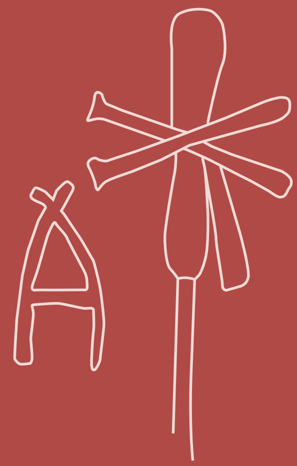

BUILDING-HISTORICAL ANALYSIS WITH DIGITAL TOOLS OF EGYPTIAN MUDBRICK CONSTRUCTIONS:

A STUDY OF THE TOMB OF QUEEN MERET NEITH AND ITS USE OF MUDBRICK

„ [...] it was believed that Meryet-nit was a king,
but later research has shown the name to be that of a woman and,
to judge by the richness of the burial,
a **queen**.“ [1]

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1 EMERY, W.; *Archaic Egypt*. 1st ed. London: Penguin Books, 1961. P.65

TU WIEN architektur + raumplanung

DIPLOMA THESIS

Building-Historical Analysis with Digital Tools of Egyptian Mudbrick Constructions:
A Study of the Tomb of Queen Meret Neith and its Use of Mudbrick

Submitted in satisfaction of the requirements for the degree of
Diplom- Ingenieurin
at the TU Wien, Faculty of Architecture and Planning

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[redacted]

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Diese Masterarbeit untersucht die Lehmziegelarchitektur des alten Ägyptens, mit besonderem Fokus auf das Grab der Königin Meret Neith in Abydos. Sie beginnt mit einem allgemeinen Überblick über Ansätze zur Bauanalyse und Dokumentation, wobei der Schwerpunkt auf analytischen Methoden liegt, die speziell für Lehmziegelkonstruktionen entwickelt wurden. Photogrammetrie spielt hierbei eine zentrale Rolle, da sie die Erstellung eines präzisen 3D-Modells des Grabes ermöglicht, welches eine detaillierte Analyse unterstützt und die Grundlage für weitere Untersuchungen bildet. Im weiteren Verlauf widmet sich die Forschung einer eingehenden Untersuchung der Lehmziegelkonstruktionen in Ägypten und liefert tiefere Einblicke in die Materialien, Techniken und deren Bedeutung in der altägyptischen Architektur. Dabei wird das Grab der Meret Neith in einen umfassenderen architektonischen und kulturellen Kontext eingeordnet. Darauf folgt eine detaillierte bauhistorische Analyse des Grabes, die sich auf architektonische Merkmale, Konstruktionstechniken und die strukturelle Organisation konzentriert. Die Ergebnisse dieser Analyse identifizieren wesentliche Indikatoren für den Bauprozess und die angewandten Methoden und dienen als Grundlage für die Ableitung von Parametern, die ein besseres Verständnis der Konstruktion des Grabes ermöglichen. Diese Parameter werden anschließend genutzt, um eine digitale Simulation des Grabes zu erstellen, mit besonderem Augenmerk auf die Techniken der Ziegellegung. Ein Teil der Forschung widmet sich zudem der digitalen Vermittlung der Ergebnisse und betont die Bedeutung innovativer digitaler Methoden für die Erhaltung und Untersuchung des kulturellen Erbes. Durch den Einsatz von parametrischem und generativem Modellieren wird ein Simulationswerkzeug entwickelt, das speziell für die Analyse und Visualisierung von Ziegelkonstruktionen und Legemustern konzipiert ist. Dies eröffnet neue Perspektiven und ermöglicht ein umfassenderes Verständnis antiker Baupraktiken.

ABSTRACT

This master thesis explores the mudbrick architecture of ancient Egypt, focusing on the tomb of Queen Meret Neith at Abydos. It begins with a general overview describing approaches to building analysis and documentation, with an emphasis on analytical methods specific to mudbrick constructions.

Photogrammetry plays a crucial role in creating an accurate 3D model of the tomb, which facilitates the in-depth analysis and serves as the foundation for further investigation. Subsequently, the research provides a detailed exploration of mudbrick construction in Egypt, offering deeper insights into the materials, techniques, and their significance in ancient Egyptian architecture, situating the tomb of Meret Neith within this broader architectural and cultural context.

A detailed building-historical analysis of the tomb follows, focusing on its architectural features, construction techniques, and structural organization. The results of this analysis identify key indicators of the construction process and methodologies employed, forming the basis for extracting parameters to enhance the understanding of the tomb‘s construction.

These parameters are then used to create a digital simulation of the tomb, with a particular emphasis on the brick-laying techniques. Part of the research also involves digitally communicating the findings, emphasizing the importance of preserving and studying cultural heritage using innovative digital methods. By employing parametric and generative modeling, a simulation tool is developed to specifically analyze and visualize brick construction and laying techniques, offering new perspectives and a comprehensive understanding of ancient building practices.

Explanation of Gender-Neutral Formulation

For the sake of readability, gender-neutral differentiation may be omitted in certain instances. Regardless of the linguistic choices made, it is to be understood that all genders are regarded as equally valued and respected throughout the content.

1

INTRODUCTION

Many cultures throughout history have used mud as a key building material because of its availability, versatility, and good thermal properties. Unfortunately, historical mud buildings are often not well-preserved due to environmental factors like rain or rising groundwater, as well as human activities such as neglect during excavations and exposure to the elements after excavation.[1] In some cases, these buildings are hard to access, as seen with the tomb of Meret Neith, which remains difficult to study and preserve.

Given these challenges, it is advantageous to maintain and protect these mud structures. Building research extends beyond historical exploration. Additionally, it encompasses the study and analysis of construction techniques to facilitate the preservation, restoration, and conservation of such structures.[2]

1 SPENCER. *Brick Architecture in Ancient Egypt*. p.3

2 GROSSMANN. *Einführung in die historische Bauforschung*. p. 1-77.

This dual focus on historical knowledge and practical application underscores the importance of building research not only as a means to understand past civilizations but also as a tool to ensure the continued survival of these structures for future generations.

In recent years, there has been renewed interest in using mud as a building material, driven in part by the growing interest in sustainable construction practices. Historical mud buildings offer valuable insights that can inform the development of modern construction techniques. By analyzing the durability, functionality, and environmental impact of these structures, we can draw innovative conclusions that may shape the future of mud-based architecture.[3]

The study of historical mud construction, therefore, not only enriches our understanding of past building practices but also provides

3 WICHMANN, WIENANDS. *Epilog oder Kehrseite der Medaillie* in *Architektur der Vergänglichkeit* [...]. p.247ff.

an opportunity to adopt and adapt ancient methods for contemporary construction challenges, demonstrating the enduring value of these historically intelligent building techniques.

By creating accurate and scalable 3D models, it is possible to study construction techniques, material use, and structural organization without physically compromising the site. This approach is particularly valuable for understanding the architectural complexity of Tomb Y and its relationship to other early royal tombs.

The research presented here addresses the question of *How can a building-historical analysis of Queen Meret Neith's tomb be conducted using digital tools as both a foundation and a means of presenting findings*. By integrating photogrammetry with parametric modeling, this study seeks to reconstruct and analyze the tomb's mudbrick construction methods.

Digital tool systems have been specifically developed to simulate these construction techniques, providing insights into the architectural processes and offering a deeper understanding of the broader context of mudbrick construction in ancient Egypt.

Through the use of digital tools and photogrammetry, this study not only reconstructs the tomb virtually but also underscores the importance of preserving and interpreting mudbrick architecture as a cornerstone of Egypt's cultural heritage.

It is hoped that the methods and findings presented here will contribute to future research and restoration efforts, ensuring the ongoing study and appreciation of this ancient site.

Building research, modern photogrammetry and digital reconstruction methods play a pivotal role in preserving and analyzing these tombs.

2

BUILDING RESEARCH

2.1 Definition

The term *Building Research* (Bauforschung) was first introduced by Armin von Gerkan in 1924. Despite its long history, the distinction between building research and architectural history remains a topic of debate. Some consider building research a subset of art history, while others associate it with disciplines like architecture, engineering, archaeology, or ethnology.

The origins of building research can be traced to early explorations of ancient, often classical, architecture, particularly during the Renaissance, a period marked by the revival of classical antiquity. Early documentation of buildings primarily consisted of drawings and surveys. While there are examples of medieval drawings, they are often imprecise and more schematic. Modern building research finds its roots in architecture and archaeology, with the 19th century being particularly significant. During this time, the primary aim was to reconstruct the original design of historical buildings, leading to a deep engagement with construction methods and forms.

Archaeological building research played a pivotal role in shaping methodologies, many of which were developed by architects. Armin von Gerkan's doctoral dissertation emphasized precise stone-by-stone documentation, including the recording of surface features and tool marks, which laid the foundation for accurate reconstruction. This approach involved creating detailed plans of individual stones, accompanied by descriptive texts with exact measurements. Von Gerkan also advocated for the integration of building research into archaeological studies, leading to the establishment of an association in Bamberg in 1926, which became the only organization dedicated to building research in Germany at the time. Over the years, the field has expanded from focusing solely on facade design to encompassing the study of construction techniques.

Building research relies heavily on insights from disciplines like architecture and art history, rarely standing as an independent field. Its primary focus is on analyzing construction phases and historical contexts. It is distinct from the investigation of modern construction defects, emphasizing historical or archaeological structures.
Historical building research involves the study of structural conditions and interrelationships, tracing a building's development from its

1 | Portait of Armin von Gerkan

earliest manifestations to its present state. Archaeology, as a complementary discipline, contributes to this knowledge by examining earlier structures and identifying destroyed parts of existing buildings or architectural element. In addition to fieldwork, building research includes archival studies, analyses of specialized literature, and other examinations of the structure. Through systematic observation, it seeks to reconstruct the history of the building and its architectural evolution.

The relationship between building research and documentation is best understood as one of mutual reinforcement. Documentation serves as a method of securing the observed condition of the building in written and visual formats. It captures both the current state of the structure and the findings uncovered during the building research process. This approach aligns closely with the concept of *Preservation through Recording*. The first step in any architectural or art-historical analysis is the systematic documentation of the building, which serves as the foundation for all subsequent research. Documentation includes the recording, evaluation, and treatment of the structure as a historical document. Only after establishing a comprehensive dataset of the building's physical and historical parameters can meaningful interpretations be undertaken.

While building research cannot always provide definitive dates or clear origins for every material or structural feature, its methodology creates the necessary foundation for further analysis. From an archaeological perspective, traces of earlier constructions underlying or preceding the current building are integral to understanding its origin and developmental history. These findings provide a critical foundation for object analysis and serve as a basis for reconstructing the building's historical narrative.

2.2 Collecting Data

Accompanying research for the historical, cultural, and art-historical classification of buildings includes a variety of methods, particularly in the natural sciences. These methods encompass dendrochronology[4], radiocarbon dating (C14)[5], thermoluminescence[6], paper chromatography[7], and other advanced dating techniques, such as the exo-electron method[8], differential thermal analysis[9], and amino acid racemization[10]. Continuous advancements in these techniques expand their applicability and precision.

Numerous analyses are also conducted to complement archaeological excavations, assisting in the reconstruction of past living conditions. Some of these methods hold direct relevance for building research.

4 Dating method for determining the age of the wood used.

5 Weakly radioactive carbon present in nature - produced by cosmic radiation and renewed during the lifetime. After death, the radiocarbon decays. Calculation and measurement of the decayed portions allow for age determination.

6 Starting material: a small amount of radioactive material. During burning, energy escapes through conversion into visible light. The accumulation process can be measured in the laboratory to determine when the material was fired (dating primarily bricks and ceramics).

7 Dating of paint layers using chemical methods.

8 Dating of bones and dental calculus.

9 Age determination of oil paints.

10 Decay process of amino acids in protein-based binders (casein).

Additionally, various scientific and humanities-based methods contribute to building research. These include geology and petrography[11], infrared technology[12], endoscopy[13], anthropology[14], and paleoethnobotany[15], alongside stratigraphy[16], epigraphy[17], archival studies[18], auxiliary historical sciences[19], stylistic analysis[20] (e.g., profiles and ornamentation), and material studies [21]. Together, these interdisciplinary approaches

11 Identification of building materials (limited to stone structures).

12 Non-destructive technique: different heat radiation is visualized, revealing variations in building materials within a structure without causing damage to the object.

13 Details in narrow areas are examined using a lens and a light source attached to a glass fiber cable, which is inserted through a borehole.

14 Examination of population metrics (density, life expectancy, etc.), highlighting the close connection between building research and archaeology.

15 Particularly from excavation findings, plant remains provide insights into vegetation and food supply.

16 Description of layers: In archaeology, cultural layers often correspond to geological strata, but also include plaster and paint layers. A construction chronology is created by assigning dated building components.

17 Historical and cultural sources are revealed through inscriptions, offering clues for dating construction phases (e.g., religious texts, specific verses, dates on construction elements, stonemason marks, brick stamps).

18 Information derived from records, plans, or historical documents (including handwritten primary sources).

19 Historical research not directly linked to written records (e.g., heraldry, sigillography, etc.).

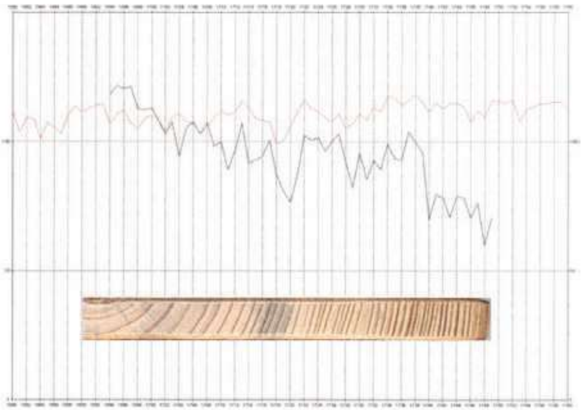
20 Tools of the art historian: aids for interpreting artworks.

21 Knowledge of the development of specific materials and building materials.

A. Hood while taking portable luminescence profiling samples.

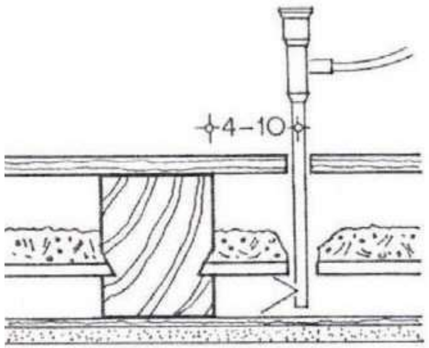
(assisted by A. McCoskey and M. Minotti)

2 | Taking Samples (pOSL), Umm el- Qaab - Tomb Y



3 | Dendrochronological Analysis

4 | Core Sample for determining the Age of the Wood



5 | Examination of a Ceiling with an Endoscope

provide a comprehensive framework for understanding historical structures and their broader contexts.

The work steps are divided into distinct phases. Initially, the preparation for the building investigation takes place, followed by on-site activities, including building surveys and descriptions, photographic documentation (measured drawings using various tools and technical methods). This is then followed by the archiving of collected data.

2.2.1 Preparation for Building Investigation

The process begins with a search for literature, illustrations, plans, and archival materials related to the structure under examination. Reviewing these sources often reveals particularly important questions. However, an unbiased approach is recommended to avoid overlooking or being influenced by previously studied topics.
The investigation starts with a thorough walkthrough of the building, which provides an overview of its structural organization and influences the subsequent workflow.

Following this, a detailed description of the building is undertaken, encompassing everything from the topography and overall structure to its internal configuration. This includes a condition report (current state), which can be carried out alongside the creation of a room book and photographic documentation.

The room book serves as a written record of all findings and observations at the building. It is primarily useful in secular buildings with individual rooms.

In sacred buildings, characterizations must be adapted to the specific conditions. Rooms are numbered and assigned abbreviations, with walls also labeled and correlated to the respective rooms. Precise terminology is important to ensure that future researchers can understand the system and terminology without prior knowledge.

Before conducting any structural analysis, detailed photographic documentation of each room in its current condition is completed.

2.2.2 Building Survey

The building survey involves creating measured drawings of the entire structure, including elevations, sections, and floor plans, represented at an accurate reduced scale. Advancements in technology have expanded the methods available for creating these drawings, ranging from hand measurements to specialized techniques using lasers, CAD systems, photogrammetry, and other devices. Despite the variety of methods, the primary goal remains the same: to provide permanent documentation of the structure and allow comparisons between different findings.

2.2.3 Tools and Technical Methods for Building Documentation

The most commonly used tools for building surveys are outlined. These range from traditional tools such as tape measures, water levels, and plumb bobs to advanced instruments like laser scanners, total stations, and photogrammetry systems, which enable precise and efficient documentation.[22]

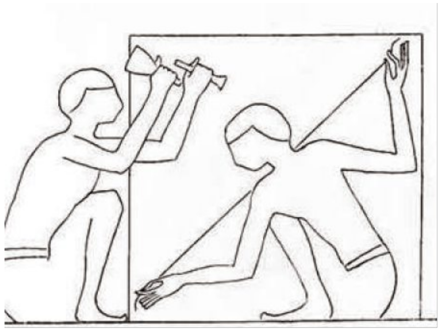
The basics of surveying were already practiced by the ancient Egyptians, who used tools like spirit levels, plumb bobs, strings, and tape measures – instruments that are still taught in architecture studies today. An interesting addition was the water level, a hose filled with water to measure uniform levels across corners and complex layouts. These tools allowed for the creation of precise frameworks for floor plans and vertical sections using triangulations and grids.

Roman surveyors advanced the process with the *groma*, a device for aligning right angles, a concept modern rotary lasers build upon. Though manual, these methods were surprisingly effective for their time, laying the foundation for more precise techniques.[23]

Basic tools commonly used by archaeologists include folding rulers for detailed measurements (up to two to three meters), measuring rods primarily for height measurements (up to 15 meters), tape measures for distances (up to 50 meters), as well as spirit levels and water levels (a hose filled with water) for creating a level reference line across a building.
Modern tools enhance precision and efficiency. A rotary laser can define axes using light beams. A plumb bob, with its iron

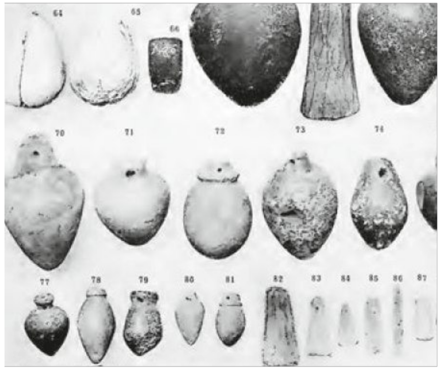
22 GROSSMANN. *Einführung in die historische Bauforschung.* p. 1-77.

23 KAYSER. *Bauaufnahme als unverzichtbares Hilfsmittel bei der Arbeit am Bestand: Vermessenes Projekt.*



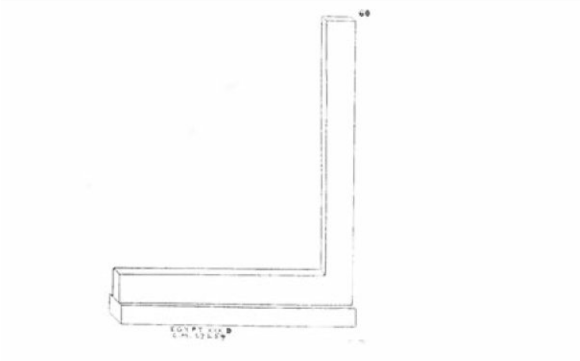
A depiction illustrates the use of a string to determine how much stone still needs to be chiseled away.

6 | Illustration in tomb of Rekhmara



The plumb bob in Egypt was first made with a groove round it, in which to tic the line.

7 | Plumb Bobs



8 | Egyptian Square

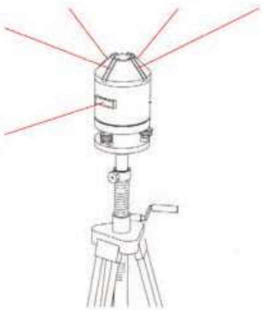
9 | Tachymeter

A leveling instrument allows precise targeting of points that all lie on the same height or horizontal plane.

(TUM;

10 | Leveling Instrument

A horizontal laser projects single laser planes



11 | Laser projecting planes

tip, provides an exact vertical reference. A prism square or angle mirror ensures fixed right angles. A leveling instrument combines horizontal angle measurement over 360 degrees with a telescope, serving as an alternative to the water level. Theodolites integrate horizontal and vertical angle measurements. Modern equipment also includes distance measurement tools and computer-assisted devices.[24]

The invention of the tachymeter in the 19th century marked a milestone in surveying. Its an optical-mechanical instrument, which allowes surveyors to measure points precisely using polar coordinates. However, early versions required complex trigonometric calculations for distance measurements. The introduction of optoelectronic laser distance measurements in the 1980s simplified this process, enabling direct digital input into CAD systems. Modern tachymeters now allow surveyors to create detailed, accurate site measurements efficiently.
Laser scanning, introduced more recently, revolutionized surveying by enabling the collection of millions of points per second. These points, recorded as polar coordinates, form highly detailed 3D point clouds. The scanner rotates horizontally and vertically, capturing everything visible from its position. However, it has limitations: scanners cannot see through walls or around objects, and precision decreases over longer distances. Multiple scans from different positions are required, which are then combined into a single comprehensive model. Despite these challenges, laser scanning is ideal for capturing complex structures quickly.

