina features two steps: the first is 1 pes high, and the second drops 47 cm into the water. The width of the stairs was set at 3 pedes, based on images from the report.[53] For the western piscina, I copied the eastern model and then adjusted the dimensions to match the measurements provided in the report. A third step was added, as described in the report as well, and the slope of the pool floor was modified to descend toward the north, rather than into the centre as seen in the eastern piscina.[54] Both piscinae were covered with simple single-sloped tiled roofs

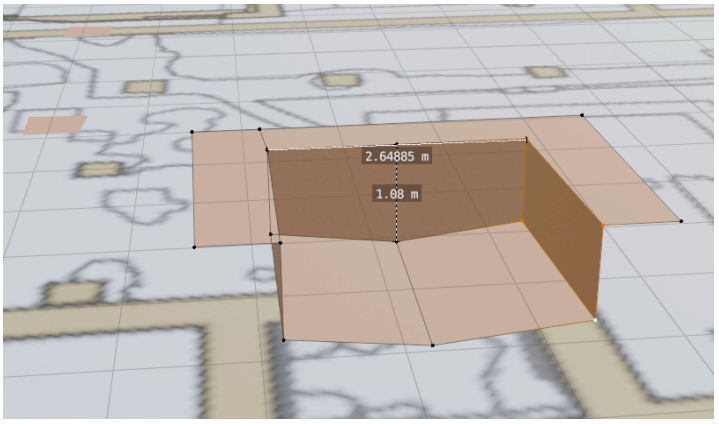


**Image 8:** Screenshot taken in Blender, showing the construction of the western piscina.

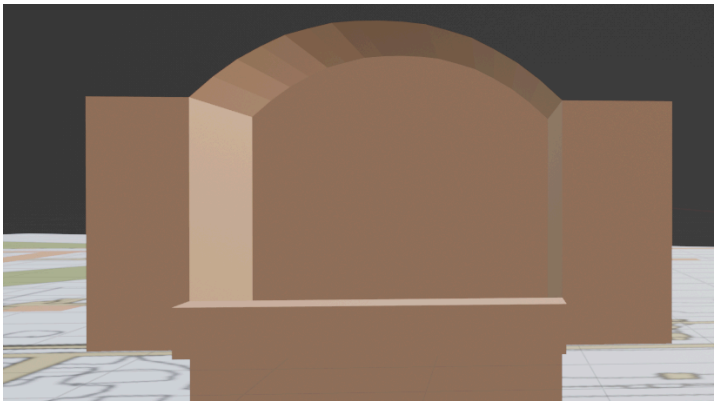

**Image 9:** Screenshot taken in Blender, showing the curved ceiling on the eastern piscina.

**Apodyterium**

I modelled the walls of the apodyterium at the same height as those of the frigidarium (4 m or 13 pedes). The roof of the apodyterium was oriented east–west, and the roof of the frigidarium joined it on the apodyterium's southern side. Both roofs share the same pitch, but due to the greater width of the apodyterium, its total height came out at 6.3 m (21 pedes).

For both the apodyterium and the frigidarium, I chose to add a flat beam ceiling underneath the roof (image 10). Rather than leaving the roof beams exposed, I opted to close off the ceiling to provide better insulation. Given the bathhouse's location, retaining heat, especially in winter, would have been essential. The flat beam ceiling also offers additional protection against moisture in the cold, damp climate. I spaced the beams at 2 pedes intervals (**image 10**).

Later, I added two small basins in the niches where the apodyterium walls connect with the piscinae of the frigidarium. While entirely hypothetical, these basins give function to the otherwise empty niches. Similar features are not uncommon in Roman baths. The water could have been supplied by a pipe or opening connected to the cold-water pools in the frigidarium. These basins could, for example, have been used for rinsing one's feet before entering the bathing area (**image 11**).

To complete the interior, I added simple stone benches and storage shelves. The benches were made 50 cm high for comfortable seating, and the shelves were placed 0.95 m above the benches, high enough to avoid hitting one's head, yet still easy to reach. These types of storage shelves were based on the changing room at the Terme Centrali of Herculaneum (**image 12**).

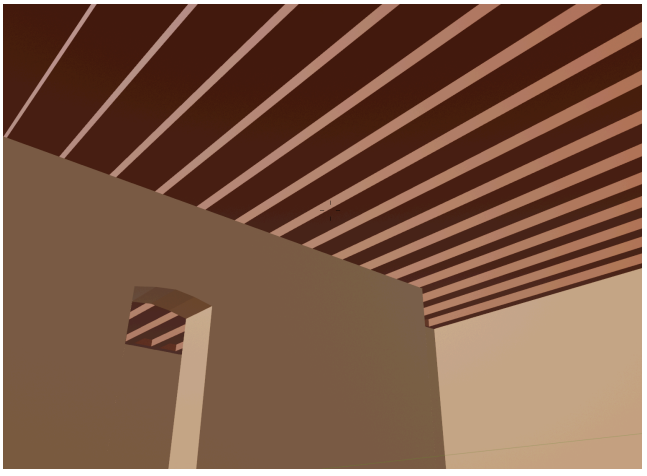

**Image 10:** Screenshot taken in Blender, showing the beams in the apodyterium.

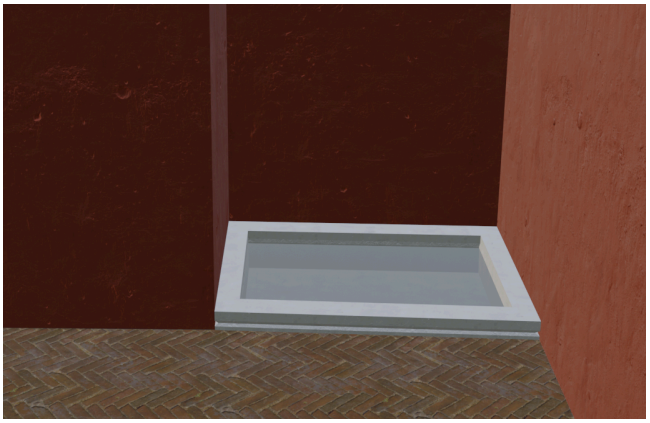

**Image 11:** Screenshot taken in Blender, showing the basin in the western niche of the apodyterium



**Image 12:** The changing room at the Terme Centrali of Herculaneum, showcasing the shelves imitated in the model of Coriovallum.

**Laconicum**

The laconicum was a round sweat room that was built on the west side of the original building after the main rooms were constructed and was accessed through the frigidarium.[55] Determining its height proved difficult. Since it sits outside the main structure and was designed to retain heat, it seemed unlikely that its vault would spring from the same height as the tepidarium or caldarium. Because it connects to the western piscina of the frigidarium, which also has lower walls, I chose to let the vault spring from the same height: 7 pedes (2.1 m). The total building reaches a height of nearly 4 m. Inside, I added two layers of benches. These are hypothetical, but some form of seating would have been logical in a sweat room.

**Alveus:**

The *alveus* in the caldarium is difficult to reconstruct, as little survives beyond its surface dimensions: 6.60 × 2.62 m (17 m²), which is exceptionally large for an alveus.[56] Details such as its depth and the manner of access are unknown. I added a four-step ledge, 60 cm high, along the north side to separate the alveus from the rest of the caldarium and prevent overflow in that direction. This elevation also ensures the bath sits high enough above the hypocaust system. For the depth, I chose a range between 110 and 150 cm, slightly deeper than the piscinae, as the alveus was designed for seated immersion rather than dipping. I included a small underwater ridge for seating. The seating is approximately 60 cm wide and placed 65 cm below the water surface to allow the average visitor to be submerged up to the shoulders. The alveus has a curved ceiling like the piscinae, inspired by examples from Pompeii, and is covered by a mono-pitch roof draining southward.[57]

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[55] K. Jeneson and W.K. Vos (2020) 173
[56] K. Jeneson and W.K. Vos (2020) 92
[57] Alamy, *Italy, Herculaneum, Urban Baths, the Central Thermae... Interior of the Female Calidarium, the Hot Water Bath, Marble Pool and Seating*, photograph, Campania (accessed August 5, 2025) https://www.alamy.com/image230447300.html.

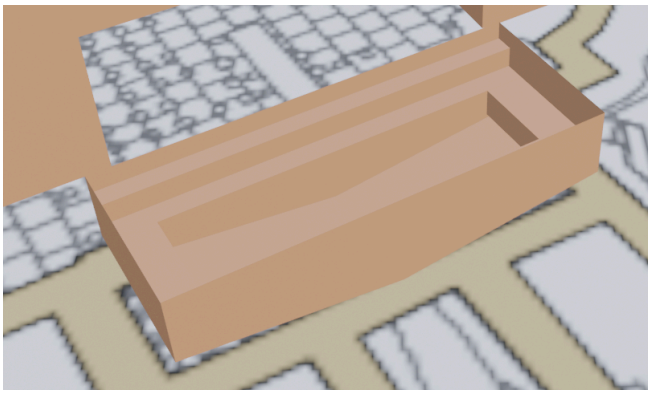


**Image 13:** Screenshot taken in Blender, showing the making of the alveus with stairs and seating.

**Praefurnium**

According to the excavation report (2020), the praefurnium was built in the same construction pit as the alveus, caldarium, and tepidarium, though its floor lay 40 cm deeper than that of the other rooms.[58] This difference in height makes it likely that the walls and roof of the praefurnium were also lower than those of the alveus. The lower floor is logical, as this space was used to fuel heat into the hypocaust system, and the furnace needed to be level with the hypocaustum itself.

Since I set the alveus' lowest point at 5 pedes (1.5 m) below Roman ground level, the praefurnium floor would be at -1.9 m. This depth made it unnecessary for the praefurnium walls to rise much above ground level. I modelled the walls at 60 cm high, resulting in a total interior height of 2.4 m, enough space for a person to stand and for furnaces to be installed.

The entrance to the praefurnium was placed in the western palaestra in the form of a staircase leading down into the space. While the report states an 'entrance' was initially found on the eastern side, this turned out to be a shaft similarly seen in coal cellars of nineteenth- or twentieth-century houses.[59] This shaft was therefore most likely used for the supply of fuel and not as a staff entrance. For the roof of the praefurnium, I chose a simple gable roof pitched at 25°

Furnus, boiler and hypocaustum

The *furnus* was placed against the centre of the north wall.[60] I modelled a vaulted fire tunnel which feeds hot air to the hypocaustum, leading directly to the area underneath the alveus in the caldarium. Underneath the alveus, I built a small 'box' in which I made an example of the hypocaust system. This way, the hypocausts *pilae* are visible, while preventing me from having to model the whole system underneath the caldarium, tepidarium and laconicum.

I added a boiler on top of the fire tunnel, a cold water tank, and lead pipes to distribute the water. These models are based on the boiler found at Boscoreale. This is the only surviving Roman example of one of these bathhouse boilers. The lead these boilers were made of was valuable, and therefore it is no surprise that the one found at Boscoreale was buried under the lava of Mount Vesuvius.[61] While the construction I made in the praefurnium is just an interpretation of the water heating systems featured in Roman bathhouses, I tried to model it in a way that conveys the general idea behind it. This idea is that water comes into the cold water tank through the bathhouse's central water system.