24 GROSSMANN. *Einführung in die historische Bauforschung*. p.85-86.

Photogrammetry, introduced in the 19th century, interprets geometric data from photographs. It was pioneered by Albrecht Meydenbauer, who sought safer alternatives to scaffold-based hand measurements. Modern photogrammetry, uses digital images to create detailed 3D models. Unlike laser scanning, photogrammetry produces richly textured and colored models but requires reference measurements for scaling. This method is particularly valuable for restoring delicate or decorative surfaces.

Digital advancements have made surveying faster and more accessible. Techniques like laser scanning and photogrammetry are highly efficient but often require complementary methods for detailed measurements. The success of a survey still depends on the expertise of the surveyor, particularly in understanding historical construction techniques. The balance of advanced tools and traditional knowledge ensures that architectural heritage is documented with accuracy and care.

After processing the building survey data, whether through manual measurements resulting in a final drawing (the final drawing being the readable, consolidated elaboration of sketches made on-site into plan materials) or through the processing of data from laser scanners or photogrammetry, will be transformed into plan graphics.[25]

2.3 Evaluation of the Building Survey - Building Analysis

Once all data has been collected, the goal is to analyze and interpret it comprehensively. Historical building research involves identifying and organizing the developmental stages of a structure based on findings and accessible external sources. The objective is to recognize and document all construction and furnishing phases. The building itself serves as the most important source and central object of investigation, forming the basis for every detailed trace analysis.

Methodologically, historical building research can be divided into three key areas: literature and archival research, the survey of the structure through building documentation, and the results of material analysis.

The synthesis of these findings leads to the evaluation of the evidence. The gathered insights are correlated, with the aim of documenting the developmental process of the examined structure from its origins to its current state in a reasoned and comprehensible manner. This includes identifying the specific architectural characteristics of function, form, material, and construction, as well as establishing the chronological order of the construction and, where relevant, destruction phases.

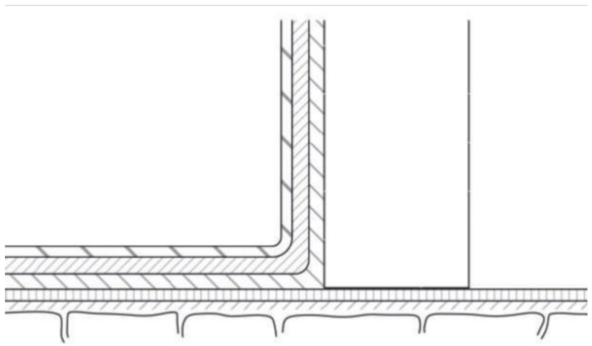
A final report integrates these findings into the broader context of expert knowledge and seeks to communicate the results of historical building research effectively. The report not only reconstructs the building's evolution but also situates its development within a larger historical and cultural framework, making the findings accessible and understandable to both, specialists and the wider audience.[26]

25 KAYSER. *Bauaufnahme als unverzichtbares Hilfsmittel bei der Arbeit am Bestand: Vermessenes Projekt.*

26 RAABE. *Denkmalpflege*. p.29.

12 | Investigation of Color Findings

13 | Examination of Wall and Cealing Layers



14 | Graphic Documentation of Color Layers

Investigation point, marked with a board including information, north arrow, and measuring rod (remains of roof cover)

15 | Investigation Point

Investigation point, marked with a board including information, north arrow, and measuring rod (main chamber Y-KK)

16 | Investigation Point

Investigation point, marked with a board including information, north arrow, and measuring rod (part of wall pilaster)

17 | Investigation Point

Various analytical methods are employed to present the findings. The previously established room numbering system, the room book, and the systematic organization of the building now serve as a framework for analysis. Spaces or structural components (depending on the object of study) are systematically examined. In sacred buildings, as previously mentioned, a tailored structure is advisable. The building is now divided into various structural components, such as walls, floors, and ceiling constructions, which are described and analyzed in detail. [27]

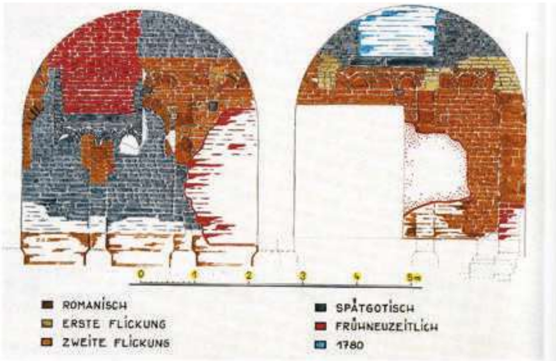
These include techniques such as mapping and construction phase plans. Building survey plans often serve as the foundation for mapping processes. The previously created and measured plan graphics provide an essential foundation for analysis. Key aspects of dimensions, including specific features and proportions, are highlighted in written form. Special characteristics are noted, explained, and contextualized to ensure a comprehensive understanding of the building‘s unique attributes. Additionally, references to literature and archival materials are incorporated to reinforce the analysis and substantiate the findings. The mappings make the various building substances within the structure visible, allowing conclusions to be drawn about the construction phases. Additionally, surface damage caused by environmental factors such as weathering, frost, or moisture is documented. Examples include phenomena like surface sanding, spalling, scaling, or structural damage to the masonry itself.

Analysis of Findings and Findings Catalog. In addition to creating a room book with object numbering, the findings catalog plays a crucial role. A finding represents a structural indication related to construction, age, construction period, or sequence. These clues are systematically collected and compiled into a catalog.[28]

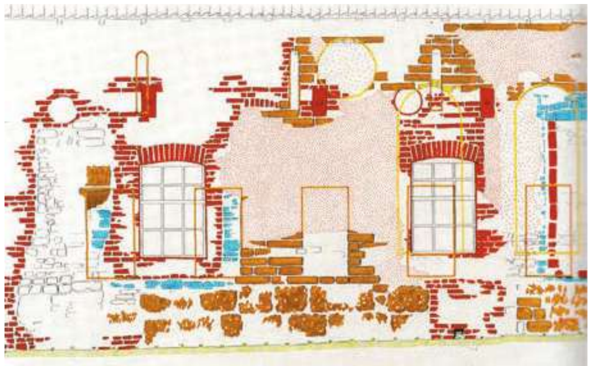
27 KAYSER. *Bauaufnahme als unverzichtbares Hilfsmittel bei der Arbeit am Bestand: Vermessenes Projekt.*

28 TUM. *Bauaufnahme.* p.82,127.

Mapping Characteristic Material

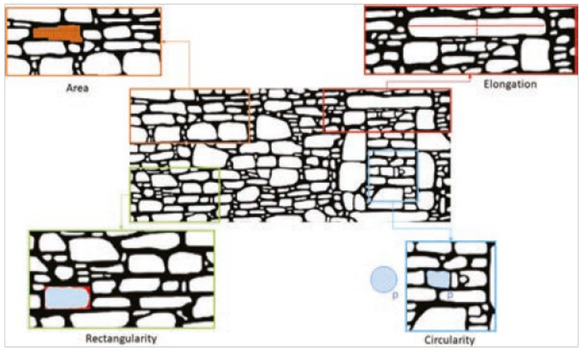


18 | Mapping of Construction Phases

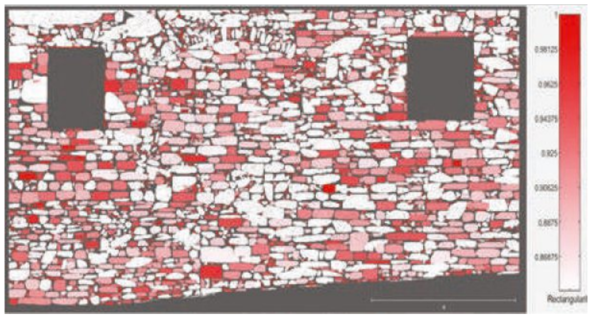


19 | Periodization of Findings

21 | Automated Segmentation of Individual Stones



22 | Illustration of Geometric Characteristics calculated



23 | Indication for Areas shaped Rectangular

When evaluating building surveys specifically for brick constructions, several methods previously described in general terms become clearer through their methodological application.

A comprehensive collection of data is achieved through detailed and well-organized commentary on the findings plans. *Figure 19* illustrates an excerpt from the photogrammetric foundation used to periodize the findings (Swisttal-Heimerzheim-Dünstekoven; former Premonstratensian convent of Schillingskapellen). In this case, not only are the construction phases delineated, as seen in *Figure 18* (former Abbey Church of St. Nicholas), but also reconstructed outlines of the openings assigned to individual phases are included.

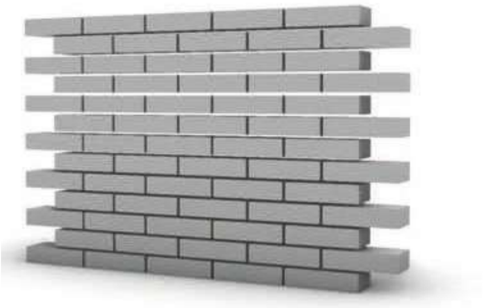
In *Figure 20* (Brauweiler, former abbey) a findings mapping derived from a photogrammetric analysis is presented. Here, the different brick masonry types and their material composition were categorized. This categorization is typically associated with the construction phases.

In addition to plan-inherent commentary, purely graphical tools are also available for describing and interpreting findings. However, these should never be used in isolation but should accompany the written report as a medium that visually clarifies complex relationships. [29]

Algorithms and methods have already been developed to enable the automated selection of individual stones within a wall. The application of this software to a sample section of a rubble masonry wall is demonstrated in the article *Digital Toolkit to Assist the Interpretation of Traditional Masonry Construction*, with individual stones distinctly coloured for identification. These masonry units are subsequently projected onto a plane tangential to the wall's surface, creating a binary orthoimage of the segmentation, as illustrated. The detected stones are then categorized based on the characteristics automatically extracted from the segmentation process. [30]

29 KNOPP, NUSSBAUM, JACOBS. *Bauforschung: Dokumentation und Auswertung*. p.123-127.

30 FORSTER, VALERO, BOSCHÉ, HYSLOP, WILSON. *Digital Toolkit to Assist the Interpretation of Traditional Masonry Construction*. p.7-8.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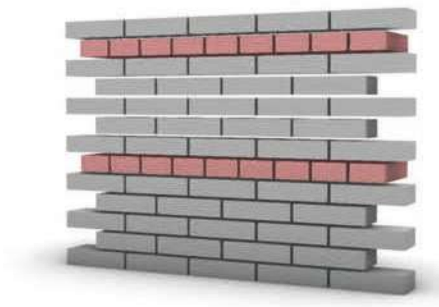
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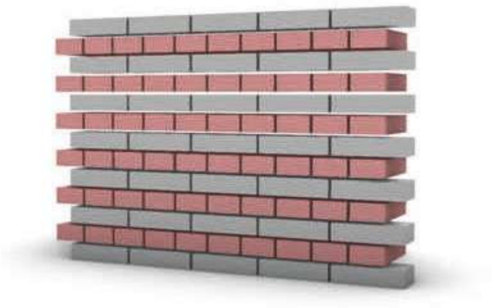
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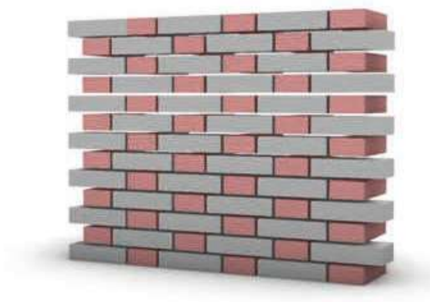
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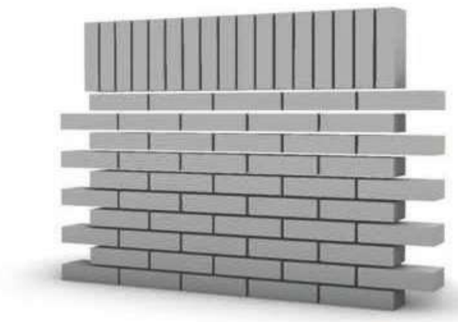
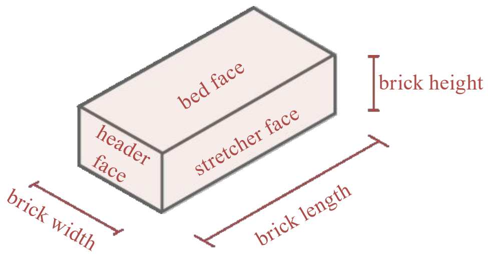
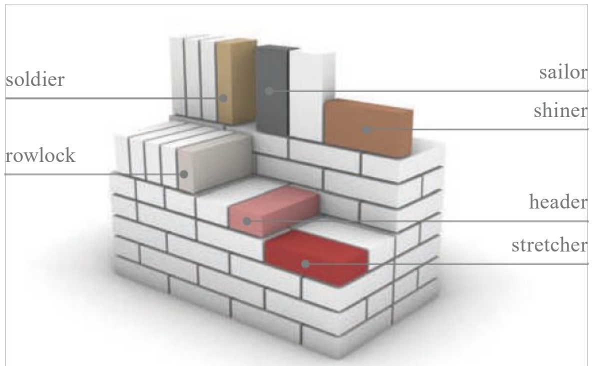

6.

1. strecher bond
2. common b.
3. english bond
4. flemish bond
5.stack bond
6. soldier course with stretcher bond



25 | Standard Brick Designations



26 | Brick Terminology

2.3.1 Brick Terminology

There are different types of bricks, such as mud brick, fire brick, clinker, and many more. These differ mainly in manufacturing processes, dimensions, and materials. Generally, a brick is a unit of a bond that is formed from a material and shaped into a specific form. The standard brick is shaped as a rectangular prism.

The standard brick consists of a brick length, brick width, and brick height. The surface resulting from the length multiplied by the width is called the bed face, the surface resulting from the length and height is called the stretcher face, and the surface resulting from the width and height is called the header face.

Different terms for bricks exist based on how they are positioned within the bond. The term refers to their specific placement.

A stretcher is a brick that lies horizontally in the wall with the long, narrow side parallel to the wall surface and rests on the bed face. A header is a brick where the short, narrow side is visible on the wall surface, with the brick resting on the bed face. A rowlock also has the narrow side visible, but it rests on the stretcher face. A soldier is a brick where the long narrow side is visible and rests on the header face. A sailor is a brick that shows the bed face side and rests on the header face. A shiner/bull stretcher rests on the stretcher face and shows the bed face side.
A bond is a composition of units that forms a regular, recognizable, and usually overlapping pattern.
When units (bricks) are laid together, they form a course, meaning the individual layers of a masonry structure are called courses. These courses together form a bond.

There are many different bonds, such as the English bond, Flemish bond, Common bond, and many others. In the English bond, headers and stretchers alternate layer by layer, with the headers placed centrally over the joints of the stretchers. In the Flemish bond, headers and stretchers alternate within each course, with the headers always placed centrally over the stretchers. The common/american bond consists of one header course between 5-6 stretcher rows. When stretchers are laid exactly on top of each other, with the joints aligned, it is called a stack bond. [31,32]

31 KUMMER. *Basics Masonry Construction*. p. 8,9,18.
32 CHING. *A Visual Dictionary of Architecture*. p. 18-20.

2.3.2 Point of Investigation for Masonry

Image rectification is crucial for establishing a foundation for mapping. By ensuring the accuracy of the images, specific areas of measurement can be supplemented or even replaced. Targets are affixed to the object and measured for rectification. In the software, the image is then rectified by aligning the targets on the image with the data collected on-site.

When conducting photogrammetry, there is the option to create orthophotos. This removes the necessity for separate image rectification, as the orthophoto provides the required foundation.[33]

Particularly in masonry analysis, significant conclusions about the construction can be drawn. The room book outlines investigation points essential for construction analysis. The information is presented objectively and neutrally. The investigation points of the masonry include, among others:

33 TUM. *Bauaufnahme*. p. 71,72.

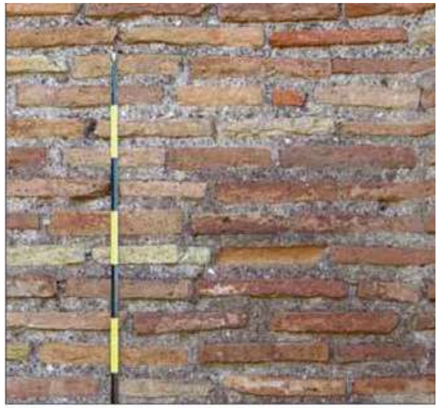
- Masonry structure (bond)
- Displacement of the stone material
- Material and format (brick dimensions)
- Mortar
- Visible damages

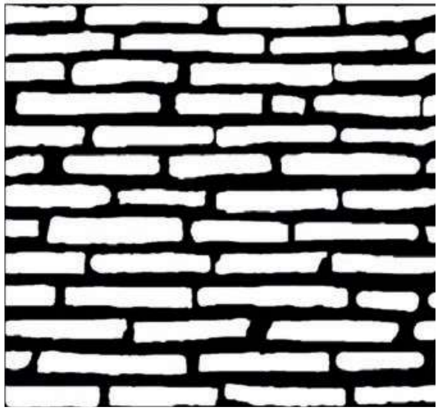
Typically, a elevation view of the wall is presented with the investigation points located. Subsequently, a detailed, objective description is provided, often accompanied by an interpretation indicating possible construction phases.[34]

To illustrate an example, *Figure 27* shows one of several masonry sections of roman masonry being investigated. The basis for this is a representation of a masonry section at a scale of 1:10 in photogrammetric processing and after segmentation (visible brick, mortar). Data was recorded, including brick dimensions (average, minimum, maximum), number of bricks, brick and mortar percentages, mortar color, materiality, and arrangement. This enables the comparison of data from different masonry structures.[35]

34 EULER-ROLLE, HAUSER, LIEBICH, MORAVI, SCHICHT. *Richtlinien für Bauhistorische Untersuchungen*. p. 39,78.

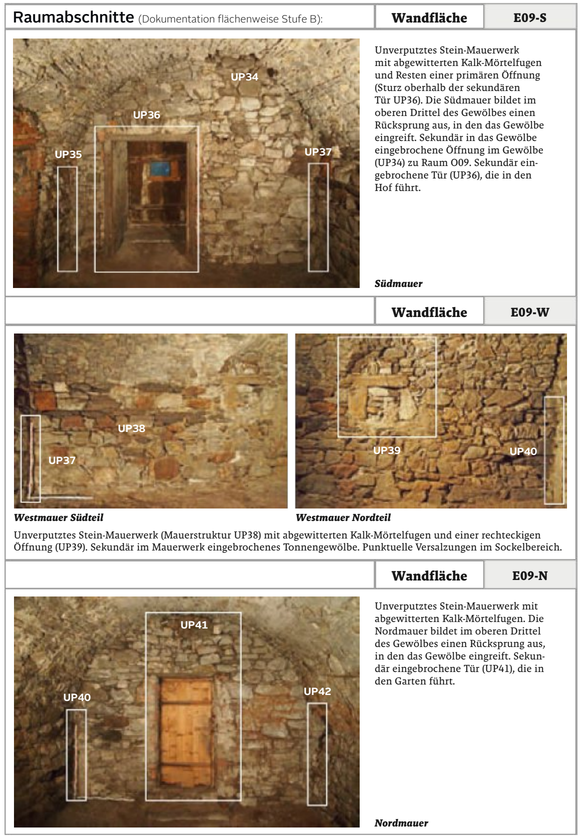
35 ESSER. *Opus Testaceum : Untersuchungsmethode zur Rekonstruktion einer Chronologie der kaiserzeitlich-stadtrömischen Ziegelmauerwerke*. p.213.





no scale
Example of an analysis of a masonry section

27 | Example Masonry Section for Analysis



Raumabschnitte (Dokumentation flächenweise Stufe B):	Wandfläche	E09-S
Unverputztes Stein-Mauerwerk mit abgewitterten Kalk-Mörtelfugen und Resten einer primären Öffnung (Sturz oberhalb der sekundären Tür UP36). Die Südmauer bildet im oberen Drittel des Gewölbes einen Rücksprung aus, in den das Gewölbe eingreift. Sekundär in das Gewölbe eingebrochene Öffnung im Gewölbe (UP34) zu Raum O09. Sekundär eingebrochene Tür (UP36), die in den Hof führt. *Südmauer*		
	Wandfläche	E09-W
Westmauer Südteil *Westmauer Nordteil* Unverputztes Stein-Mauerwerk (Mauerstruktur UP38) mit abgewitterten Kalk-Mörtelfugen und einer rechteckigen Öffnung (UP39). Sekundär im Mauerwerk eingebrochenes Tonnengewölbe. Punktuelle Versalzungen im Sockelbereich.		
	Wandfläche	E09-N
Unverputztes Stein-Mauerwerk mit abgewitterten Kalk-Mörtelfugen. Die Nordmauer bildet im oberen Drittel des Gewölbes einen Rücksprung aus, in den das Gewölbe eingreift. Sekundär eingebrochene Tür (UP41), die in den Garten führt. *Nordmauer*		

28 | Example Room Book with Investigation Points of Masonry

The representations in this chapter serve as examples of the application of various methods across different buildings or initial conditions. The selected methodologies are applied both to buildings where the primary objective is restoration, and in archaeology, where the goal of the investigation is to uncover valuable insights into past history.