[58] K. Jeneson and W.K. Vos (2020) 61
[59] K. Jeneson and W.K. Vos (2020) 118
[60] K. Jeneson and W.K. Vos (2020) 61
[61] K. Jeneson and W.K. Vos (2020) 93

This is connected to the alveus through a pipe that leads into the wall, and to the boiler, so water can be heated. From the boiler, there is also a pipe to the alveus and one that leads further into the bathhouse.[62]

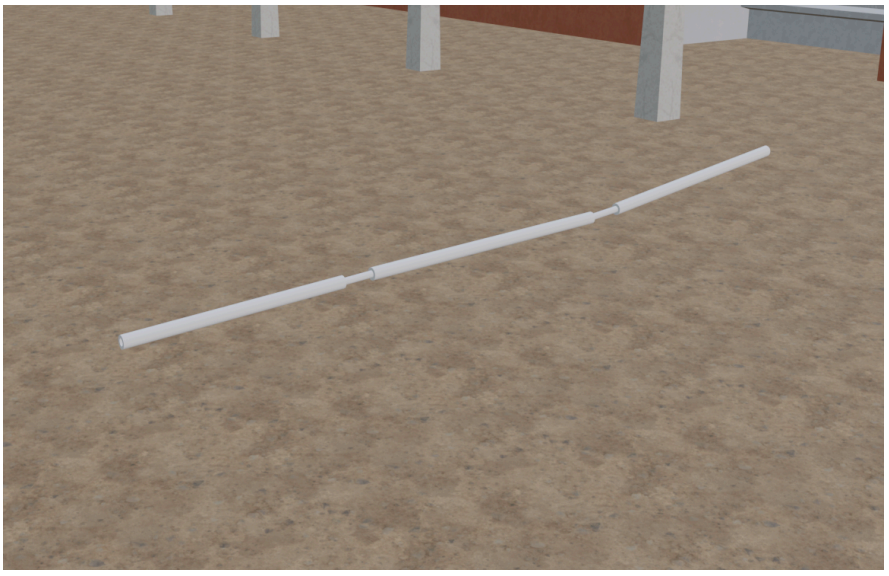


**Image 14:** Screenshot taken in Blender, showing the modelling of the water pipes.

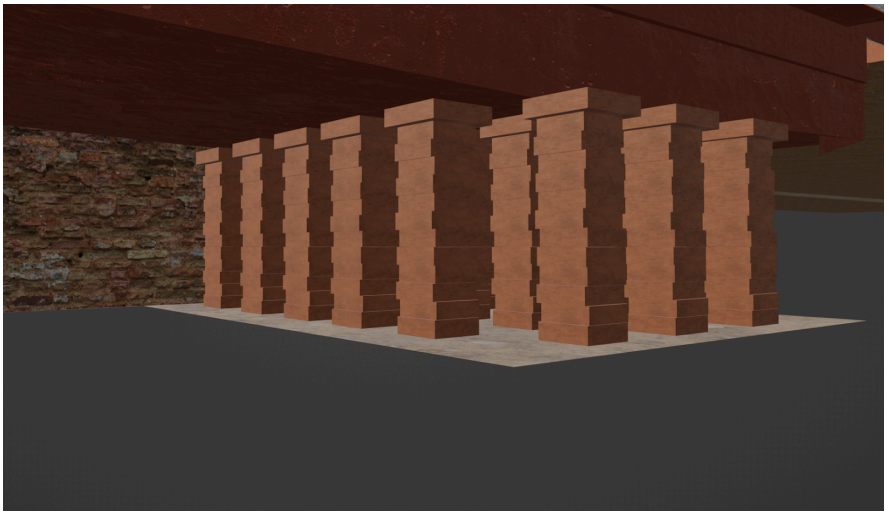


**Image 15:** Screenshot taken in Blender, showing the modelling of the hypocaust ‘box’.



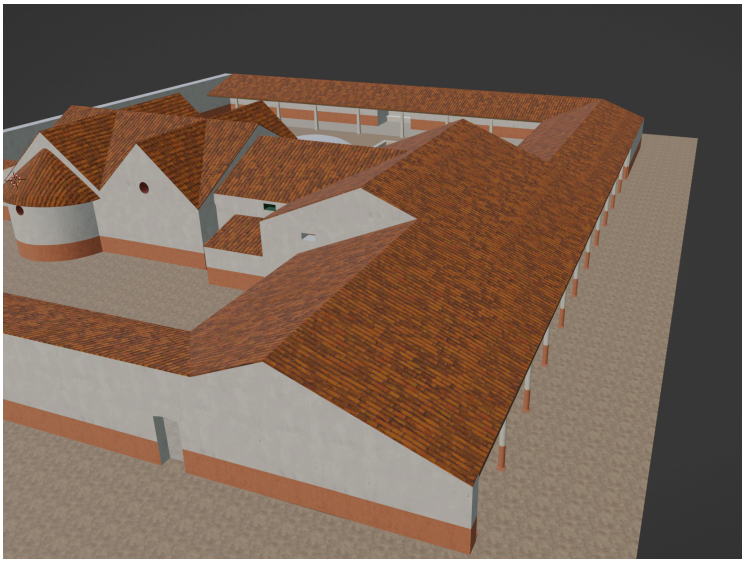
**Image 16:** Screenshot taken in Blender, showing the finished boiler system.

**Tabernae**

The three rooms in the eastern portico were most likely shops that faced the street to the north of the bathhouse and could have offered products like oils and food.[63] These tabernae were built into the eastern portico and were roughly 3.6 x 4m. To create the idea of shops that were accessible from the street, I created openings in the northern walls that could have served as counters. On the southern sides, I created three doors to access the shops.