Regardless of the discipline or the reason for the analysis, the objective remains consistent: these methods are employed across a broad spectrum to produce meaningful and coherent results.

The core process always follows the same structure. First, literary information about the target object is gathered to establish a foundational basis. Subsequently, on-site work begins, during which the object is surveyed and documented. This includes the creation of lists, such as investigation points (extraordinary features of the structure or object) and room books.

At last, the data collected is used as a tool for further processing. The plans produced serve as a foundation for analytical methods, such as cartographic representations, which, accompanied by explanatory texts, function as a medium. These materials are embedded into a framework consisting of plans, findings, and documentation, which are synthesized into a cohesive unit.

The choice of methodology for surveying the objects, converting the data into plan material, and dating the objects is left to individual discretion, as qualitative differences can arise depending on the methods selected.

3

DIGITAL DOCUMENTATION THROUGH PHOTOGRAMMETRY

3.1 Photogrammetry as Measurement Tool

The purpose of photogrammetry is to reconstruct an object in terms of its position and elevation using photogrammetric images. Photography serves as a measurement tool, providing a method based on the perspective properties of the photographic image. A photograph offers a realistic and vivid representation of the recorded object, which plays an essential role directly and indirectly in measurement processes. Geometrically, the image represents a plane that reflects the perspective of the object. This means that the flat surface of the image and the three-dimensional object are connected by straight lines that converge at a single point, known as the perspective center.

The perspective relationship between the image and the object follows certain rules: for instance, straight lines on the object are depicted as straight lines in the image, and parallel lines on the object extend toward a vanishing point in the image. These fixed perspective relationships are crucial for correcting distortions and creating an accurate final product.[36]

36 FINSTERWALDER. *Photogrammetrie.* p.22.

The master‘s theses by Sara Treccarichi Scavuzzo, titled *Immersive Experience of Ancient Architectural Heritage and Related Historical Events - Reconstruction and Visualization of the Fire Incident at the Tomb of First Dynasty Egyptian Queen Meret-Neith in Abydos*, and by Florian Sövegjarto, titled *Augmented Presentation of Historical Architecture Using the Example of the Tomb of Meret Neith in Abydos*, place a particular emphasis on the digital documentation of the tomb chamber through photogrammetry. Both authors were integral contributors to the overarching project and successfully obtained their master‘s degrees through these works.
These studies serve as valuable references and form a foundational basis for the subsequent chapter, offering both methodological guidance and critical insights.

Photogrammetry offers the advantage of creating accurate, to-scale virtual representations of structures, which can be easily accessed for analysis and study. While high-resolution models require specialized equipment for inspection, a standard resolution is sufficient for most applications, providing an efficient means of visualization.

29 | Chart X-Rite; ColorChecker Classic

BEFORE

COLOR CALIBRATION

30

AFTER

COLOR CALIBRATION

31 | Wall Surface; Tomb Y

It plays a vital role in preserving cultural heritage by creating detailed digital models of original structures, which can be explored without risking damage to the actual site. These models are crucial for building-historical analysis, offering unrestricted access, sectional views, and insights into construction techniques, materials, and craftsmanship. By combining accurate representation and accessibility, photogrammetry helps protect and preserve cultural heritage for future study.

3.2 Data Capture and Post-Processing

Key aspects need to be defined before the data capturing and post-processing. Understanding the object and its surroundings is crucial for achieving optimal results. Factors such as barriers, vegetation, terrain structure, and accessibility can affect capturing the object effectively. In addition, the time factor, the available equipment and size of the object determine the resulting level of detail of the images.

3.2.1 Capturing Images Methods

Photographs suitable for 3D reconstruction can be taken with any digital camera, provided specific guidelines are followed to ensure high-quality results. Proper planning of the photo session is essential for optimizing data collection. Cameras with a resolution of five megapixels or higher are recommended, and lenses with focal lengths between 20 and 80 mm are preferred, as ultra-wide-angle or fisheye lenses may distort images. Fixed lenses are more consistent, and if zoom lenses are used, the focal length should remain constant. Camera settings should prioritize quality, with RAW images converted to TIFF to avoid compression noise. To minimize noise, keep the ISO value low, and use a fast shutter speed, especially when shooting handheld. Since the photos were taken in the desert, exposure was optimal, and no additional settings were needed on the iPhones. Reliable EXIF data ensures better calibration during reconstruction, and lens distortion should be modeled accurately using the Camera Calibration dialog.[37]

Achieving consistent color reproduction in photography is challenging due to variations in how different cameras and lenses capture and interpret colors. Custom profiles, such as DNG or camera profiles, help mitigate these inconsistencies. Incorporating a

37 AGISOFT. *Agisoft Metashape User Manual [...]*. Chapter 2.

ColorChecker Classic target during photo shoots improves workflow consistency and reproducibility. Placed in the same lighting conditions as the subject, it serves as a reference for analyzing color accuracy across various systems.

Additionally, setting a manual white balance aligns the color temperature with the specific lighting at the location, further enhancing color fidelity. [38]

The object and scene to be reconstructed require careful consideration. Non-textured, reflective, or transparent surfaces are unsuitable for accurate photogrammetry. If reflective objects must be photographed, overcast conditions are preferable. Foregrounds and moving objects within the scene should be avoided, and flat surfaces should be documented from multiple angles to ensure completeness.

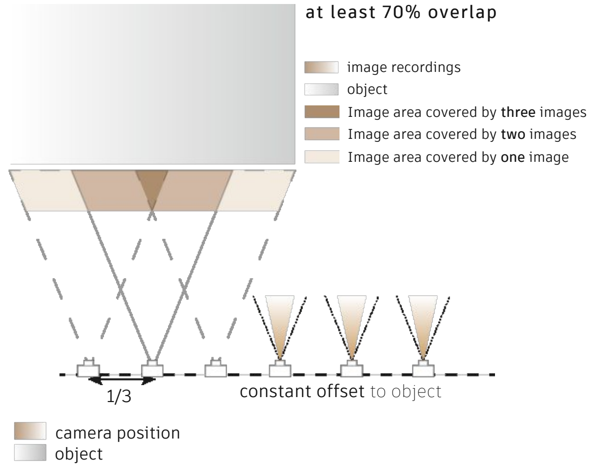
(1.) Capture strategies depend on the object and environment. Ensuring at least 70% overlap between images in all directions is critical for reliable 3D modeling. For aerial photography 80% forward overlap and 60% side overlap are recommended.

To capture interiors or facades, images should be systematically taken parallel to surfaces or using offset paths to document corners comprehensively. Blind zones must be minimized, and the object should occupy the majority of the frame. Proper lighting without glare or flash is essential, and measurement markers should be placed if the reconstruction requires spatial referencing.

(2.) Different strategies are employed in photogrammetry to optimize image capture. Parallel recording involves systematically capturing images parallel to the object's surface to maintain consistency. Offset recording follows the contours of the object, with particular attention to features such as corners or indentations. When documenting corners, the camera must be positioned parallel to the wall and moved fully to the edge to prevent the loss of 3D data. Subsequently, semicircular paths around corners can be used to capture all angles and positions with maximum precision, ensuring comprehensive documentation of the object's geometry.

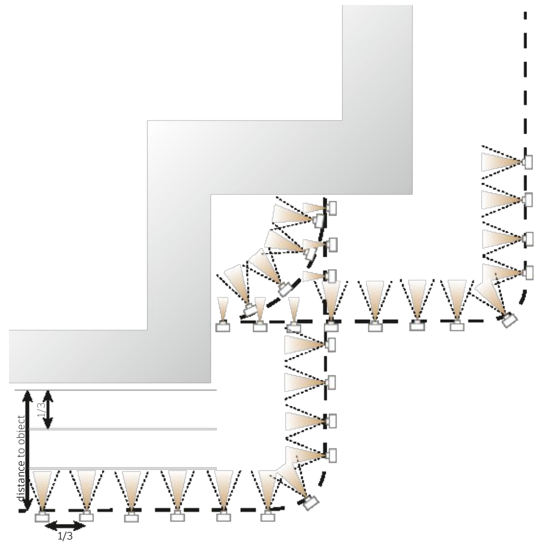
38 X-RITE. *User Manual ColorChecker Passport*. p.4,12.

1.



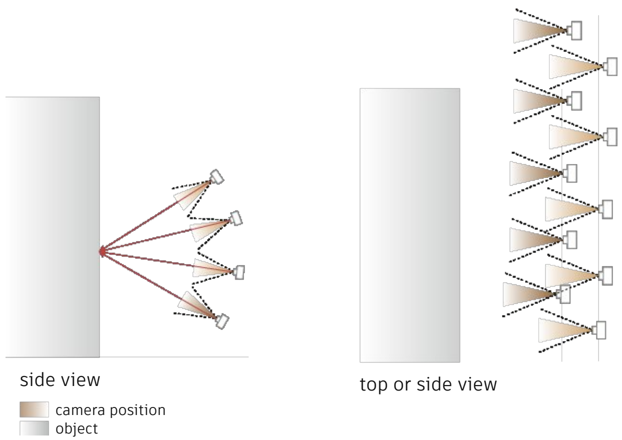
32 | Graphic; Method Image capturing

2.



33 | Graphic; Method Image capturing

3.



34 | Graphic; Method Image capturing

(3.) Tilting the camera is a helpful technique to enhance object capture. For uneven surfaces, a strictly parallel capture may be insufficient. By tilting the camera, even the undersides or indentations can be effectively captured. Additionally, it is beneficial to create two layers: one closer to the object and another at a greater distance. This approach facilitates alignment and ensures a high level of detail.

Ensuring sharp and clear images for a good outcome, blurry images will have troubles to align properly in the post-processing part. Furthermore, Objects with smooth, shiny or transparent surfaces are not suitable for photography as software struggles to register such textures, which prevents proper alignment and linkage of images.
Photogrammetry software operates objectively, focusing on distinct points rather than recognizing objects. Therefore, factors like changing lighting conditions (e.g. sun reflections) causing cast shadows. Ideal conditions for photogrammetry are cloudy weather with diffuse light.[39]

3.2.2 Workflow of Capturing Images

When preparing equipment for fieldwork, ensuring all batteries, cameras, self-timer devices and storage media are fully charged and packed is essential. It should manage the large volume of high-resolution images typical in photogrammetry.Backing up data on multiple hard disks in different locations reduces the risk of data loss.

In scenarios where time is limited and it's a onetime chance to have access to the sight, losing data can lead to significant complications and time-consuming rework. Ensuring consistent weather and lighting conditions during image capture is critical for software to effectively merge data. In addition, it is recommended to calculate initial models in low resolution on site, because it allows early verification of data adequacy.

39 AGISOFT. *Agisoft Metashape User Manual [...]*. Chapter 2.

For example, when recording walls, a path should be recorded from top to bottom, parallel to the wall, and another path with the camera tilted upwards. The copings of the walls can be represented as cylinders.

This approach is useful for capturing any break-out areas of masonry, which can be photographed by following the outline of the structure in circular movements. Finally, overview photos should be taken of the entire area to create a general framework, which serves as a basis for organizing the more detailed photos.

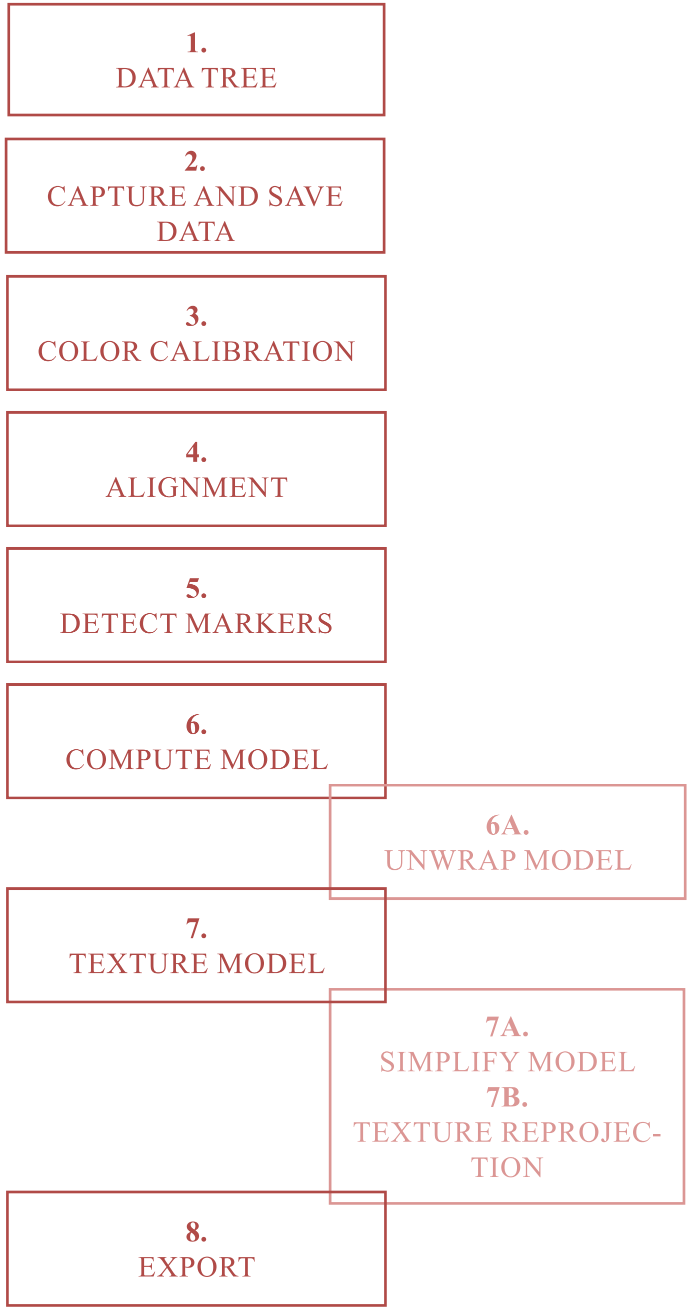
It is advisable to always start at the same point, for example such as the upper left corner (northern point), to maintain proper orientation. When the objects are very similar or monotonous, it can be easy to lose track. Creating systematic paths for the areas helps prevent overlooking certain regions.

It is recommended to take pictures from top to bottom and from bottom to top. Without a tripod to set up on the floor, it can be difficult to maintain a consistent height throughout the entire recording.

Two paths should be created: one parallel to the wall and another with a slight pivot. Capturing a path with the camera pivoted is particularly advisable, as the surface structure may be uneven, and minimal bumps can be captured more effectively with the pivot.

The top of walls and breakout areas can be captured using semi-circular movements. Additionally, internal holes can be photographed to create a more detailed basis. A compact camera can be used in these cases, as it can be partially held inside the holes to capture the necessary angles.

In the final step, overview pictures with and without targets should be captured to provide both a general context of the area and precise reference points for alignment. This helps provide a clear, scale-accurate representation of the entire scene.



3.2.3 Workflow of Post-Processing

1. Data Structure (Data Tree)

The importance of maintaining a structured workflow cannot be overstated. A well-organized data hierarchy that reflects the project workflow ensures efficiency and clarity. Developing a structured data tree is essential for correctly storing and organizing image data.

Date_Component/ChamberNumber_[Detail]

- Date_Component_[Detail]_Images
    - Date_Component_RAW
        - Date_Component_Target
        - Date_Component_NoTarget
        - Date_Component_ColorChart
    - Date_Component_JPG

- Component_[Detail]_RC
    - Date_Component_RC-file
    - Date_Component_distance-file

- Component_[Detail]_Export
    - Date_Component_RC-obj
        - Date_Component_RC-export-simplified
        - Date_Component_RC-export

2. Data Capture

During on-site data acquisition, it is crucial to use a color calibration chart regularly. This step ensures accurate color representation in the captured images. The files should be systematically saved directly within the designated folders of the data tree to maintain consistency and facilitate subsequent workflows.

3. Generate Color Calibration

Using a color calibration passport on-site is vital for ensuring realistic color accuracy in the data. The color checker images captured can be processed with a software to generate calibration profiles. These profiles are later applied to the captured images, ensuring accurate and consistent calibration across the dataset.

4. Alignment

Image alignment, also known as registration, involves detecting image features and identifying tie points to generate a sparse point cloud. During this process, the software calculates camera positions, orientations, and intrinsic parameters for every captured image. Images that share sufficient overlap and recognizable features are grouped into a component. This ensures precise alignment, laying the foundation for further reconstruction processes.

5.Detect Markers

The software can automatically identify circular, single-ring markers that have been strategically placed within the scene prior to image capture. This automated process facilitates the placement of control points across the dataset.

6. Compute Model

Models can be reconstructed in various levels of detail, such as preview, normal, and high. Higher levels of detail, such as normal and high, require more computational power and time but yield dense point clouds and meshes. Unlike the sparse point cloud from the alignment phase, this dense point cloud consists of vertices from the reconstructed mesh and forms the basis for texturing and further analysis.

6a. Unwrap

Unwrapping is a crucial step for generating UV maps, which serve as 2D representations of 3D objects. These maps are necessary for applying textures to the model. The unwrapping process can be performed before texturing. If adjustments are required, the Unwrap tool can be used to recompute new UV maps.

7.Texture

Texturing significantly enhances the visual quality and is widely utilized in many industries. This process generates image files that include detailed color information for all polygons of the model. These textures are applied to the UV maps, creating a high-quality and realistic representation of the object. Texturing is an integral step in ensuring the final model meets both aesthetic and functional requirements.

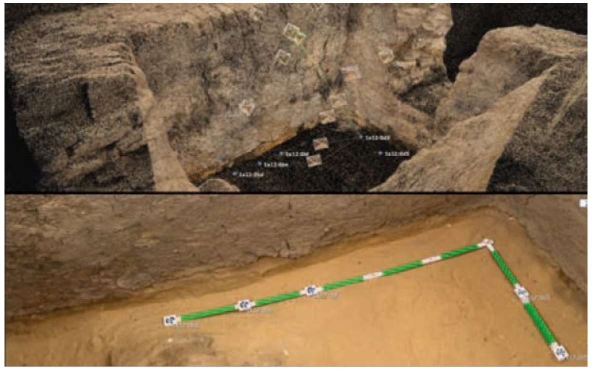
7 a,b: Simplify Model and Texture Reprojection

The simplification process reduces the polygon count of the model, creating a low-poly version. High-resolution textures can then be reprojected onto this simplified model, striking a balance between file size and visual quality. Although this step reduces the size of the exported file, some loss of quality is inevitable.

35 | Sparce Cloud and Camera Positions

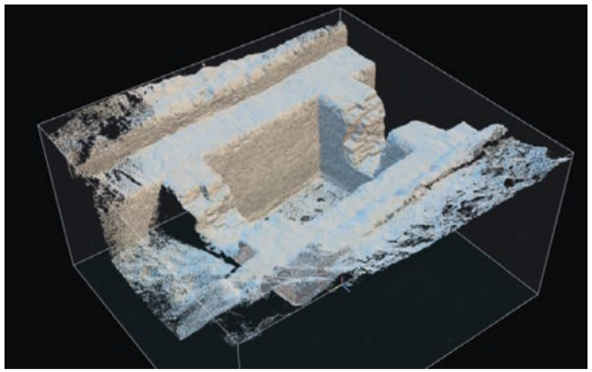
36 | Sparce Cloud and Camera Positions

37 | Sparce Cloud

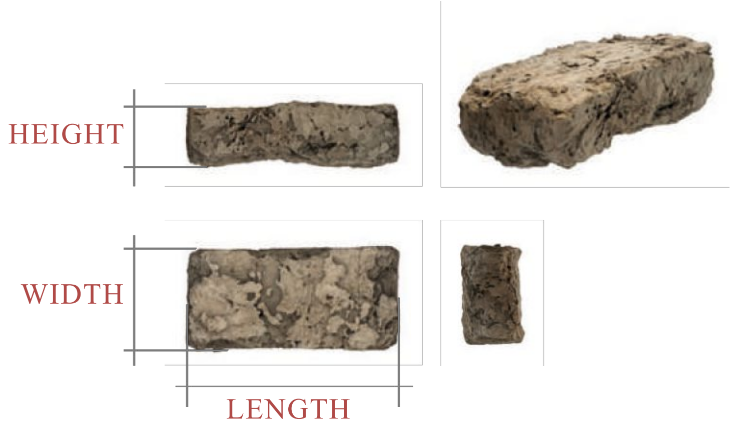


38 | Sparce Cloud and detected Targets/Markers

39 | Ruler with Circular Targets every 20cm



40 | Dence Mesh and Point Cloud



41 | Example Photogrammetry: Mudbrick (Tomb Y)

8. Export

The final model is typically exported in OBJ format. During export, it is essential to ensure that the file names align with the established data tree and naming conventions. This practice maintains consistency and ensures that the data can be easily accessed and understood within the broader workflow.[40]

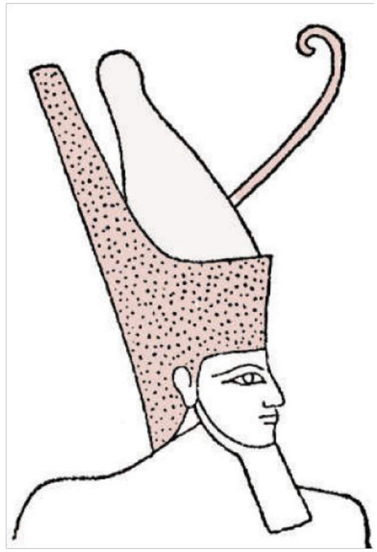
Finally, the architectural analysis can be conducted based on the 3D model. This includes a variety of methods such as stratigraphic mapping and the description of architectural elements and findings. The created model of Meret Neith's tomb serves as the sole foundation for this analysis. Elevations, floor plans, sections, and unfolded views will form the basis for describing the structure in detail and explaining its construction. These representations function as accompanying media to support the interpretation.

To provide an understanding of the structure and the mudbrick construction, the following chapter will outline the general development of mudbrick architecture in ancient Egypt. This serves as an introduction to the detailed analysis of tomb complex Y.

40 CAPTURING REALITY. Platform: *RealityCapture Help Center*.

4

HISTORICAL CONTEXT OF MUDBRICK CONSTRUCTION IN EGYPT



42 | Red Crown (Deshert)

43 | White Crown (HeWadji)

44 | Map of Egypt

45 | Double Crown (Sekhemti)

4.1 The Rise of Early Egyptian Civilization and State Formation

Periods of intense dryness forced populations to settle near the Nile, where annual floods provided fertile land suitable for agriculture.[41]
Early architecture was rudimentary, consisting primarily of mud huts and wattle constructions. Nomadic groups initially settled in small clusters, resulting in modestly built villages. Burial practices also began to take shape, with individuals placed in pit graves in a fetal position, wrapped in linen or animal skins. This simple form of burial, particularly common among lower social classes, persisted for an extended period.
Abydos was the center of the prehistoric Naqada culture and flourished during the fourth millennium BCE *(Figure 44)*.[42]

By around 3400 BCE, Egypt rapidly transitioned from an advanced Neolithic culture to two organized monarchies - one in the Delta and the other in the Nile Valley. This period witnessed the emergence of writing, monumental architecture, and refined arts and crafts, reflecting a well-structured and affluent civilization. The abrupt nature of this transformation suggests the arrival of a new group in the Nile Valley, bringing distinct cultural influences that accelerated Egypt's development.

During the historic period, Egypt was divided into two rival kingdoms: Lower Egypt, with its capital at Buto, and Upper Egypt, centered in Hierakonpolis. Despite their differences, Political unification, integrated Egypt into a single state. This consolidation provided the resources and stability necessary for rulers to commission monumental architecture, not only as an expression of state power but also to support religious institutions. This period saw significant advancements, including the appearance of complex writing systems and sophisticated architectural forms, which seem to have emerged without a clear evolutionary precedent.[43]

This unification was a gradual process, achieved through both peaceful means and military conflict. The final leader of this unification effort was King Narmer, who played a decisive role in consolidating Upper Egyptian control over the Delta.[44]

41 HENDRICKX, VERMEERSCH. *Prehistory* in *The Oxford History of Ancient Egypt*. p. 17-41.

42 MIDANT-REYNES. *The Naqada Period* in *The Oxford History of Ancient Egypt*. p. 49.

43 EMERY, *Archaic Egypt*, p. 38

44 DREYER. *The tombs of Abydos*, p.55

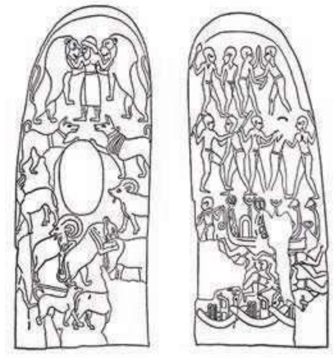
4.2 Urban Development

In ancient Egypt, everyday structures such as houses, animal enclosures, city walls, and fortresses were primarily constructed from mudbrick, a material well-suited to functional and climate-responsive architecture. In contrast, temples and tombs, built for eternity, were constructed from stone. Despite these material differences, sacred and secular architecture shared common origins, as principles from mudbrick and wooden structures were later adapted to stone construction.

The ephemeral nature of mudbrick buildings has contributed to a misunderstanding of their role in Egyptian architecture. Villages and cities, typically located in the fertile but flood-prone Nile Valley, suffered from rising groundwater levels, periodic flooding, and erosion, leading to the near-total disappearance of mudbrick structures over time.

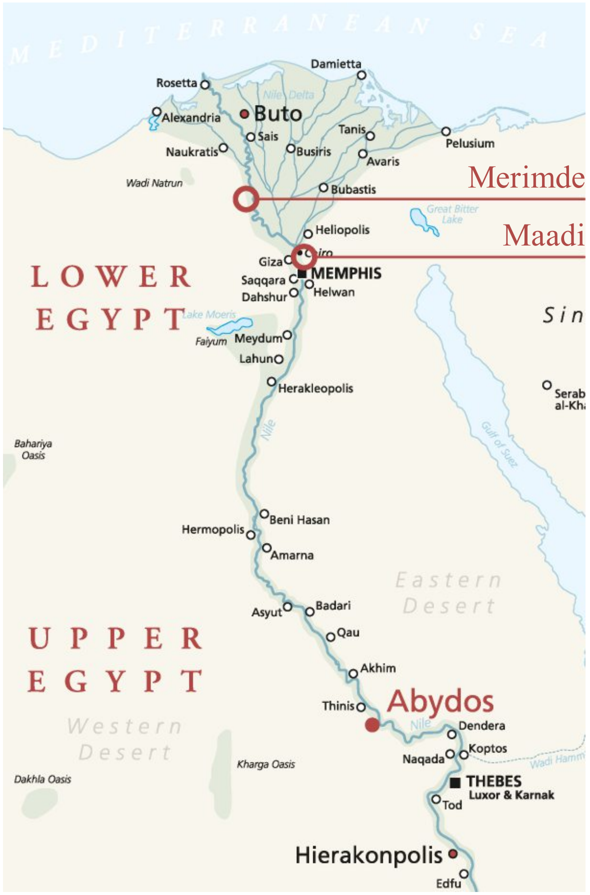
Settlements were generally established near water sources, often on elevated ground for security. They exhibited little distinction between residential, defensive, and economic spaces, as all were constructed using the same materials, with only religious buildings receiving particular architectural emphasis. The survival of these communities depended on collective labor, which included agriculture, the maintenance of buildings, and protection against environmental and human threats. Mudbricks flexibility as a material enabled advancements in urban planning, such as the construction of extensive irrigation systems, ventilation structures, and mills, showcasing the resourcefulness of these societies. However, settlements relying on mudbrick often faced resource scarcity, particularly in protein-rich food, leading to the expansion of trade networks. These societies maintained simple yet highly labor-intensive social systems, which required constant upkeep and left little room for alternative lifestyles. This dependency made them vulnerable to collapse and, at times, exploitation.

The structural characteristics of mudbrick settlements were dictated by material limitations. Buildings were arranged in dense, terraced formations, with walls reinforced at intervals of three to four meters. Particularly tall walls were stabilized by incorporating towers or transverse structures. The dimensions of interior spaces were determined by the length of wooden beams used as ceiling supports, influencing the

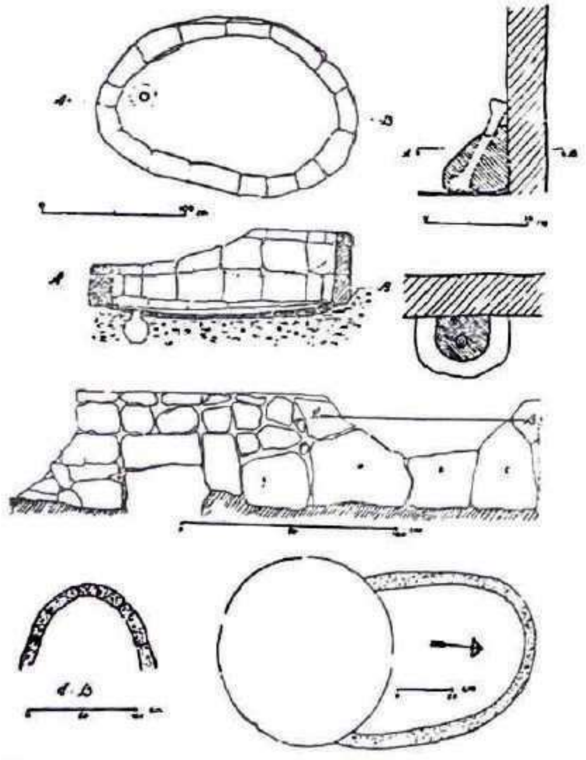


Knife-handle from Gebel-el-Arak. Mesopotamia origin found in Hieraconpolis

46 | Knife - Handle; Mesopotamia



47 | Map of Egypt



48 | Hut (Merimde)

Riemchen construction in Uruk/ Warka (Iraq) Elongated brick with a square cross-section circa 3000 BCE

49 | Mudbrick Construction, Uruk (Iraq)

uniformity of layouts and architectural elements such as door and window placement. These spatial configurations, shaped by the constraints of mudbrick construction, defined the characteristic appearance of Egyptian mudbrick architecture.[45,46]

4.3 Influence on Architectural Development

Large-scale brick structures first appeared in early dynastic mastabas at Saqqara and Naqada, as well as in the royal tombs of Abydos, demonstrating advanced architectural techniques and the skilled use of materials. However, the widespread adoption of brick construction may have been influenced by external sources, as earlier Nile Valley communities did not commonly employ large-scale brickwork.

Artifacts such as slate palettes, ivory labels *(Figure 46)*, and mud sealings suggest a possible Mesopotamian influence that contributed to a phase of rapid architectural development.[47]

The development and spread of mudbrick architecture in Egypt remain subjects of ongoing research, particularly regarding whether the technology was influenced by external regions such as the Levant and Mesopotamia or developed independently. Evidence from Maadi, Buto, and other Chalcolithic sites in Lower Egypt (early 4th millennium BCE) suggests early brick enforcement and the use of decorative nails, similar to Mesopotamian influences. The earliest evidence of brick construction in Mesopotamia dates back to the 9th millennium BCE, indicating a long-established tradition of mudbrick building in the Near East.

Finds from Merimde (5000–4100 BCE), suggest early construction techniques using three-meter-wide structures, possibly filled wooden frames with mud lumps *(Figure 48)*. These may represent a transitional phase leading to true mudbrick construction. By 4000 BCE, hand-shaped bricks, or cob bricks, appear in some examples. Egyptian evidence shows a division between hand-shaped brick construction in the Nile Valley and molded brick architecture in the Delta, but the transmission of technical knowledge remains unclear - whether through stylistic features, production methods, or construction techniques.

45 WIENANDS. *Zum Lehm als Baumaterial* in *Architektur der Vergänglichkeit [...]*. p. 11-26.

46 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit [...]*. p. 26-30.

47 SPENCER. *Brick Architecture in Acient Egypt.* p.5ff.

The evidence from Maadi (3900–3500 BCE) is limited and ambiguous; it is uncertain whether the structures were made of bricks or cut earth blocks, possibly representing a precursor to true mudbrick construction. Brick dimensions and bonding techniques in Maadi differ from those in the Levant. Light construction architecture, including semi-subterranean structures, has been found at Maadi.

At Tell el-Iswid, earth-based construction elements with gypsum coatings on plant panels were more common than mudbrick fragments, especially for grave pit fillings. This suggests that both mudbrick and lightweight construction techniques coexisted. In Hierakonpolis (Upper Egypt), evidence includes reed mat fences covered with earth, while Buto (Naqada III) shows clearer signs of mudbrick use. However, in Adaïma, despite being an inhabited site, mudbrick remains are scarce, raising questions about the continuity of brick architecture in Upper Egypt.

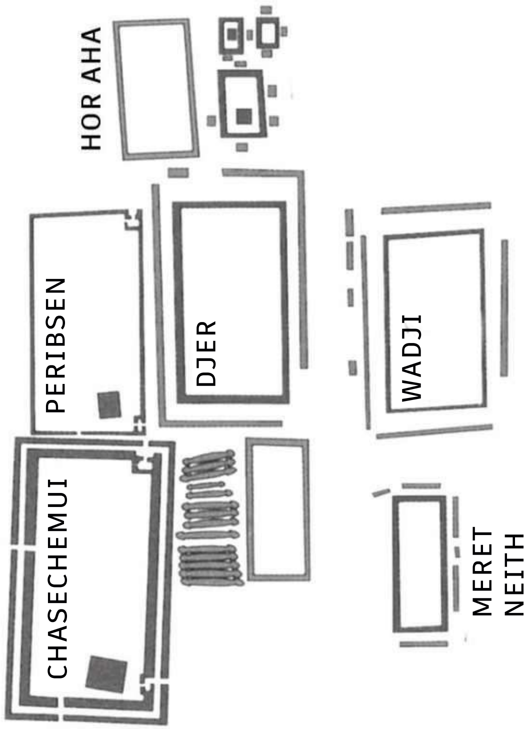
The earliest confirmed evidence of mudbrick in Upper Egypt comes from Hierakonpolis, where both hand-shaped bricks and clay lumps were used. At the same time, Southern Levant introduced molded bricks during the Early Bronze Age, accompanying the rise of urbanization. In Lower Egypt, brick architecture appears in the second third of the 4th millennium BCE, with Upper Egyptian construction techniques influencing Lower Egyptian brick dimensions. The standard size was twice as long as its width, with the stretcher-header technique indicating the use of molds.

A chronological analysis suggests that mudbrick use in the Delta followed soon after hand-formed brickwork in Hierakonpolis but preceded the construction of the U-j tomb at Abydos. The U-j tomb contains numerous Levantine grave goods, confirming trade connections. Similar practices and architectural concepts appear in distant Uruk-period Mesopotamia, while Levantine sites also share identical artifacts. This suggests that early trade networks may have initially influenced Lower Egypt, with mudbrick technology spreading to Middle and Upper Egyptian settlements by the mid-4th millennium BCE. The presence of terracotta cones in Buto, closely resembling Uruk examples, and decorative nails further indicate a potential Mesopotamian connection.

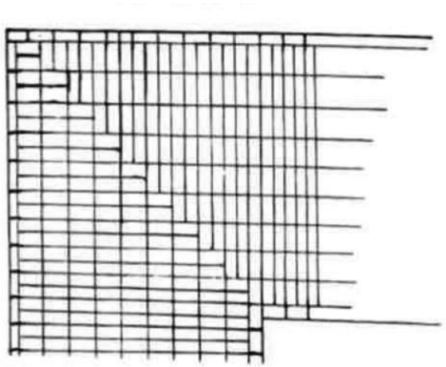
50 | Schunet el-Zebib, Abydos (Chasechemui)

The vast rectangular enclosures, surrounded by brick walls and still preserved nearly 5,000 years after their construction around 2700 BCE, are part of the royal tombs of the 1st and 2nd Dynasties in Abydos. The function of the monumental structures remains unclear.

51 | Schunet el-Zebib, Abydos (Chasechemui)



52 | Schematic Plan of the Valley Districts (Abydos)



53 | Corner Bonding in Typical Mastaba

Ongoing research investigates whether mudbrick technology was imported from the Near East before the second half of the 4th millennium BCE or independently developed in Egypt.

Some evidence points to external influence, while other findings suggest an autonomous center of innovation. Comparisons with Near Eastern sites indicate that both regions underwent similar architectural advancements, including light construction with cladding, hand-formed bricks, and structured facades, potentially as parallel developments. However, in the Near East, the transition to mudbrick was gradual, whereas in Egypt, it appears to have occurred rapidly, hinting at possible external influence. Despite these hypotheses, the lack of extensive excavations and preserved structures makes it challenging to draw definitive conclusions.[48]

The various migrating populations that entered Egypt may not have had a history of monumental architecture, but they introduced distinct ways of life, including specific dwelling and burial practices, tools, and cultural traditions. The earliest groups laid the foundations for architectural development, later blending with incoming populations that had more advanced cultural traditions. These exchanges, shaped by political, social, and cultural interactions, contributed to state formation and created the conditions for monumental architecture to emerge.

The architectural forms and concepts of ancient Egypt were also influenced by the contrasting worldviews of its inhabitants - primarily nomadic and agrarian communities.

Hierakonpolis, for example, represented a fusion of these traditions, both politically and culturally. Upper Egypt was dominated by nomadic societies, while Lower Egypt had a predominantly agricultural character. These differing ways of life shaped architectural traditions, influencing the development of built environments throughout Egypt's early history.[49]

48 BUCHEZ, GEREZ, GUÉRIN, MINOTTI. *The emergence of mudbrick architecture [...]*. p. 111-130.

49 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs*. p. 22,109.

4.4 Characteristics of Mudbrick

Mud is a soil mixture composed of clay and sandy components, with a gradual transition between sand-rich and clay-rich soils that is difficult to define. While its composition varies by region, clay remains a fundamental element. It originates from the weathering of primary minerals in igneous rocks, such as feldspar in granite. When mixed with sand, it forms what is commonly referred to as mud.

The binding properties of mud are derived from its clay content, while sand particles act only as fillers, contributing to stability but lacking cohesive strength. Pure clay, despite its high plasticity, is unsuitable for construction due to its lack of structural integrity. It consists of fine, plate-like crystals that absorb water through capillary action, making the material moldable. As mud dries, water evaporates, and the clay particles harden, losing their plasticity. Construction mud is therefore a composite material where clay serves as the binding agent and sand provides the structural framework. Mud with a low clay content is classified as *lean mud*, while *fat mud* contains a higher percentage of clay.

One of the primary advantages of mud as a building material is its widespread availability, particularly in arid regions with minimal rainfall. It is easy to process, highly moldable when mixed with water, and allows for flexible architectural designs. Additionally, mud provides excellent thermal insulation, regulating indoor humidity and retaining heat, which contributes to a stable indoor climate. When dry, it also exhibits resistance to fire and frost. However, a significant drawback is its low tensile strength, which makes mudbrick structures vulnerable to cracking and failure under tensile stresses.[50]

The composition of mudbricks in ancient Egypt varied depending on environmental conditions. Early dynastic bricks were primarily made from pure black Nile mud, while later periods saw more variation based on material availability and structural requirements. The size of bricks also differed according to their function: smaller bricks facilitated faster construction, whereas larger ones required more precise placement. The mortar used was a thin mixture of mud and sand, applied to bind bricks together. Builders

50 WIENANDS. *Zum Lehm als Baumaterial* in *Architektur der Vergänglichkeit [...]*. p.20

pressed bricks tightly to ensure adhesion, filling joints with additional mortar. In larger structures, loose sand was sometimes used as a foundation to distribute weight more evenly.

To protect mudbrick walls from erosion, they were often coated with a layer of mud mixed with sand or straw to enhance durability. These coatings were tested for cohesion to prevent cracking or crumbling. Additional structural reinforcements, such as sloping headers at the base of walls, helped direct rainwater away from foundations, reducing erosion. The laying of bricks followed established bonding techniques, frequently alternating between headers and stretchers, a method similar to the modern English bond. This technique, dating back to the First Dynasty and continuing through the Roman period, sometimes included multiple courses of stretchers followed by headers for added stability.