The roof was difficult to model, as it connects to multiple adjoining structures: on the south side, it extends into the roof of the eastern portico; on the north side, into the roof of the northern portico; and on the west side, it connects to the roof of the apodyterium. Because of this, I had to return to the roof of the tabernae at a later stage, once the surrounding structures had been built, to make everything fit properly.

To make the tabernae come to life a little bit, I added some decorations. I modelled amphora, bread, alabastra and wine flasks.



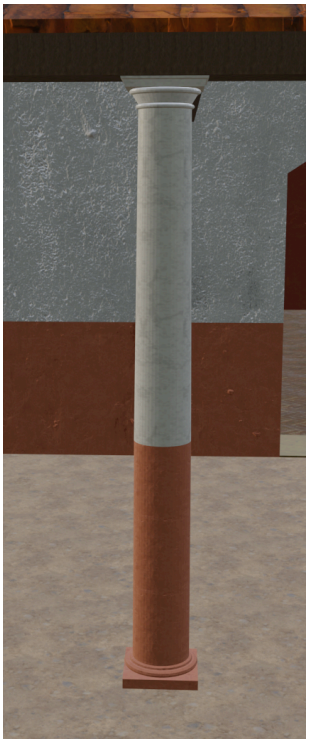


**Image 17** (left)**:** Screenshot taken in Blender, showing the completed roof of the tabernae, connecting to the surrounding structures.
**Image 18** (right): Screenshot taken in Blender, showing the final model for the Tuscan columns.

**Northern portico**

The portico at the entrance on the north side of the bathhouse featured a roof supported by columns. The excavation report (2020) states that only one element of the columns has been excavated. This is the column base with a double torus, revealing that it must have been a Tuscan column. The diameter of the base was used to calculate the height of the column: 'Based on a common ratio between the diameter of the bottom of the column and the height of the column of 1:6¾ to 1:7½, the columns in the portico were between 223 cm and 247.5 cm high. This is equivalent to between 7½ and 8 Roman feet.'[64] I therefore settled on a height of 2.4m or 8 Roman feet and based my model of the columns on general images

[63] K. Jeneson and W.K. Vos (2020) 99, 179
[64] K. Jeneson and W.K. Vos (2020) 82-3

of Tuscan pillars.[65]

Since six column bases were found on the east side of the portico, Van Giffen concluded that another six must have stood on the west side, with a room, identified by him as a possible latrine, occupying the remaining space at the western end of the northern portico.[66] While this interpretation remains uncertain, I chose to follow Van Giffen's reconstruction of twelve columns and a room at the western end, both for symmetry and due to the lack of a more compelling alternative. This resulted in a total span of 38.5 m from the eastern outer wall to the wall of the presumed latrine. Dividing this by eleven (the number of spaces between twelve columns) gives an approximate column spacing of 3.5 m.

Although the latrine room was modelled, Karen Jeneson informed me that it is very unlikely a latrine was located here. I therefore left the space empty to indicate that its original function remains uncertain.

**Palaestrae**

The palaestrae are divided into eastern and western sections. The western palaestra was accessible to visitors, while the eastern side was likely reserved for maintenance activities and shopkeepers. Unlike the porticoes of the main bath complex, the palaestrae featured square masonry pillars, not columns, to support their covered walkways.[67] These measured approximately one Roman pes each and were placed along the eastern palaestra based on the foundations uncovered during excavation. This was something not displayed in the maquette at the *Thermenmuseum*, which incorrectly used Ionic columns for both the portico and the palaestrae.

At this point, I redesigned the roof of the tabernae to seamlessly continue into the roofs of the northern portico and the southern palaestra. I then modelled the roofs of the portico surrounding the palaestrae and added rafters and beams that were inspired by the maquette of the *Thermenmuseum.*[68] A central beam runs along the roof edge, with angled rafters extending from the outer wall toward this central beam, supported at regular intervals by the square masonry pillars. This setup proved particularly complex to align and model correctly, and required a lot of time to implement.

Internally, the porticoes surrounding the palaestrae reach a height of 2.4 m, matching the northern portico, while the rear slopes up to 3.9 m to connect with the outer wall. I settled on this height of the outer wall since it aligns with the roof pitch, offers sufficient structural coherence and drainage, and is high enough to provide privacy for the palaestrae. The entrance to the western palaestra was placed just beside the main entrance of the bathhouse complex, in the northern portico, which is the most logical location for it, as it was meant to be easily accessible for visitors of the bathhouse. In the outer wall, two small niches were identified. The report suggests these may have functioned as *exedra* (seating areas where visitors could sit and converse) or possibly housed a fountain or basin.[69] I chose to interpret them as sitting spaces and modelled them accordingly, incorporating a sloping roof and a small bench within each niche.

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[65] Wikipedia, *Tuscan Order*, diagram, last modified July 2023, https://en.wikipedia.org/wiki/Tuscan_order (accessed August 6, 2025).
[66] K. Jeneson and W.K. Vos (2020) 51
[67] K. Jeneson and W.K. Vos (2020) 68
[68] Corvinus, *Reconstruction Drawing of the Roman Baths in Heerlen*, image, published May 2018, https://corvinus.nl (accessed August 6, 2025) https://i0.wp.com/corvinus.nl/wp-content/uploads/2018/05/Baths-Heerlen.jpg.
[69] K. Jeneson and W.K. Vos (2020) 110

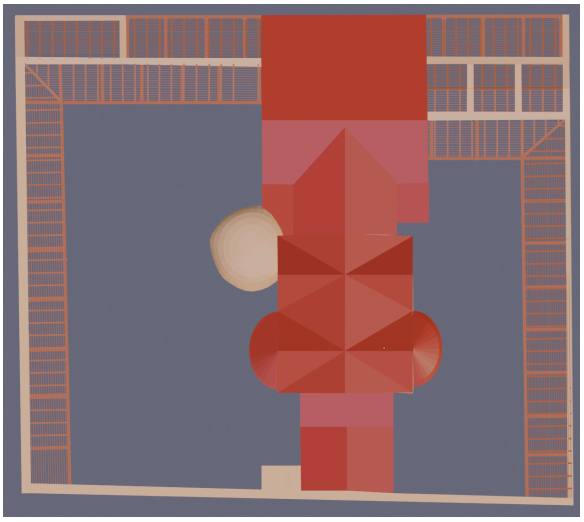


**Image 18:** Screenshot taken in Blender, showing the beams and rafters added to the porticoes of the palaestrae, the northern portico, and the tabernae.