In some cases, gaps were left between bricks for ventilation, and unique bonding patterns - such as diagonal or tilted arrangements - were occasionally used for both structural and aesthetic purposes.[51]

51 PETRIE. *Egyptian Architecture*. p. 3ff.

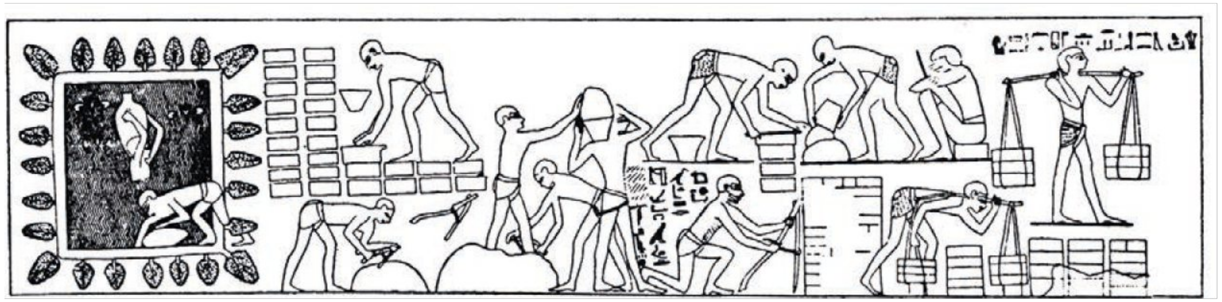
4.5 Production of Mudbrick

The production of mudbricks in Egypt has remained largely unchanged since antiquity. The region's environmental conditions, particularly its hot and arid climate, have influenced construction methods and the choice of building materials. Mudbricks were traditionally made by mixing Nile mud with sand, plant fibers, or small stones to enhance their structural properties.

The process involved pressing the mixture into molds, smoothing it by hand, and allowing the bricks to air dry in the sun *(Figure 54)*. This method, still practiced in modern Egypt, results in bricks that shrink as water evaporates during drying. The inclusion of straw or other plant materials helped to minimize shrinkage and reinforce the bricks.[52]

This process of shaping the bricks using wooden molds is a technique, confirmed by numerous archaeological finds of wooden brick-making boxes. Once shaped, the bricks were left to dry for several days, turned over to ensure even drying, and then stacked for further use. The inclusion of plant fibers, such as straw, increased flexibility but slightly reduced compressive strength. Experimental

52 ARNOLD. *Lexikon der ägyptischen Baukunst*. p. 282.



54 | Process of making Bricks for Storehouse (Temple of Amun; 18th dynasty)

studies suggest that a well-dried brick with fine sand can withstand a load of 52 kg/cm², though adding organic material slightly decreases its load-bearing capacity.

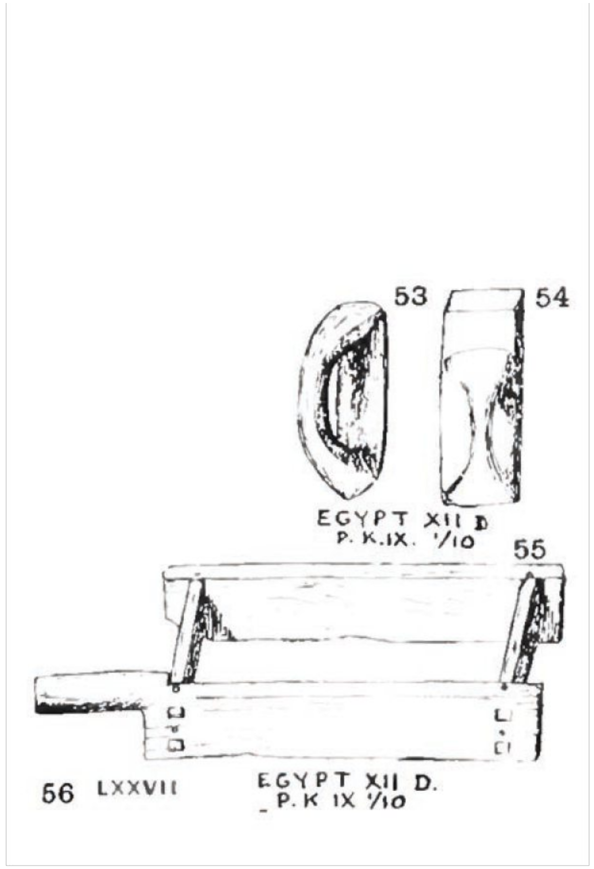
Historical records, such as a depiction in the tomb of Rekhmire in Thebes, provide additional insights into the mudbrick manufacturing process (*Figure 56*). The scene portrays not only the technical procedure but also a ritual in which the king himself symbolically molds the first brick of a construction project, invoking divine sanction for the building effort. The process involved sourcing suitable Nile mud, which varied in consistency depending on the location along the river. Assistants dug pits to mix the mud with water until it formed a thick paste. Sand or chaff was then added before the material was carried to the brickmaker, who pressed it into molds and placed the newly shaped bricks on the ground to dry. This step-by-step process ensured efficient production, with bricks arranged in rows until they hardened sufficiently for stacking and transport.[53,54]

4.6 Earth Building Types in Acient Egypt

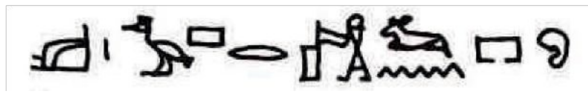
Monumental architecture in Egypt emerged when intellectual and cultural developments sought formal architectural expression. The prehistoric and early historic periods saw a range of architectural forms, including tents, mudbrick houses, burial mounds, and house tombs.

Construction techniques from this period can be divided into two primary categories: skeletal construction using wooden frames

53 SPENCER. *Brick Architecture in Acient Egypt*. p.3ff.
54 CLARKE; ENGELBACH. *Ancient Egyptian Construction and Architecture*. p.207ff.

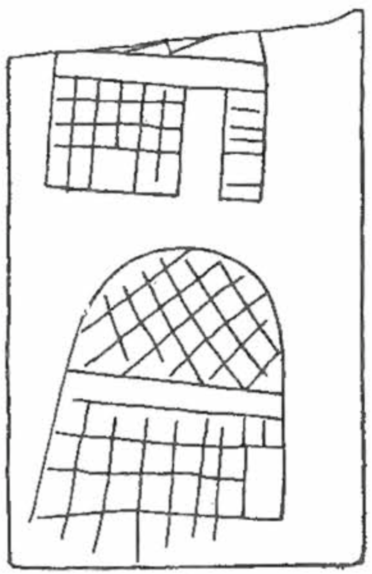


55 | Wooden Mold; 12th Dynasty



The king himself molded the mudbrick in a form while addressing Horus, declaring that he was making the brick for the sanctuary.

56 | Scene in tomb of Rekhmire at Thebes;



57 | Representation of Round Hut

covered with mats and massive construction using air-dried mudbricks made from Nile mud. The transition from nomadic tent-based structures to mudbrick buildings was gradual, with intermediate forms such as mud lump construction marking the shift toward permanent settlements. This process laid the foundation for architectural development, and as state authority solidified, monumental stone construction emerged. However, early stone buildings retained features of their mudbrick predecessors, illustrating a continued evolutionary process.[55]
The properties of mudbrick as a material led to diverse building types, with climatic conditions influencing architectural forms such as vaulted or flat-roofed structures. Structural constraints, particularly the maximum length of wooden beams, dictated the span of interior spaces. Many mudbrick buildings featured tapered walls, allowing for greater heights and enabling multi-story construction. This architectural approach also contributed to security, as defensive elements like protective walls, watchtowers, and fortifications were integrated into urban planning.[56]

55 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs*. p. 1,22ff.
56 WICHMANN. *Architektur der Vergänglichkeit.* p. 11.

4.6.1 Primeval Mound

The Egyptian concept of the primeval mound, representing the emergence of land from the primordial waters, predates the unification of Egypt and cannot be attributed to any single cultural group. This idea is evident in the sanctuaries of Hierakonpolis and Heliopolis. The sacred site at Hierakonpolis, dating to the First Dynasty or earlier, was built from rough stone, reflecting a nomadic worldview. In contrast, the sanctuary at Tell el-Yahudiya, constructed with stamped Nile mud and covered with bricks, aligns with the perspective of sedentary populations. Both sites indicate the use of elevated mounds as sacred forms, though surviving examples from this period are limited.[57]

4.6.2 Tent Construction

The earliest Egyptian temples, as depicted in miniature seal impressions from the early third millennium BCE, were originally tent chapels. These consisted of lightweight wooden frames covered with mats and animal skins, enclosed within mudbrick walls featuring niche patterns.[58]

57 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs.* p.25.
58 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit [...].* p. 30.

Tent construction evolved into more permanent architectural forms, such as the mat palaces of Upper Egyptian kings, which originated from the grand tents of early nomadic rulers. This transition is evident in the Neolithic settlement of Merimde-Benisalam, where a visible shift from tent structures to mudbrick houses occurred. Although wood was scarce in Egypt and mainly used for tent frameworks, it was imported for larger constructions, such as palaces. Tent construction persisted into the Third Dynasty, likely serving a symbolic rather than practical function.

While no physical remains of these early tent structures have survived, their representations appear on ceremonial objects, including decorated doors, palace facades bearing Horus names, and cylinder seals. The term *itr.t*, meaning *bast hut*, further underscores the symbolic association with these early architectural forms.

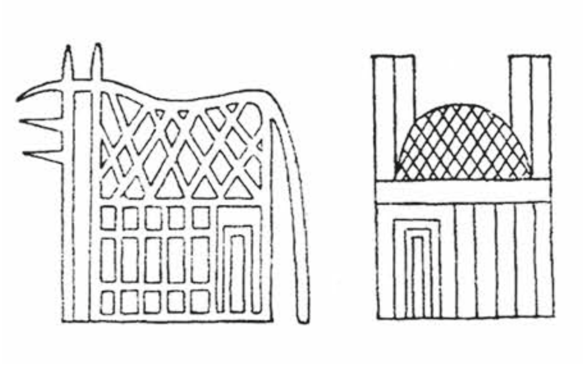
Residential tents followed skeletal construction with vertical walls and a curved rhomboid-shaped roof. The roof was not a simple structure but rather mimicked the shape of an animal‘s back, including tail- and horn-like features, possibly inspired by the rhinoceros. This design is supported by replicas found in the tomb of Hor-Aha at Saqqara. Alternatively, some artifacts from Abydos suggest the tent’s design may have been influenced by the hippopotamus. As a standalone structure, the tent lacked enclosing walls, emphasizing its symbolic and solitary nature.

The tent palace of the Upper Egyptian king likely developed as a monumentalized version of the nomadic royal tent, gradually losing its archaic animal-inspired form. While no complete depictions of the mat palace exist, its main entrance has been represented, allowing for various reconstructions.

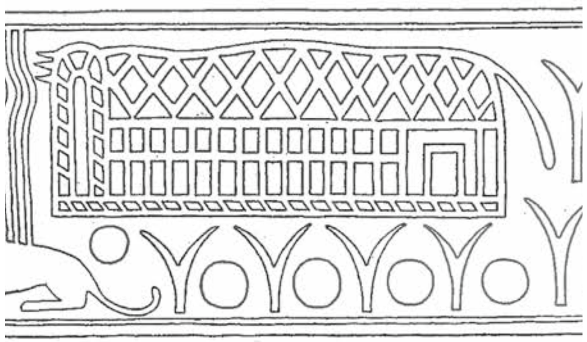
4.6.3 Tumulus Tomb and House Tomb

The tumulus burial is a characteristic grave form for nomadic communities, as individuals without a permanent residence would bury their dead where they passed away. Grave goods served to protect the deceased from looting and animals, with the additional consideration that, in the absence of the concept of a *house*, these offerings could have been intended for the afterlife. The burial itself consisted of a pit grave, a simple excavation in the ground, where grave goods were placed in close proximity to the deceased. The construction of an artificial mound over the burial not only marked the

58 | Relief of Mat Architecture



59 | National Shrines of Upper and Lower Egypt



60 | Representation of the Upper Egyptian *itr.t*

The grave was covered with sticks and matting, with a layer of sand and rubble placed on top.

61 | Tomb of early First Dynasty

site but also provided protection against erosion by the wind, often incorporating technical measures to stabilize the structure. The positioning and orientation of the deceased appear to have been deliberately chosen.

In contrast, the house tomb represents a form of burial associated with sedentary agricultural societies, where the most immediate architectural reference was the rectangular, solidly built mudbrick house. Excavations at Merimde have revealed burials within the ground between residential structures, indicating that the dead were interred in close proximity to the living, without a distinct, separate burial ground. However, classifying these two burial types - tumulus and house tomb - as fixed categories is challenging, as they may represent developmental stages rather than distinct traditions. Moreover, the possibility of transitional forms and hybrid practices suggests that these burial customs could have emerged independently rather than as a result of external influences.

However, the architectural superstructure of monumental tombs presents a different case. These structures extend beyond the mere necessity of burial and instead reflect the deceased's status in the state, society, and family, preserving their social position even after death. The construction of monumental tombs was thus driven by a need for formal expression, emphasizing the continued significance of the individual beyond their lifetime.[59]

4.6.4 Mudbick Constuctions

Royal tombs from the First and Second Dynasties in Abydos remain remarkably well-preserved, along with the mudbrick walls that once enclosed their precincts. These niche-structured walls, measuring ten meters in thickness and twelve meters in height, have survived for over 5,000 years. [60]

In Lower Egypt, the prehistoric royal palace was likely constructed using mudbrick, incorporating concentric layers forming barrel vaults. Enclosed within a precinct wall, its layout resembled that of a settled farmer's estate. The sanctuary depicted on the *Lions Palette* may represent a structure with tall posts and a circular design (*Figure 59; right*), similar to round huts found in ivory carvings. Rather than rhomboid in shape, these structures followed a concentric circular arrangement, suggesting the use of

59 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs*. p.26-41.

60 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit [...]*. p.38.

mudbrick barrel vaults in their construction. Despite the limited preservation of ancient cities, mudbrick architecture has been documented through grave goods such as the so-called *soul houses*. These clay models, approximately 1:20 in scale, depict a range of mudbrick structures, illustrating distinctions between urban houses and rural estates.

Rural estates typically consisted of roofed rooms aligned along one side of a courtyard, enclosed by a surrounding wall. Urban models, in contrast, feature two-story arcades on three sides of an inner courtyard, with the street-facing side remaining closed. Roofs were either flat, supported by palm trunks, or constructed using domes and barrel vaults. High-rise structures made from limestone models further provide insight into mudbrick construction techniques, including the placement of beams between floors, door and window arrangements, and the masonry techniques employed in brick courses.

An example of later mudbrick architecture is the sanatorium at Dendera, dating to the last century BCE. This structure functioned as an ancient Egyptian hospital, featuring a surrounding corridor leading to small, cell-like treatment rooms. Thick exterior walls contrasted with thinner interior partitions, while essential components such as basins, tubs, and water conduits were made of fired bricks.

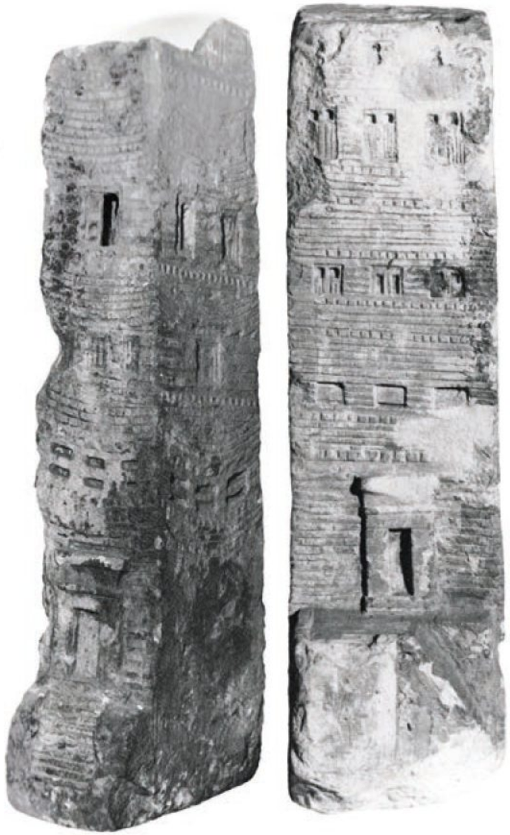
Unfortunately, during temple excavations, surrounding mudbrick structures were often overlooked or destroyed due to careless handling. However, Elephantine Island preserves a well-documented chronological record of mudbrick architecture, extending back to the late fourth millennium BCE. Its massive city walls unified the urban and temple areas into a cohesive architectural complex. Other significant examples include Kom el-Sultan (mid-third millennium BCE) and the city walls of Elkab (early second millennium BCE). These structures display advanced construction techniques, such as segmenting mudbrick walls into sectors and alternating between distinct patterns: sections with concave, sagging brick courses and sloping, tapering walls, followed by convex courses that broaden at the wall's crown. This interlocking design created a structurally stable system.[61]

Many mudbrick constructions were later dismantled to create fertile soil for agriculture. Additionally, early excavations

61 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit* [...]. p.44ff.

Soul houses are small models placed in graves as offerings for the afterlife. In some cases, architectural details and building materials can be identified.

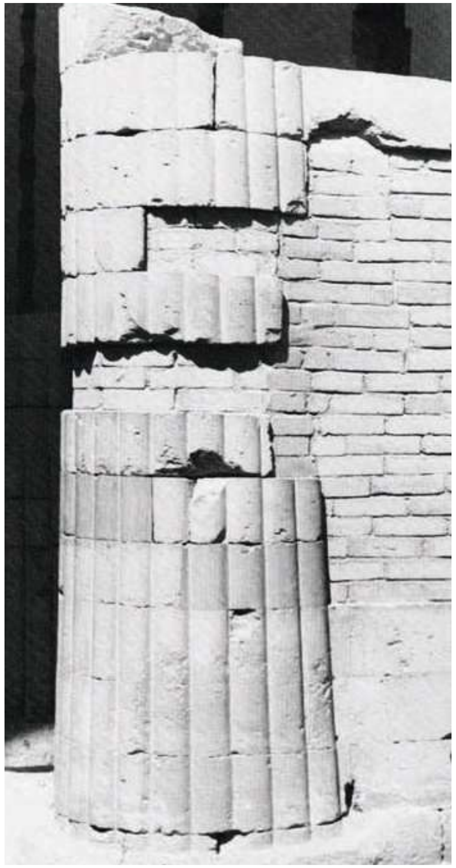
62 | Soulhouses (Grave Goods; Clay)



63 | Soulhouses (Grave Goods; Limestone)

The structure was built from limestone. The masonry strongly resembles mudbrick architecture.

(Entrance hall, Djoser complex)



64 | Half-column made of Limestone (2650 BCE)

65 | Sanatorium Dendera (Mudbrick; 200 BCE)

often prioritized stone monuments over mudbrick structures, resulting in their neglect or destruction. The entire complex surrounding the temple at Dendera, for instance, was lost without documentation, while similar destruction occurred in Edfu during renovations of the Temple of Horus. The long-standing focus on stone architecture, combined with the tendency to generalize and marginalize the significance of mudbrick construction, has further obscured its role in ancient Egyptian architectural history.[62]

4.6.5 Transition to stone Architecture

Between 3000 and 2650 BCE, sacred structures in Egypt were still constructed using mudbrick. However, with the royal complex of Djoser, a transition toward stone architecture in religious buildings began. Temples, often built from stone, typically occupied the center of towns, while surrounding buildings - constructed from mudbrick - served more utilitarian purposes. Many of these secular structures were directly or indirectly connected to temples, which functioned as economic centers in ancient Egyptian society. Although most surviving Egyptian architectural heritage consists of stone structures, particularly religious monuments, they often exhibit clear influences from earlier mudbrick construction techniques. Egyptian artisans worked extensively with various types of stone, including limestone for relief walls, sandstone for temples, and rose granite for stelae. The resulting constructions defied traditional material constraints, moving beyond simple geometric forms to create elaborate architectural features. Instead of basic stereometric shapes such as cubes and cylinders with smooth vertical walls, Egyptian stone architecture incorporated intricate elements, including sculpted figures, plant-inspired columns, sloping walls, and niche structures, all of which were highly complex and technically demanding.

Notable examples include the enclosure wall of the Djoser Step Pyramid at Saqqara (c. 2650 BCE), built from limestone with sloping walls and niche decorations, and the sandstone pylon of Luxor Temple, completed around 1250 BCE. Early stone blocks were similar in scale to mudbricks, and walls retained projections and recesses, structural features originally necessary in mudbrick construction but no longer required in stone. Traditional wooden architectural elements

62 SPENCER. *Brick Architecture in Acient Egypt.* p.1.

were also translated into stone: rounded beams from mudbrick structures were replicated in relief carvings, palm trunks evolved into palm columns, and bundled papyrus stems were reinterpreted as papyrus columns.

The Step Pyramid at Saqqara, composed of six stacked tiers of small limestone blocks, demonstrates its origins in mudbrick architecture. The structure features sloping walls and was originally clad in smooth limestone. It represents the first large-scale attempt at monumental stone construction.[63] Djoser's complex at Saqqara further refines the architectural traditions of the Naqada period. The Step Pyramid, essentially a stepped mastaba with a subterranean burial chamber, retains elements of earlier nomadic burial mounds in its superstructure. The offering site, likely located on the eastern side as in Abydos, featured a symbolic or false entrance. The complex, consisting of the Step Pyramid, burial chamber, and offering court, reflects Upper Egyptian influences. However, architectural features reminiscent of Lower Egyptian mudbrick structures indicate a fusion of both traditions.[64]

4.6.6 Mudbrick Constructions Today

Building with mudbrick has remained a defining architectural tradition in Egypt, with modern mudbrick houses closely resembling their ancient counterparts.

The production process has also remained largely unchanged for millennia. Beyond industrialized nations, mudbrick structures and remnants of ancient civilizations continue to exist, particularly in arid regions subject to extreme climatic fluctuations.

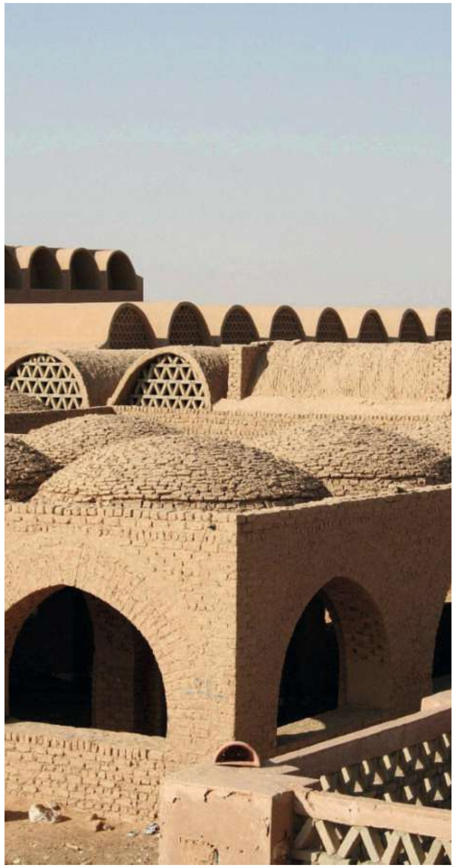
Despite its relatively low resistance to wind and water, mud remains an essential building material due to its widespread availability and the abundance of loamy soil. Its practicality and accessibility have made it a preferred construction material in these environments. However, its perishable nature necessitates constant maintenance and periodic renewal to ensure the longevity of structures.[65]

63 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit [...]*. p.27ff.

64 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs*, p.13.

65 WILDUNG. *Lehmbau in Altägypten* in *Architektur der Vergänglichkeit [...]*. p.6,51.

66 | Pyramid of Djoser at Saqqara



A public building complex designed by Hassan Fathy in 1967, featuring a museum in the foreground and a market in the background.

67 | Public Building (New Baris; Hassan Fathy)

The Royal Tombs at Abydos

Monumental architecture in Egypt gradually developed from various architectural forms, shaped by cultural and environmental influences. The architectural styles of the historical period emerged through the interaction between Upper Egyptian traditions, rooted in nomadic structures, and Lower Egyptian architecture, which reflected an agrarian lifestyle. While structural similarities facilitated their integration, the distinct characteristics and stylistic tendencies of each tradition prevented a complete fusion.

As a result, all monumental buildings from this period can be understood as hybrid forms that incorporate elements from both traditions.

The royal tombs at Abydos, built for the kings and queens of the First Dynasties, were constructed in the cemetery of their Upper Egyptian ancestors, reinforcing their cultural origins. These tombs illustrate an evolution from earlier nomadic burial practices, transitioning from simple mounds to increasingly abstracted architectural forms, eventually leading to the development of the pyramid. However, the internal design of these burial chambers reflects influences from Lower Egyptian house tomb concepts, demonstrating the architectural synthesis of both regions.[66]

In the following chapter, the cemeteries and tombs of Umm el-Qaʿab will be examined in greater detail.

66 RICKE. *Bemerkungen zur ägyptischen Baukunst des alten Reichs*. p.109ff.

5

CEMETERIES AND TOMBS OF ABYDOS IN CONTEXT


Rosetta
Damietta
Alexandria
Buto
Sais
Tanis
Busiris
Avaris
Naukratis
Pelusium
Nile Delta
Gaza
Rafah
Dead Sea
Wadi Natrun
Bubastis
Great Bitter Lake
Heliopolis
Cairo
Giza
MEMPHIS
Saqqara
Helwan
Dahshur
LOWER EGYPT
Lake Moeris
Faiyum
Meydum
Lahun
Herakleopolis
Sinai
Timna
Serabit al-Khadim
Gulf of Suez
Gulf of Aqaba
Nile
Bahariya Oasis
Beni Hasan
Hermopolis
Amarna
Eastern Desert
Asyut
Badari
Qau
UPPER EGYPT
Akhim
Thinis
Abydos
Dendera
Western Desert
Naqada
Koptos
Wadi Hammamat
Quseir
Kharga Oasis
Dakhla Oasis
THEBES
Luxor & Karnak
Tod
RED SEA
Hierakonpolis
Edfu
Kom Ombo
Aswan
First Cataract
Bernike

5.1 Preface

The tomb of Queen Meret Neith, located in the royal cemetery of Umm el-Qa‘ab at Abydos, provides a unique opportunity to dive into the architectural and cultural history of early dynastic Egypt. This burial site, named after *Mother of Pots* due to the numerous ceramic vessels deposited there as offerings, is not only a reflection of ancient spiritual beliefs but also a critical resource for understanding the social, administrative, and artistic advancements of the time.

The cemetery, approximately 500 kilometers south of Cairo, is situated between the fertile lands of the Nile Valley and the arid Western Desert. Spanning around 150 by 600 meters, it comprises Cemetery U, Cemetery B, and the monumental tomb complexes of early rulers, including Tomb Y, attributed to Queen Meret Neith. These tombs, constructed primarily of unbaked mudbrick, are significant for understanding the architectural traditions that shaped ancient Egyptian funerary practices.[67,68]

Excavations at Umm el-Qa‘ab have a long history, beginning with the work of Émile Amélineau, who cleared significant portions of the site in the late 19th century. However, it was Flinders Petrie’s systematic excavations in 1899 that provided the first comprehensive understanding of the royal cemetery. Subsequent Günter Dreyer and more recently Univ.-Prof. Dr. E. Christiana Köhler have added critical insights into the architecture and cultural significance of the tombs. Köhler‘s re-excavation of Tomb Y, supported by high-resolution photogrammetry, has allowed for detailed documentation of its architectural features, ensuring that this cultural heritage remains accessible for future study.

Queen Meret Neith’s tomb, constructed using unbaked mudbrick, highlights the foundational role of this material in ancient Egyptian architecture.[69] Although fragile, these structures have endured due to the protective layers of sand that cover them.

67 DREYER. Abydos: *Der heiligste Ort Ägyptens* in *Begegnung mit der Vergangenheit [...]*. Chapter 24-27: p.184

68 KÖHLER. *Die Königsnekropole in Abydos: Zur Entstehung des pharaonischen Königtums*. p. 17-22.

69 KÖHLER, FERSCHIN, HOOD, JUNGE, KOVACS,MI-NOTTI; *A Preliminary Report of New Archaeological Fieldwork at the Tomb of Queen Meret Neith [...]*, p.1-2.


P
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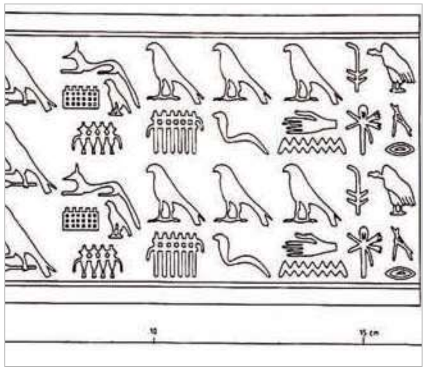
On the door of Den's tomb. Lists the kings from Narmer to Den, including Meret Neith.



70 | Necropolis Seal

5.2 Tomb Architecture and Cemetery Sites regarding Abydos

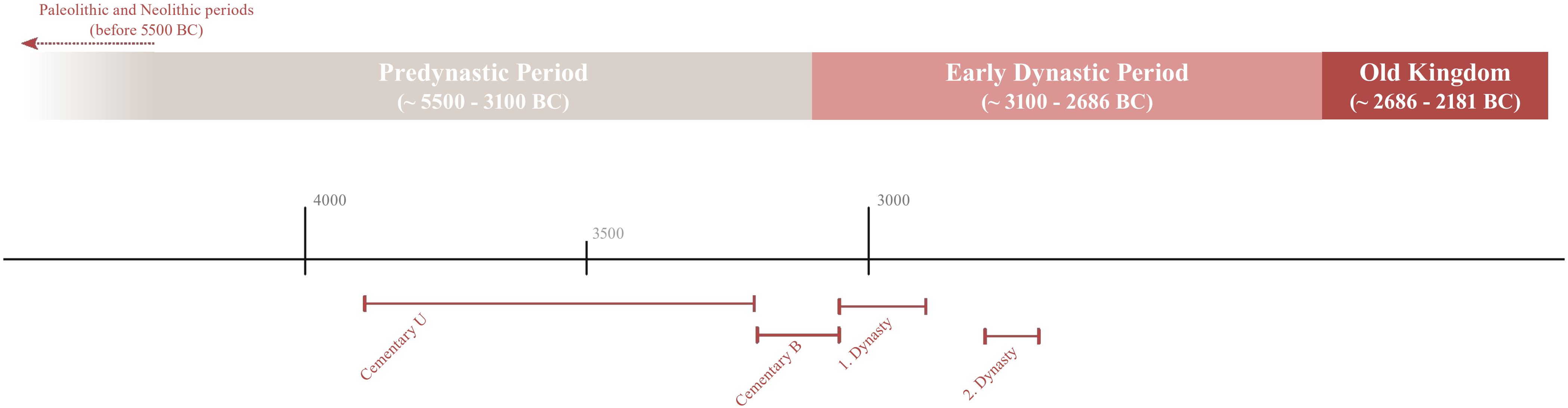
During Middle Kingdom excavations around 2000 BCE, the location was reinterpreted as Osiris's resting place, transforming Abydos into a major center for the Osiris cult.

The study of early royal cemeteries, such as Umm el-Qa'ab at Abydos, sheds light on the evolution of afterlife beliefs and resurrection concepts in ancient Egypt. This site provides essential insights into the social hierarchy, the roles of rulers, the development of administrative systems, and the progression of writing, trade, art, and craftsmanship, while also serving as a chronological reference point.

Burial customs in early dynastic Egypt, particularly among the ruling class, remained closely linked to later practices. Whether journeying with the sun-god Re or Osiris in the afterlife, the deceased's body had to be preserved, and the tomb was designed as a house filled with all necessary comforts for the afterlife. Funerary architecture evolved as awareness of tomb robbery increased, leading to deeper structures with protective stone portcullises. Seals found at the site hold great historical value. These seals often bear the names and titles of officials, occasionally private citizens, and numerous institutions, revealing the administrative structure and state organization.

One notable seal at the entrance of Den tomb suggests that Meret Neith, bearing the title *King's Mother*, held a status equivalent to the Horus falcon and likely served as regent for her son, Den, thus earning her place within the royal cemetery.[70]

70 DREYER. *Königsgräber ab Djer: Wege der Auferstehung* in *Begegnung mit der Vergangenheit [...]*. Chapter 26: p.197-208.



CEMENTARY U	CEMENTARY B	TOMBS OF FIRST AND SECOND DYNASTY	
(~3900 - 3200 BCE)	(~ 3200-3050 BCE)	(~3050-2900 BCE)	(~2800-2700 BCE)
Predynastic, Proto-Dynastic	Proto-Dynastic, late Dynasty 0 – early 1st Dynasty	First Dynasty	Second Dynasty
	Irj- Hor, Ka, Namer und Aha	*Djer, Wadji, Anedjib, Meret Neith, Den, Qa'a, Semerchet*	*Peribsen, Chasechemui.*

[1,2]

1 BRITISH MUSEUM. *Timeline of ancient Egypt*.
2 KÖHLER. *Die Königsnekropole in Abydos: Zur Entstehung des pharaonischen Königtums*. p.18, 19.

Timeline of the rulers of Upper Egypt

Predynastic Period

Tasa / Badari

Naqada I

Naqada II

Dynasty 0 (~3180–3030 BCE)

Scorpion

Iry-Hor

Ka

Narmer

Unification of Egypt (circa 3000 BCE)

Early Dynastic Period

1st Dynasty

Aha

Unknown

Djer

Wadji

Meret Neith

Den

Anedjib

Semerchet

Qa‘a

2nd Dynasty

Peribsen

Khasekhemwy[1]

1 DREYER, POLZ; *Begegnung Mit Der Vergangenheit* : 100 Jahre in Ägypten. p.341.

This Area consists of three primary sections. Cemetery U contains graves from the predynastic period, roughly from 3900 – 3200 BCE

Cemetery B holds Proto-Dynastic, late Dynasty zero – early first Dynasty tombs of rulers Irj- Hor, Ka, Namer and Aha from 3200 - 3050 BCE.

Seven large tomb complexes, housing rulers like Djer, Wadji, Meret Neith, Anedjib, Semerkhet, and Qa‘a from the First Dynasty (3050 - 2900 BCE), and Peribsen and Khasekhemwy from the Second Dynasty, complete the Area, covering the period from 2800 - 2700 BCE.[71]

71 KÖHLER. *Die Königsnekropole in Abydos: Zur Entstehung des pharaonischen Königtums*. p.18, 19.

The Northern and Southern Type

Despite political unification, Egypt retained separate administrations under the dual crown. This division led to elaborate coronation ceremonies and dual burials for the rulers, each following the customs and symbols of Upper and Lower Egypt.

Beginnings of Brick Architecture is seen in the Tomb U-j and Narmers tomb (B17/18).

Narmer was buried in a brick-lined tomb at Abydos, an early example of Egypt’s architectural progression. This tomb, located in the cemetery B, measured approximately 11 by 9.4 meters, and utilized bricks to line the walls, representing a significant innovation (in the South).

Whereas earlier pit graves (Cementary U) involved only basic earth excavation, these constructions incorporated brick-lined walls, advancing toward fully developed architectural forms.

In Naqada, Queen Nithotep (Narmer’s consort) was honored with the first *northern type* superstructure, a massive tomb complex set on a plateau with a recessed facade, marking the origins of monumental sacred architecture. Similar structures appeared in Saqqara, where tomb designs continued to evolve.

Tombs during this period, known as mastabas, typically had an underground substructure covered by a rectangular brick superstructure resembling the houses or palaces of the time. These early mastabas had a distinctive design: a rectangular brickwork exterior painted in bright colors to imitate woven mats, and an elevated outer wall surrounding a hollow core filled with rubble up to seven meters high. They were surrounded by enclosure walls and often included halls with boat burials, though no evidence suggests an entry point to the burial chamber after internment.
Queen Meret Neith was also given two tombs, constructed with the same grandeur as those of kings. Her monumental burial sites indicate her unique role not only as a mother or consort but as a ruler of unified Egypt.

This marked the beginning of monumental royal tombs that later evolved into the Step Pyramid of Djoser and the subsequent pyramid complexes, solidifying Egypt's grand funerary tradition[72]

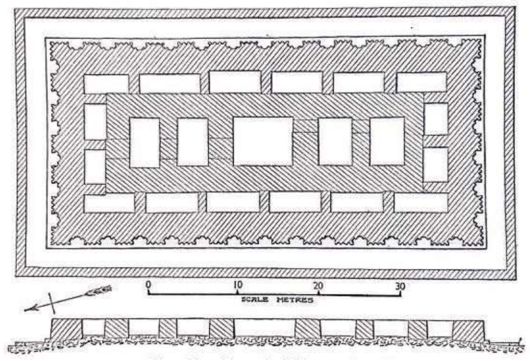
72 EMERY. *Archaic Egypt*. p. 47-131.

5.3 Cementaries in Umm el Qa'ab

5.3.1 Cementary U

Despite significant disturbance from looters and early excavations, remnants within Cemetery U remain valuable. The earliest burials date back to the early Naqada period NI, around 3700 BCE. The deceased were typically wrapped in matting, placed in a fetal position on their left side with the head to the south, and buried in small round or oval pits. This orientation remained characteristic throughout the predynastic period, with minimal grave goods such as one or two vessels.

Over time, both the size of the graves and the number of grave goods increased. Efforts to better protect the burials from the surrounding sand became apparent, including additional mat coverings and traces of wooden frames around the bodies. Coffins made from woven matting with reinforced edges also appeared. Eventually, grave pits were reinforced and covered with wood and matting. Grave goods expanded to include not only food but also items like jewelry, hygiene objects, and tools, reflecting a belief in providing for the deceased in the afterlife.
These burials from the Naqada I to early



72 | Top View and Section; Mastaba of Nithotep

73 | Photograph Mastaba Queen Meret Neith at Saqqara

Slits can be seen in the mudbrick walls, representing passageways. The burial chamber resembles a model of a residential palace.

74 | Tomb U-j; Predynastic

Cementary U (Tomb U-129) Remains of the mat in which the body was wrapped were also present.

75 | Burial in a pit Grave in contracted Position

Naqada II period form the largest group. Compared to other cemeteries in the Abydos region and Upper Egypt, many similarities exist; however, the size and wealth of individual graves at Abydos are particularly notable.

During the early Naqada II period, there was a decline in burials at Cemetery U, with an apparent hiatus of about 50 years where no burials took place. In the late Naqada II period, around 3000 BCE, Cemetery U was reused, but only large graves with remnants of once-rich furnishings were found. These graves were covered with crossbeams, mats, and a mud coating, and some were likely reinforced with wooden planks.

Burials were placed in wooden coffins in the southern half of the grave pit, with storage vessels placed in the northern half.

Some objects bear later hieroglyphs, indicating that an administrative system already existed at that time. The size of the graves and their rich assemblage of prestige objects and exotic materials obtainable only through long-distance trade leave little doubt that these were burials of the upper class - perhaps even early rulers.

This reinforces the impression that Cemetery U served as a special burial place during the Naqada II period.

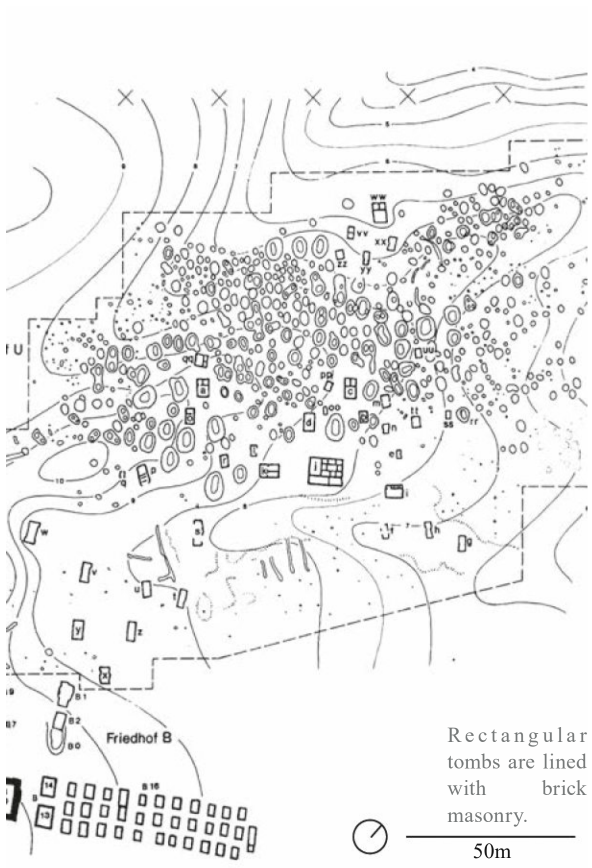
While burials in pits continued in other cemeteries, almost all graves from this time in Cemetery U were lined with bricks. Some graves were simply lined pits, while others had masonry subdivisions into two chambers - the layout and arrangement mirroring those of the Naqada II period, with the coffin and burial in the south and storage chambers in the north, sometimes further subdivided. The graves were covered with beams resting on the walls, mats, and a layer of bricks or thick clay.

A special case is Grave U-j, which was divided into twelve chambers, measuring 8 by 10 meters and 1.55 meters deep. The burial chamber was located in the west, containing a wooden shrine, and was followed to the east by nine storage chambers connected by door slots, symbolically accessible to the tomb owner. The magazines were arranged around a central room, representing a model of a residential house or palace with a central courtyard. The complex was later expanded to the south with two large chambers. These rooms served to store various grave goods, and the richness of the furnishings leaves no doubt that the owner, who possessed an ivory scepter, was already regarded as a king. It can be assumed that the eleven graves that follow topographically and chronologically in Cemetery U are also royal graves - a continuous sequence leading up to the kings of the 0 Dynasty buried in Cemetery B: Iry-Hor, Ka, and Narmer.