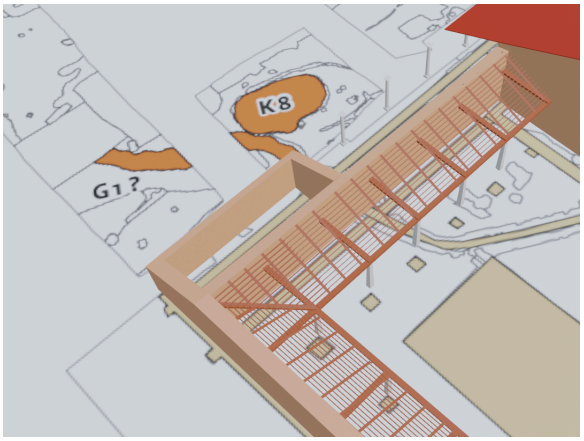



**Image 19:** Screenshot taken in Blender, showing the construction of the beams and rafters and placing the columns in the western palaestra portico.

In the western palaestra, the *natatio* was added. This was an outdoor pool that, according to the report, would have been between 1 and 1.5m deep.[70] The edges of the pool were observed by Van Griffen to have a height of 75-115cm. I therefore modelled an edge of 115cm high around the pool and let the pool itself sit 15cm into the ground on the inside to create a total depth of 1.3m. The report briefly mentioned steps in the north-west corner of the natatio, so I added some steps inside and outside of the pool to make the entrance easier.[71] I used some blue painted plaster textures for the inside of the pool and grey plaster for the outside, as the report mentioned that possibly blue plaster was found, which suggests the inside of the pool may have been painted.[72]

While the palaestrae would originally have been decorated with foliage, I chose to omit this due to hardware limitations. Plant models tend to have a high polycount, which significantly slowed down my system. Since the model is partially intended for potential use in a browser-based VR environment, such high polycounts are not desirable.

[70] K. Jeneson and W.K. Vos (2020) 90
[71] Ibidem
[72] Ibidem

Lighting

To achieve effective lighting inside and around the bathhouse, I used a combination of chandeliers and protruding ledges fitted with oil lamps. The design of the ledges is inspired by the virtual reconstruction of the bathhouse created by Submedia for the Thermenmuseum, which was provided to me in full via a closed link. As this link is not publicly accessible, it cannot be included here.

Textures

The textures used for the bathhouse are inspired by information from the 2020 excavation report and comparative research. However, finding suitable textures can be challenging, and in some cases, the original material is not well documented. The textures have therefore been added primarily for aesthetic purposes and to enhance immersion in the VR educational environment. They should not be considered historically accurate, but are rather a hypothetical interpretation of how the bathhouse might have looked.

## 5.2 Output

Output

The output of this master's thesis project consists of this report, the Blender file of the 3D reconstruction, a series of eleven renders (which includes three renders of the colour-coded uncertainty index), and a screencast demonstration of the VR educational environment Coriovallum VR.

The report is provided in PDF format, the rendered images in PNG, and the screencast in MP4. The Blender file remains in BLEND format. Information about the sources used in the output is presented as a short general text accompanying the images and screencast. The report will be stored alongside the images and screencast, allowing it to be referenced directly if needed.

Uncertainty

Uncertainties are addressed by including three additional renders of the outside of the model with colour overlays representing different certainty levels, following the 'Degrees of Certainty' system developed by the 4DRL (see image below).[73] This system comprises six classes, ranging from 'certain' to 'very uncertain'. Since a lot of the descriptions of the different uncertainties on the website of the 4DRL are aimed towards objects instead of structures, I would like to clarify some of my decisions.

The bottom layer of most structures is coloured blue for 'certain'; this refers to the location and foundational shape of the structure, which are known. What immediately becomes clear when looking at these renders is that the higher, the more uncertain things become, which is logical for a reconstruction based on mostly foundational remains. In general I have used 'moderately certain' for walls which were certainly present and of which the shape is known, but the exact height is uncertain; 'not so certain' was used for parts of the structure that have more variability in their shape; 'quite uncertain' for parts that might have looked quite different; and 'very uncertain' I only used for the roof over the caldarium

[73] 4D Research Lab, *Degrees of Certainty for Reconstructions* (2020) https://4dresearchlab.nl/degrees-of-certainty-for-reconstructions/.

and tepidarium, as this part is purely hypothetical and could have looked very different. The columns and pillars are the only things that were classified as ‘quite certain’ because their shape is practically known from imprints and remains.

The structural interior of the bathhouse generally follows the uncertainty index shown in the renders of the exterior. However, smaller structural and decorative details are mostly quite uncertain to very uncertain. I chose not to include renders of every room’s uncertainty because the walls and ceilings would have the same uncertainties as on the outside, whereas the rest would mostly be labelled brown and red.