Despite the poor state of preservation of the graves, Cemetery U, alongside Naqada and Hierakonpolis, ranks among the most important burial sites in predynastic Egypt.

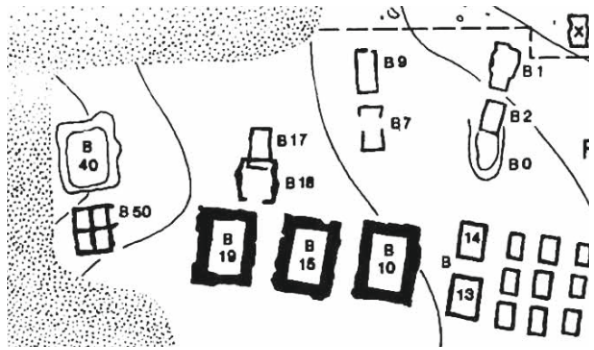
Seal impressions, tag pendants, and vessel inscriptions attest to an administration and the beginning of bureaucracy - the development of the writing system - which is an important resource for understanding the emergence of centralized power structures.[73]

73 HARTUNG. *Der prädynastische Friedhof U: Nilpferdjäger und erste Bürokraten* in *Begegnung mit der Vergangenheit [...]*. Chapter 24: p.187-193.

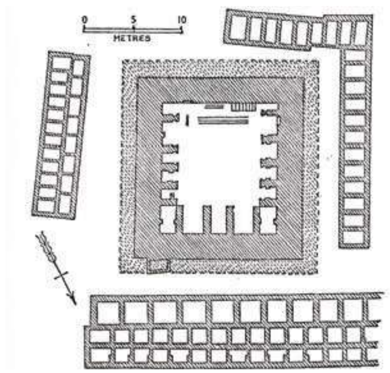


Rectangular tombs are lined with brick masonry.

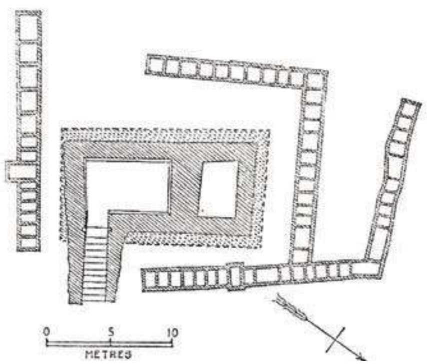
76 | Cemetary U



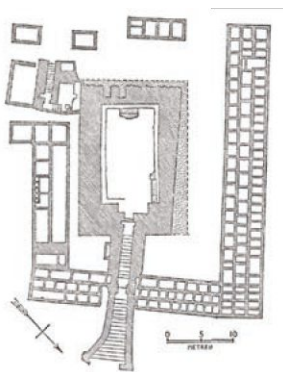
77 | Part of Cemetary B



78 | Plan View; Tomb O of Djer



79 | Plan View; Tomb X of Anedjib



80 | Plan View; Tomb T of Den

5.3.2 Cementary B

The early monumental architecture of Cemetery B illustrates the transition from simple to elaborate royal tombs, as seen with the last rulers of Dynasty 0, including Iry-Hor, Ka, and Narmer. Their tombs, such as Iry-Hor's (B1/2), Ka's (B7/9), and Narmer's (B17/18), remained modest, featuring air-dried brick enclosures in line with predynastic traditions. Iry-Hor's original chamber (B2) collapsed and was repurposed for grave goods, leading to the addition of chamber B0. Ka expanded to two chambers, a design also used by Narmer, whose chambers were initially connected but later separated due to structural collapse.

Horus Aha, identified with Menes, constructed two chambers (B13/14) with stronger reinforcements, including a wooden shrine in B14. His tomb marked the first monumental royal burial, later expanded with additional chambers (B10, B15, B19), featuring thick walls and large wooden shrines supported by massive posts. The tomb's covering consisted of wooden beams, reed mats, and plastered bricks, while the king's body was placed in a central chamber with a slightly vaulted ceiling. A tumulus, symbolizing the primordial mound, likely covered the main chambers.

East of B13/14, 35 the addition of small burial chambers marked a significant advance in tomb construction, reinforcing the king's status.[74]

5.3.3 Tombs of the First Dynasty

Starting with the tomb of Djer, the royal burial complexes of the First Dynasty in Cemetery B at Abydos were constructed with a large central chamber for the king and rows of smaller chambers on all sides, which served as auxiliary burials or storage for grave goods, similar to those in Aha's tomb. The sizes of these burial chambers varied considerably, from Anedjib's smaller tomb, measuring 23 by 30 meters, to Djer's, which spanned 40 by 70 meters. The dimensions of the royal chambers also differed, with Anedjib's being the smallest at four by selven meters and two meters deep, while Den's was the largest, measuring 8.9 by 15.2 meters and 5.75 meters in height. Den's reign marked the peak of the First Dynasty, and from his time onward, the royal chamber was accessed via a closable staircase.

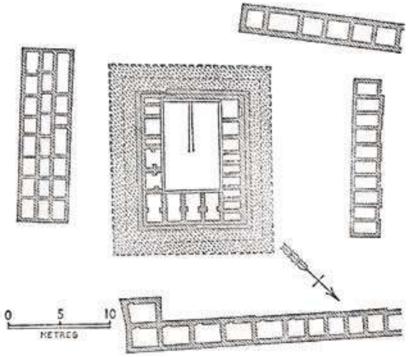
74 DREYER. *Friedhof B: Vom König zum Gott - Die Anfänge monumentaler Architektur* in *Begegnung mit der Vergangenheit [...].* Chapter 25: p.193-197.

The ceilings of these tombs were constructed with thick wooden beams, spaced approximately 20 cm apart, and layered with plastered reed mats and bricks, keeping the upper edge just below desert level. A wooden shrine, a primary feature within the tombs of Djer and Wadji, was placed within these chambers, supported on three sides by walls. In Den's tomb, the shrine stood freely, allowing for circulation around it. Only remnants or impressions of these shrines remain, along with scattered copper strips and nails. The majority of grave goods were placed in the shrines, along with the wooden coffin of the deceased, while additional items were stored in the surrounding chambers and corridors. These chambers were generally undecorated, though Djer and Wadji's tombs contained a niche-door in the southern wall, and from Den's time onward, walls were covered with reed mats, possibly in colored patterns.

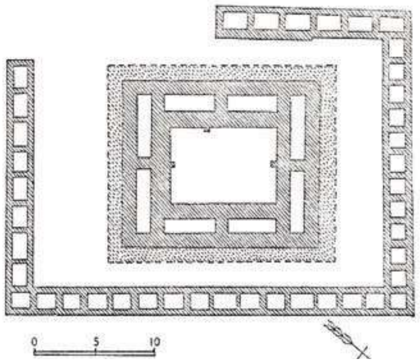
Den's tomb was particularly elaborate, with a floor of alternating red and black granite slabs, marking a significant architectural achievement. Above the king's chamber, a sand tumulus - a mound symbolizing the primeval mound - served as both a protective and symbolic structure. Petrie's excavations of Wadji's tomb revealed a 1.25-meter-high sloped brick wall above the king's chamber, surrounding the sand filling but left unplastered on the inside. This concealed tumulus had no structural purpose, likely functioning instead as a religious representation of the burial mound associated with resurrection and rebirth.

The burial mounds symbolized the renewal of life for the king or queen buried there. Similar backup mounds were integrated into the ceilings of Den and Qa'a's burial chambers, and this practice might also explain the vaulted ceiling of Aha's central chamber.

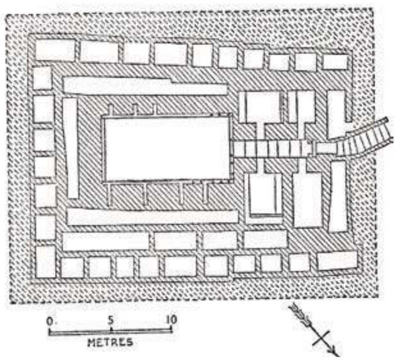
The steles marking the royal names are thought to have been placed on or in front of the tumulus. Wadji's limestone stela, for example, depicted a falcon perched on a palace facade with the king's name, Snake, inscribed. In front of these steles, sacrificial areas were likely established, and each tomb was accompanied by a large, walled enclosure with a small cult building located about two kilometers from Umm el-Qa'ab, at the edge of the fertile land (Shunet el-Zebib, *Figure* 50,51).



81 | Plan View; Tomb Z of Wadji



82 | Plan View; Tomb Y of Meret Neith



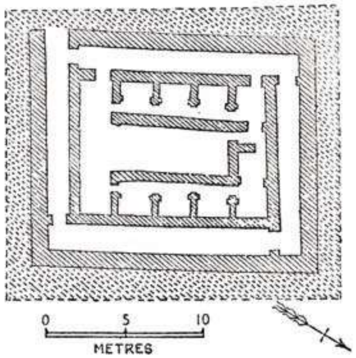
83 | Plan View; Tomb Q of Qa'a

The number of chambers used for burial purposes increased under Djer and Wadji, reaching up to 200, before decreasing toward the end of the First Dynasty, with Meret Neith having 42 subsidiary chambers. These subsidiary chambers often contained modest offerings, small steles identifying the individual, simple wooden coffins, and sometimes animals intended to accompany the deceased into the afterlife. Initially, these subsidiary chambers were arranged at a certain distance from the king's chamber.

The west was considered the entrance to the afterlife, aligning with the mouth of the large wadi that opened into the western mountain range, underscoring the concept of tombs as transitional points on the journey to eternal life.

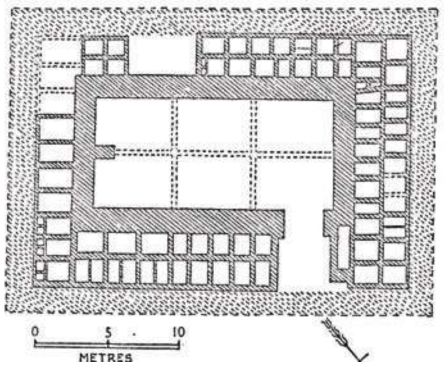
The tomb of Qa'a, the last ruler of the First Dynasty, presents a complex construction history with nine building phases. Originally consisting of the king's chamber and two subsidiary chambers. Semerchet's tomb is far superior to that of Anedjib. It features a brick-lined subterranean burial chamber with an entrance on the east side, accessed via a sloping passage. The tomb is surrounded by subsidiary chambers, all of which were likely roofed, with the entire structure carefully constructed.

Evidence from other tomb furnishings supports the notion that the Abydos tombs date later than the Saqqara structures, making it illogical to believe that the royal burials were completed only at Abydos. These findings, along with other clues, support the conclusion that Abydos was indeed the burial site of the kings, while the Saqqara tombs were designated for high officials or royal family members.
Later repair work using large bricks was undertaken on the tombs of Djer, Den, and Khasekhemwy, indicating that the graves were reopened during the Middle Kingdom. Ceramic finds within the king's chambers suggest that the tombs were accessed to establish cult sites for Osiris, the god of the dead, reinforcing Abydos's status as a major cultic center for this deity.



84 | Plan View; Tomb P of Peribsen

85 | Plan View; Tomb V of Chasechemui



86 | Plan View; Tomb U of Semerchet

5.3.4 Tombs of the Second Dynasty

For internal political reasons, the early kings of the Second Dynasty were buried in Memphis, particularly at Saqqara. However, Peribsen and Khasekhemwy, whose power bases lay in Upper Egypt, returned to Abydos for their burials. Unlike First Dynasty tombs, their burials lacked subsidiary chambers and instead featured stone-reinforced ramps extending from the southwest, emphasizing the enduring belief in resurrection.

Peribsen's tomb measured 18 by 15 meters and 2.6 meters deep, with a layout resembling a house within an enclosure wall. The plan included storage rooms flanking a central chamber that led to private rooms in the north. Initially, the structure was built 5 meters below the desert surface, with a central brick chamber surrounded by storage rooms accessible through a corridor. In later phases, the tomb expanded to 88 by 70 meters with additional magazine chambers, and evidence suggests further planned extensions to the south. A later addition included a stone chamber (5.25 by 3.2 meters, 1.8 meters deep), likely covered with stone slabs and concealed by a Nile mud coating.

Limestone blocks in the tomb show chiseling marks indicating organized quarrying. Most walls display remnants of wooden ceiling beams, enabling a full reconstruction of the roof structure. The brickwork in the middle section, initially 2.3 meters high and 0.8 meters thick, was later compressed, suggesting the presence of a tumulus that covered the main chamber. The reconstructed tumulus was likely 35 meters long and possibly encased in limestone blocks, resembling the early mastaba form of Djoser's complex at Saqqara, which later evolved into the stepped pyramid.

The architectural features of Peribsen and Khasekhemwy's tombs, particularly their stone-reinforced ramps and tumulus construction, mark a shift in royal burial practices. These elements influenced later monumental structures in Egypt. The poor preservation of these tombs has led to ongoing debates about their relationship with the niche tombs at Saqqara. Petrie's documentation of Wadji's tomb, where a brick wall supported a sand tumulus, remains a key reference for reconstructing early royal burial mounds.[75]

75 DREYER. *Königsgräber ab Djer: Wege der Auferstehung* in *Begegnung mit der Vergangenheit [...].* Chapter 26: p.197-210.

6

BUILDING-HISTORICAL ANALYSIS BASED ON TOMB Y

Plan View 3D Mode; Exterior Walls manually attached

without scale

6.1 Meret Neith's Tomb: Architectural Description

The architecture of the tomb features a central area made from unfired mudbrick, measuring 18 by 14 meters along the local north-south axis. This entire structure was built underground, with the tops of the walls lying just below the ancient desert surface. The walls were bound with mud mortar and originally plastered with mud. Surrounding the main chamber are eight elongated side chambers, positioned parallel to the central chamber and presumably used as magazines for storing the queen's funerary equipment. The burial would have been at the center of the tomb, although Petrie did not observe any human remains.

The tomb may have been constructed in phases over a long period. Its exterior and interior walls, up to 1.3 meters thick, appear to have been built roughly at the same time, but many of the partition walls between the side chambers were likely added later. The roof was initially planned to be at a lower level than where it was completed.The central area is surrounded by 42 small subsidiary chambers arranged in continuous lines to the north, east, and south, with a shorter line to the west and a gap in the southwestern corner. Once the burial and grave goods were deposited, the chambers were covered with wooden beams, matting, and layers of mudbrick, as evidenced by findings in various areas (Y-KK-2). Timber was placed along the lower level of a ledge that ran along the interior of the walls. On top of the construction, it is speculated that a large sand tumulus covered the central area. Like many tombs in the royal cemetery, this tomb shows evidence of intense secondary burning, which significantly damaged the walls and chamber contents. Some mudbrick walls were literally fired through, and the sandy ground transformed into a hardened, partially molten mass, indicating a prolonged fire at very high temperatures.

The chamber contents revealed different stratigraphic layers compared to Petrie's results form excavations 120 years ago. The main chamber (Y-KK) measures 9.05 by 6.42 meters with a depth of 2.76 meters. Its interior walls and floor show damage and burn marks from the ancient fire. The ground is irregular, with numerous secondary pits and damage. A large piece of timber was discovered on the floor of the main chamber, exactly where Petrie indicated, suggesting it may have been part of a wooden floor.

without scale

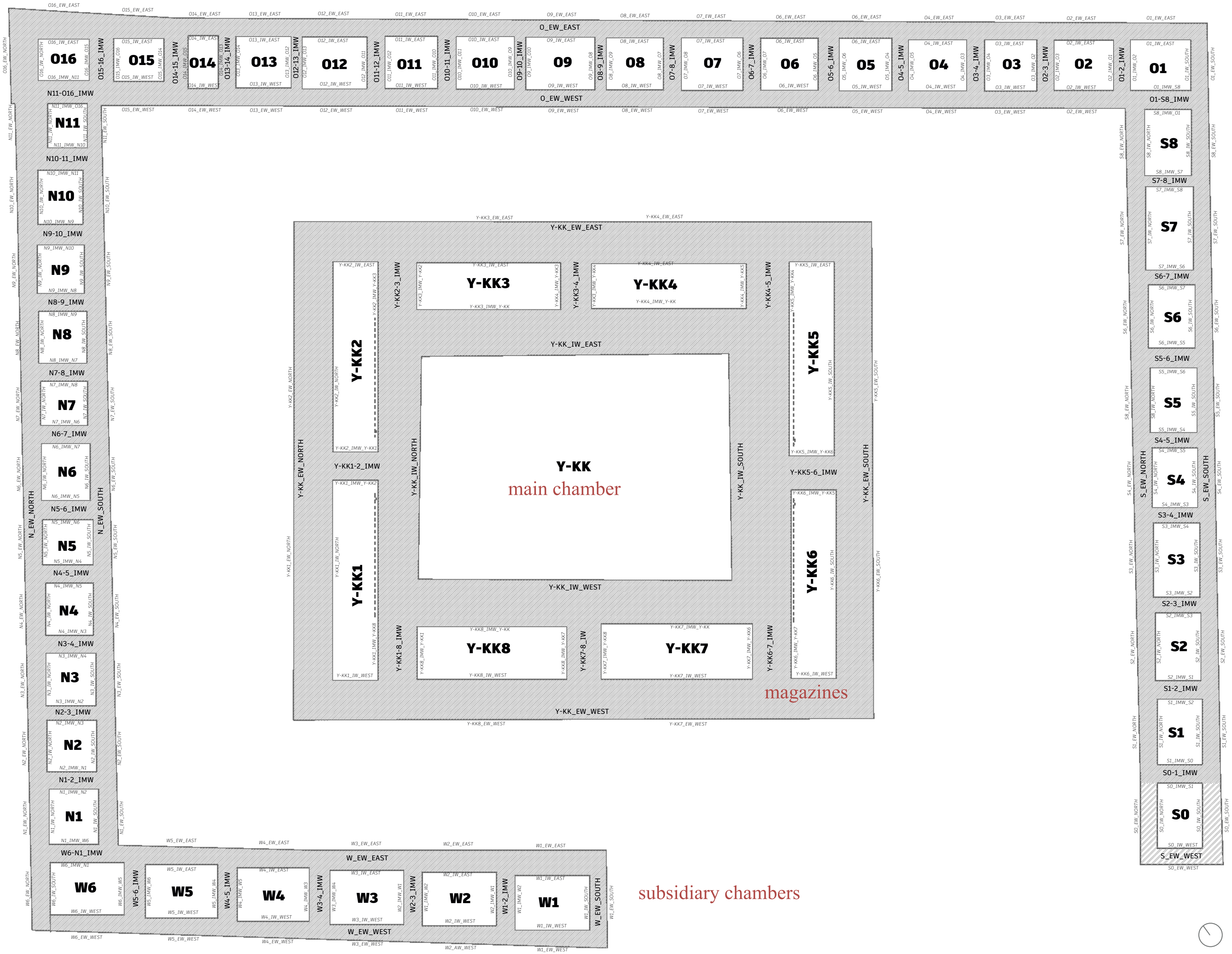
Discolorations on the ground and walls from the fire suggest that timber may have been placed vertically, hinting at a wooden compartment or *shrine* within the main chamber, similar to those in other tombs. This structure is suggested to have had six small pilasters and four larger ones in each corner, which may have supported upright wooden posts in post holes. Petrie regarded these structures as later additions to the original design, possibly added during a later phase before the funeral. Remnants of small mudbrick wall pilasters along the walls are also thought to be secondary additions, layered on top of the walls with plaster and fill.

The partition between YKK 1 and YKK 2, built on a layer of fill and slightly higher than the north and south walls, indicates that YKK 1 was constructed after the main chamber. YKK 3 shows burns only on the upper part, with mud remaining on the floor, suggesting it originally had a mud floor. The north wall of this chamber has a hieroglyphic inscription, first observed by Dreyer, with three signs, likely denoting oil and food related to the chamber's contents.

Burned timber was found on the ledge in the northeast corner of YKK 3, while YKK 4 showed limited burning at the top. Chambers YKK 5, YKK 6, and YKK 7 were heavily burned, and YKK 8 contains a low partition wall made of four to five irregular and unmortared courses of mudbrick, along with pottery vessels and fragments, possibly added later. The southern wall of YKK 8 is relatively undamaged, revealing indications of two construction phases: in Phase one, the main exterior and interior walls were built with pilasters forming the southeast and southwest corners of the chamber, while in Phase two, the gap between them was filled to form a partition wall between YKK 8 and YKK 7.