Therefore, for detailed information on uncertainties inside the building, as well as a more specific analysis of the uncertainties of the exterior, I refer to section 5 (‘Workflow and Modelling Process’) of this report, where each part of the structure is discussed in detail.

| Certainty Class | Variability | Indication | Example | Colour |
|---|---|---|---|---|
| Certain | None | Empirical | Scanned remains | 89a5c1 |
| Quite certain | Low | Logical extension | Missing part of relatively complete object | 95bf8f |
| Moderately certain | Limited | Close parallel | Same type, direct relation | eee3ab |
| Not so certain | Considerable | General parallel | Same type, indirect relation | d9cfc1 |
| Quite uncertain | High | Historic context | General stylistic traditions | a77e58 |
| Very uncertain | Very high | Theoretical | Constructional argument | ba3f1d |

**Image:** Degrees of certainty as defined by the 4DRL.[74]

Software

The output images and the screencast demonstration were produced in Blender (version 3.6.17). Audio for the screencast was added in Final Cut Pro (version 10.8), and smoke effects were added to one rendered image (the praefurnium) in Adobe Photoshop (version 26.2).

Accessibility

The rendered images are presented in the following section and are also available for download in 4K resolution on OSF (Open Science Framework). A DOI is presented below, which links to the OSF. The Renders, as well as the screencast demonstration and the report, will be available there too. To access it, navigate to the linked page, open the “files” section at the top of the page, and select either the ‘images’ or ‘screencast’, or ‘report’ folder as appropriate.

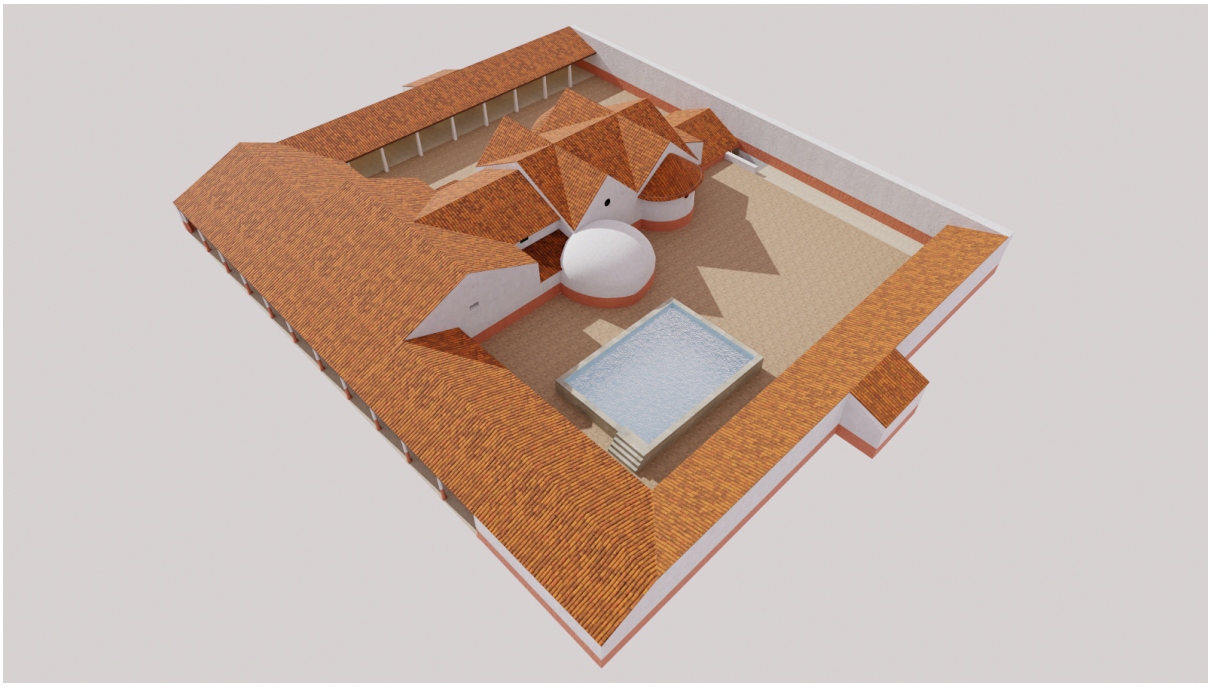
**DOI 10.17605/OSF.IO/A2RW7**

**Note:** *The screencast player gets cut off slightly in the OSF environment. To see it fully, double-click it to watch it in full screen. It is also advised to turn on the sound.*

[74] 4D Research Lab, *Degrees of Certainty for Reconstructions* (2020) https://4dresearchlab.nl/degrees-of-certainty-for-reconstructions/.

## 6. RESULTS

Renders





The top render provides a full view of the bathhouse from above, taken from the northwest.

The bottom render shows the western palaestra from beneath the portico, with the alveus in view and the laconium behind it.





The top render shows the praefurnium, with the boiler positioned above the furnus and the cold-water tank to its right. Behind the flames, the hypocaustum can be seen.

The bottom render depicts the middle taberna, its shutter lifted to reveal items for sale, including oil flasks (alabastra) and bread.





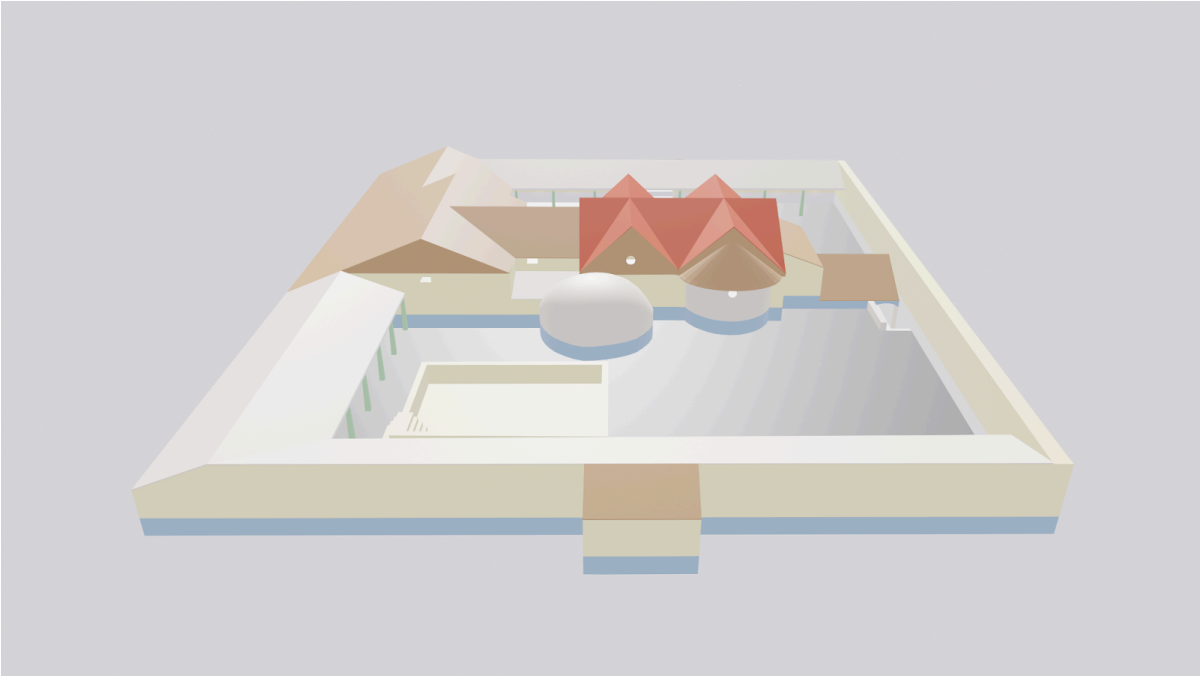
In these two renders, the caldarium is shown. The first image depicts the alveus from the north, while the second is taken from within the alveus, looking toward the half-domed eastern apsis of the room.

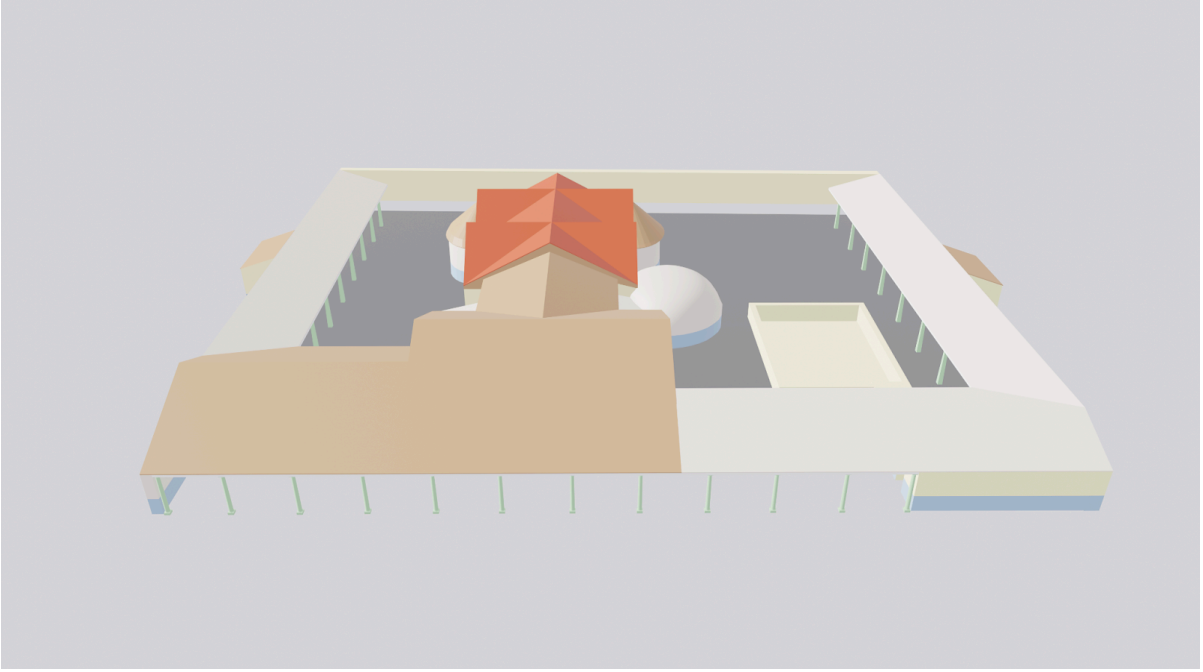




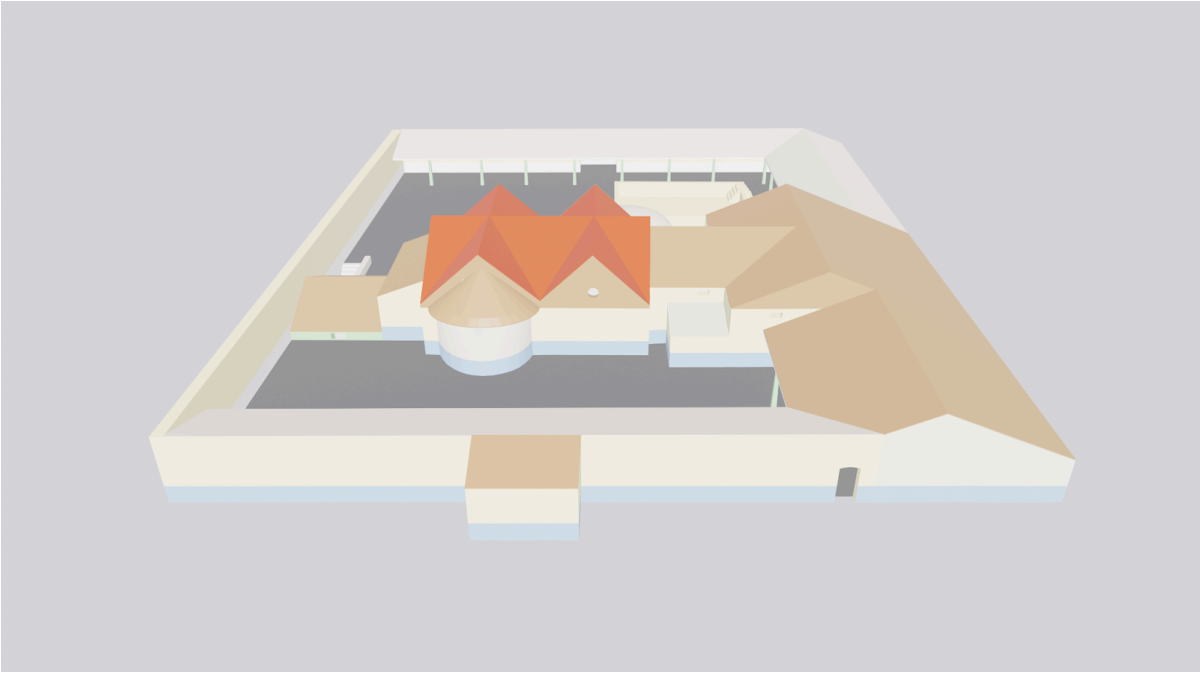
The top render shows the tepidarium from the western side, looking toward the eastern cold-water basin.

The bottom render depicts the apodyterium, with a Tuscan column visible through the doorway. The shelves for storing personal belongings can also be seen.





*Information on the above two renders can be found on the next page.*



These three renders above show the model, from top to bottom, from the west, north and east. They display a colour-coded certainty index developed by the 4DRL mentioned in the previous section and shown again below for ease of access.

| Certainty Class | Variability | Indication | Example | Colour |
|---|---|---|---|---|
| Certain | None | Empirical | Scanned remains | 89a5c1 |
| Quite certain | Low | Logical extension | Missing part of relatively complete object | 95bf8f |
| Moderately certain | Limited | Close parallel | Same type, direct relation | eee3ab |
| Not so certain | Considerable | General parallel | Same type, indirect relation | d9cfc1 |
| Quite uncertain | High | Historic context | General stylistic traditions | a77e58 |
| Very uncertain | Very high | Theoretical | Constructional argument | ba3f1d |

**Image:** Degrees of certainty as defined by the 4DRL.[75]

As mentioned in the previous section, the screencast demonstration of CoriovallumVR and all the rendered images above are available on OSF through the following DOI:

**DOI 10.17605/OSF.IO/A2RW7**

[75] 4D Research Lab, *Degrees of Certainty for Reconstructions* (2020) https://4dresearchlab.nl/degrees-of-certainty-for-reconstructions/

## 7. DISCUSSION AND CONCLUSION

This thesis project aimed to create a virtual reconstruction of the bathhouse of Coriovallum and to explore how the virtual reconstruction could be utilised as an educational tool.

The first of these goals, producing a scientifically grounded virtual reconstruction of the bathhouse, resulted in a 3D model based on the excavation report *Roman Bathing in Coriovallum* by K. Jeneson and W.K. Vos, supplemented with comparative research. The workflow and modelling processes were documented as extensively as possible. Transparency was addressed by creating renders with a colour-coded certainty index, highlighting areas of uncertainty within the model. This was not implemented in the other two reconstructions made for the *Thermenmuseum* Heerlen. Eight fully textured semi-realistic renders were produced to show the potential of the model for its use in an eventual VR educational environment. The textures were added for aesthetic reasons, and while they are generally based on information presented in the excavation report (2020) and comparative research, historically justified textures would have been preferred. Finding all the right textures or even making custom ones did not fit within the scope of this thesis. This would be advised for future projects.

While the model is firmly grounded in scientific research, many elements remain uncertain. The workflow and modelling process descriptions, combined with the renders showing the certainty index, provide a clear degree of transparency about these uncertainties, yet ideally, more ways to promote transparency could have been implemented. For example, the ability to model and easily switch between alternative hypotheses would have been an effective way to show the different ways the bathhouse might have appeared. However, within the scope of this thesis project, producing multiple alternative hypotheses and presenting them at the same quality as the primary reconstruction was not feasible. In future projects, particularly in the full realisation of CoriovallumVR, incorporating such alternatives would be desirable.

Other uncertainties in the model stem from the fact that it was built largely on my own architectural assumptions. As someone trained in archaeology, my knowledge of structural integrity is limited. A more interdisciplinary approach would therefore be advisable for future projects. Collaboration with an architect could reduce uncertainties in the virtual reconstruction and help ensure that the model is structurally accurate.

The second goal, exploring the use of the model as an educational tool, was achieved by creating a screencast demonstration of how CoriovallumVR could function. The visuals shown here represent the web-based version of the VR educational experience, designed to ensure accessibility in classrooms or at home. The eight semi-realistic renders illustrate how CoriovallumVR could appear if implemented in a museum setting.

However, the exact implementation of the 5E Instructional Model and its effects on learning require further study. The influence of visual quality on the learning experience, the retention of knowledge compared to standard learning methods, and the optimal structure and layout of the environment are all topics that warrant additional research.

A full version of CoriovallumVR has not been realised yet, but the combination of the theoretical framework, the screencast demonstration, and the final renders showing its full potential provides a solid basis for future projects to build upon.