For chronometric dating of the tomb, radiocarbon (C 14) samples were collected, along with pottery vessels, wood, and charcoal samples. Additional samples of mudbrick and ceramics were taken for portable luminescence profiling (pOSL). Restoration efforts focused on the southeastern section of the main chamber and the southern area of YKK 8.[76]

76 KÖHLER. Final Report on the Fall 2021 and Spring 2022 […]. p. 2-17.



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6.2 Designations

The tomb consists of several parts. The inner structure includes the main chamber surrounded by the magazines. This complex forms the center of several connected smaller chambers called subsidiary chambers. A concept was developed to designate areas such as walls or wall surfaces. In principle, each chamber has a number except for the main chamber. The inner complex is listed with Y-KK as a prefix, followed by the chamber number.

The tomb contains 8 magazines. The main chamber is referred to as Y-KK while the magazines are labeled as Y-KK 1 to Y-KK8. The same principle is repeated for the subsidiary chambers. Here the designation consists of the orientation and then the number. This is why the subsidiary chambers in the North are called N1-N11 and so on. This concept was taken up by existing archaeological plans of the tomb.

An additional system for designating walls and wall surfaces has been introduced. In this sense, a designation consists of the chamber number followed by the component, the compass direction and additional, more detailed information. These designations are separated by an underscore.

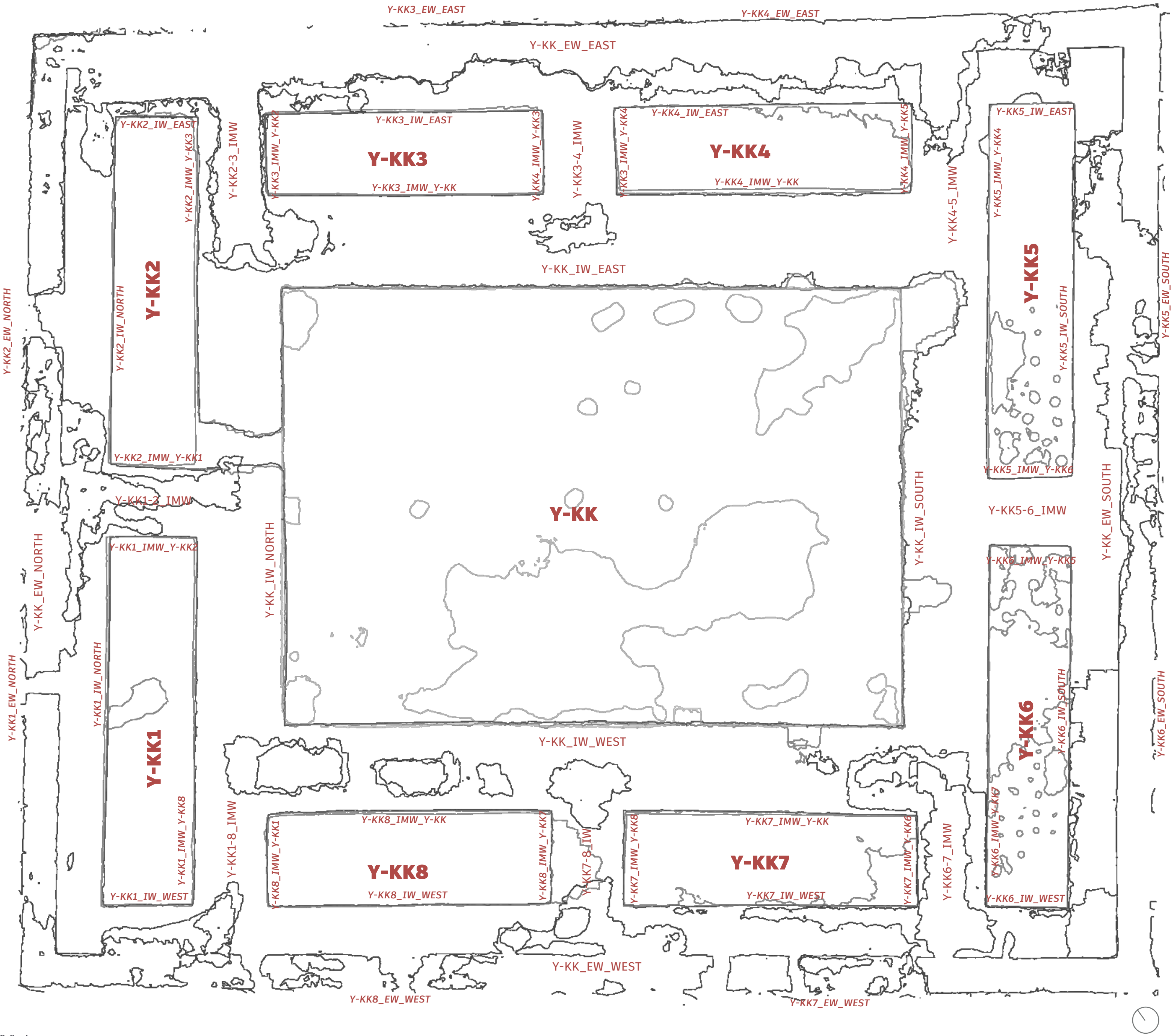
The basic structure is as follows:

ChamberNumber_Component_ Direction_[Detail]

The chamber number consists of the number of the object. Subsequently, the component in this case refers to the type of wall. There are interior walls identified by the code IW, intermediate walls by the code IMW, and exterior walls by the code EW. The chamber number, as the prefix of the intermediate walls, consists of the two chambers that the intermediate wall separates. Finally, the direction of the component is defined by the point of origin, which is set at the center of each chamber.

The wall surfaces were defined according to the same principle: first the name of the chamber, followed by the component, and finally the direction. For wall surfaces and intermediate walls, the direction is not exclusively defined by compass directions. If the object borders another chamber, the designation of the neighboring chamber takes precedence over the compass direction.

The following analysis focuses on the inner complex. The analysis aims to determine the constructional characteristics of the burial chamber using specific methods and, finally, to formulate a hypothesis based on the findings that proposes a reconstruction.



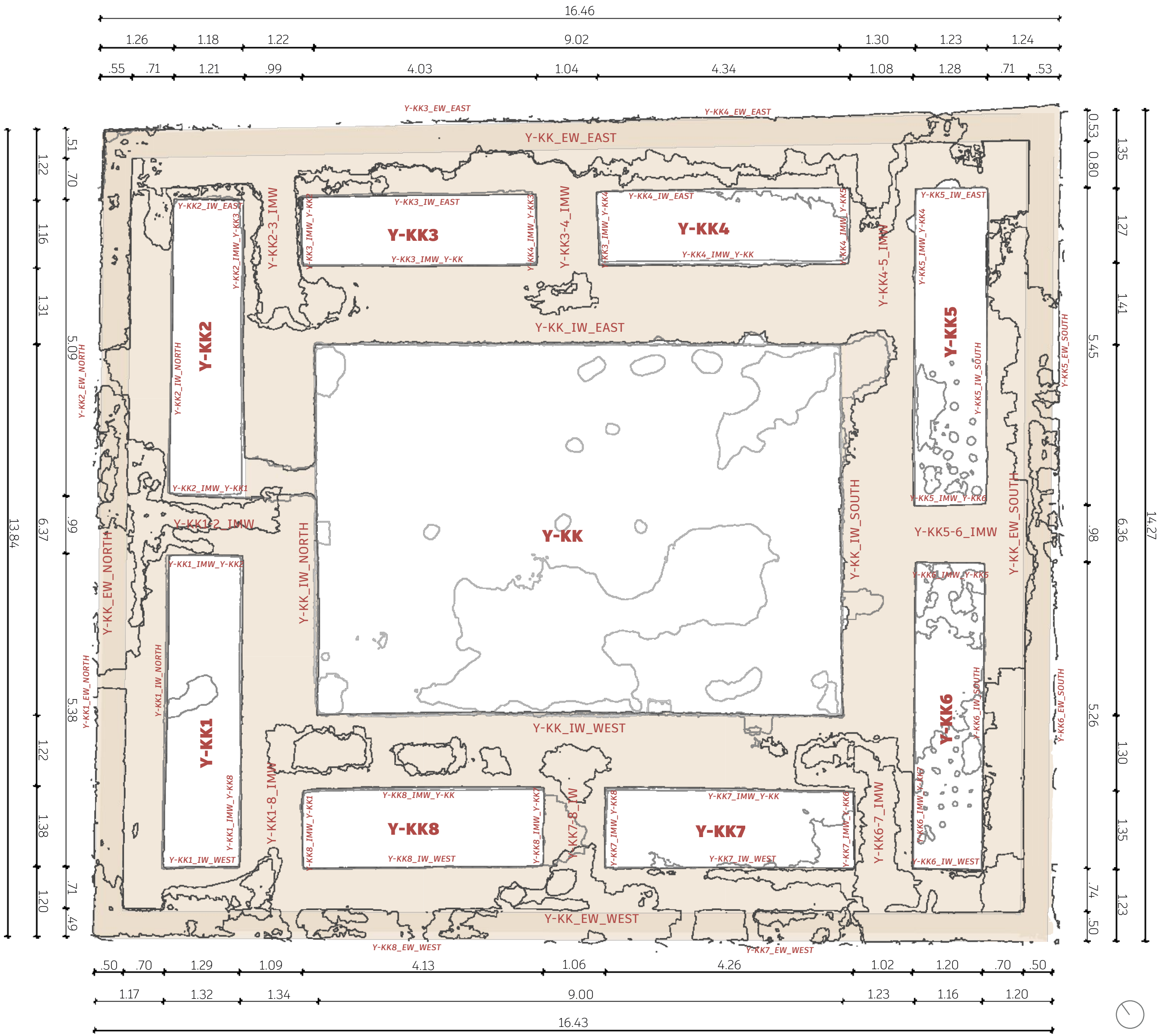
Plan View Main Complex with Designations

without scale

Within the analysis, the developed system of designations is used as a means of communication to ensure clear expression. In conclusion, the construction is characterized by its use of unbaked mudbricks, a material whose properties significantly influence the structure's condition and the analysis process. The age of the structure, combined with the inherent qualities of the material and the methods of its construction, result in slight variations in dimensions. These variations are particularly evident as irregularities, such as offsets along the edges, which may arise when walls tilt, expand, or narrow unevenly. To gain a deeper understanding of the structure, multiple sections have been taken from a 3D model and overlaid to create detailed visual representations.

These graphics form the basis for the architectural and constructional analysis presented in the following chapter. However, the material's natural inconsistencies necessitate careful interpretation of the findings. Overall, the analysis acknowledges the challenges posed by the material and the structure's age, noting that while the dimensions are accurate, minimal deviations may occur due to the properties of the unbaked mudbricks.

These slight inconsistencies, such as offsets or irregularities, are inherent to the material and construction process but do not significantly impact the overall measurements. Therefore, the findings should be interpreted as precise within the context of these minor variations.


Y-KK
Y-KK1
Y-KK2
Y-KK3
Y-KK4
Y-KK5
Y-KK6
Y-KK7
Y-KK8
Y-KK_EW_EAST
Y-KK_IW_EAST
Y-KK_IW_WEST
Y-KK_EW_WEST
Y-KK_IW_NORTH
Y-KK_EW_NORTH
Y-KK_IW_SOUTH
Y-KK_EW_SOUTH
Y-KK2-3_IMW
Y-KK3-4_IMW
Y-KK4-5_IMW
Y-KK5-6_IMW
Y-KK6-7_IMW
Y-KK7-8_IMW
Y-KK1-8_IMW
Y-KK1-2_IMW
Y-KK3_EW_EAST
Y-KK4_EW_EAST
Y-KK8_EW_WEST
Y-KK7_EW_WEST
16.46
16.43
13.84
14.27
without scale

6.3 Architectural Description of the Main Chamber and Magazines

The main chamber, Y-KK, forms the central part of the structure and, with its 57 m², is the largest chamber in the entire complex. Surrounding this central space are the magazines, which vary in dimensions. The width of all magazines is approximately 1.25 m, but their length differs depending on whether they are positioned to the North/South or East/West of the main chamber.

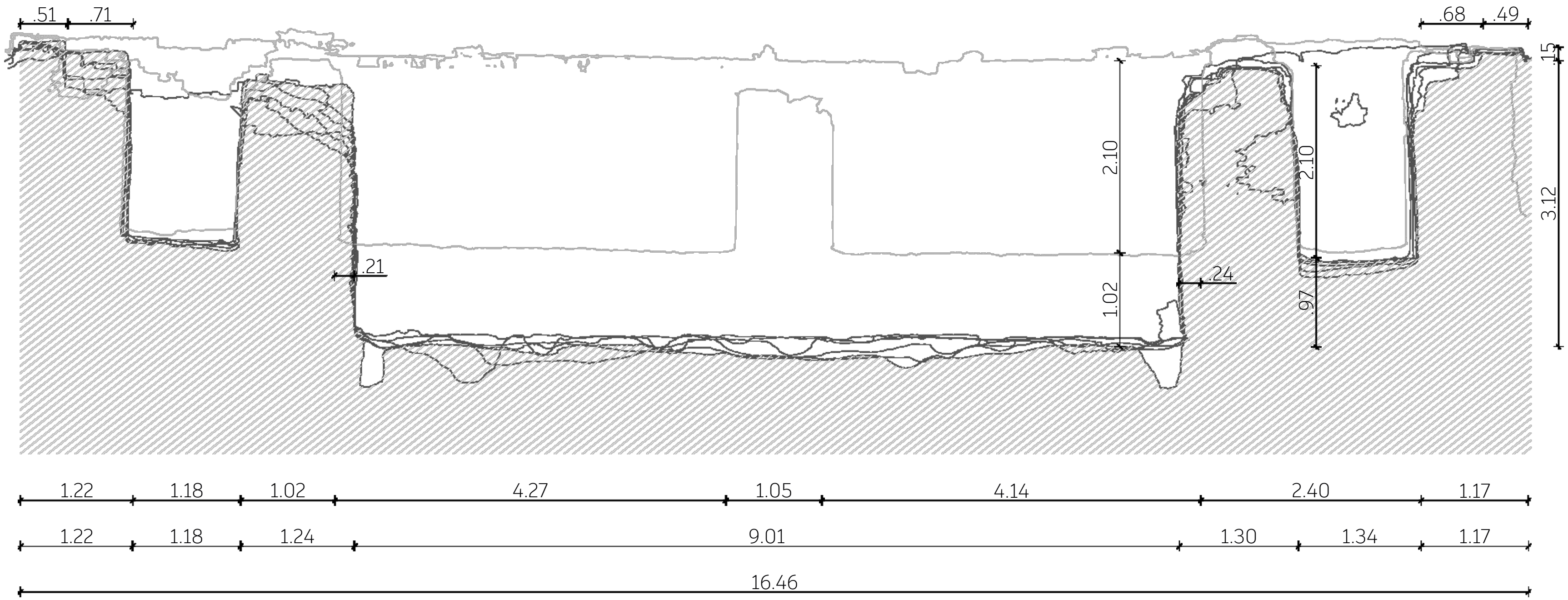
The magazines located to the North and South have lengths ranging between 5 and 5.5 m, while those situated to the East and West are roughly one meter shorter. As a result, the total area of the magazines amounts to 48.2 m², which is approximately 10 m² less than the area of the main chamber.

The walls between the magazines and the main chamber are the interior walls of the structure. These walls are all approximately the same width, ranging between 1.2 and 1.4 m. The exterior walls are the walls that form the boundary between the magazines and the surrounding soil. These outer walls have a similar thickness to the interior ones, measuring between 1.2 and 1.3 m. Additionally, they feature a kind of mudbrick edging, approximately half a meter thick. The height of the main chamber, as well as the interior walls oriented toward Y-KK, is nearly three meters, while the magazines are slightly shorter, measuring two meters in height.

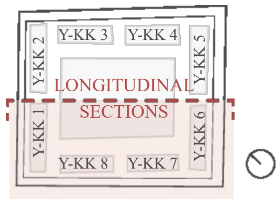
6.4 Construction Details and Key Observations

Brick construction enables precise and symmetrical design where intended., and it is evident that the main chamber has been divided into interior walls, intermediate walls, and exterior walls. When observing only the tomb from above, a consistent structural system becomes apparent. The main chamber forms the center and is enclosed by the interior walls, all four of which have equal thickness. The overall spatial layout, including both the rooms and walls, is symmetrical, with the North-South and East-West axes mirrored to each other. Parallel to the interior walls, the exterior walls create a gap forming the magazines, which have a similar width..

This results in the basic structure being offset outward in three equal sections. The middle ring, the area where the magazines are located, is divided by the intermediate walls.

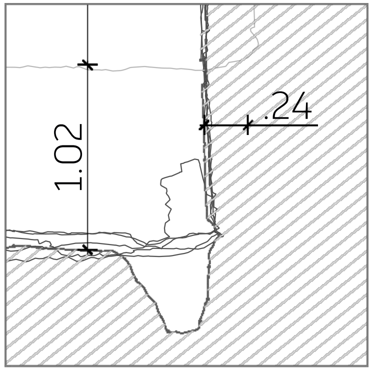


several cross-sections were taken from the midpoint at one-meter intervals through the 3D model and stacked on top of each other.



SCALE 1:75

Offset between inner edge of Y-KK_IW_NORTH and inner edge of intermediate wall Y-KK1-8_IMW



93 | Detail Longitudinal Section

Corner of Y-KK_IW_NORTH and Y-KK_IW_WEST

94 | Snapshot 3D Model

These intermediate walls also have a uniform thickness. The division follows one axis in the center between the interior and exterior walls and, on the East and West sides, aligns with the outer edges of the interior walls (Y-KK_IW_NORTH and Y-KK_IW_SOUTH).This means that these walls are aligned in the same line but vary in thicknesses. This raises questions about the construction technique of the brick walls - whether they were interlocked or built without interlocking. It is particularly noticeable that the exterior wall includes an additional brick edging, positioned at the outermost edge of the wall. Such a stepped detail is not as clearly visible on the other walls. However, distinct remnants of an additional course are visible on the interior and intermediate walls, though it is only partially preserved.

Figure 92 consists of multiple sections taken from the 3D model (one above the other). It reveals that the upper section of the interior walls is more heavily damaged compared to the rest of the structure, with larger portions missing in some areas. Despite this, the remaining sections still allow for meaningful conclusions to be drawn.

What is evident here is the main chamber in the center, with a length of 9 m and a height of approximately three meter. The magazines have a height of around two meter, while the main chamber extends one meter deeper into the ground. The tops of the walls are at the same level, reflecting the height differences in how deep each room extends into the earth. Thus, the main chamber is not only the largest room in terms of area but also the highest and, consequently, the deepest room of all. Due to the multiple sections drawn in *Figure 92*, a comparison can also be made to chambers Y-KK 7 and Y-KK 8, which are just as deep as the magazines Y-KK 6 and Y-KK 1.

It is noticeable that the inner edge of the interior wall Y-KK_IW_NORTH is offset forward by approximately 25 cm compared to the edge of the intermediate wall Y-KK1-8_IMW.

(Figure 93). The hole in the ground at the base of the inner side of the interior walls was created in an attempt to locate the starting point of the wall. The walls were constructed without any type of foundation; they rest directly on the ground without

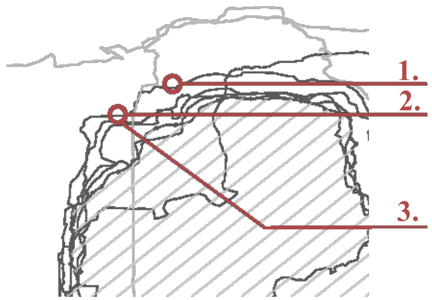
any built form of support.

Despite the destruction of the upper part of the wall, certain sections of the model provide valuable insights into reconstructing the original state. It becomes evident that the interior wall was designed with a stepped profile.

(1.) The entire surface of the wall, including its edges, appears to have been plastered. This is supported by the presence of a thicker, smoothed plaster course, which clearly marks the areas where the edges of the wall must have originally been located. This plaster course not only defines the structural boundaries but also hints at the finishing techniques employed during construction. In addition, parts of the upper structure of the wall remain intact. Positioned on top of the thick plaster course is an additional row of bricks that was deliberately arranged, providing further evidence of the stepped design.

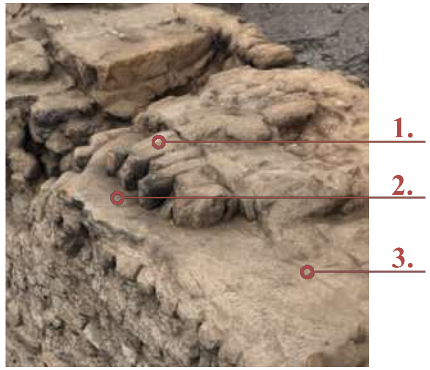
(3.) At a specific point where the Northern interior wall meets the Eastern interior wall, fragments of the wall bond are visible in the plan view. These fragments offer critical clues about the construction technique used in this area. However, certain aspects remain ambiguous. For instance, it is unclear whether the wall edge was initially built as a straight surface and later modified to include a stepped profile, or if the outer ring of the wall was constructed higher than the inner section from the beginning.

Nevertheless, it is apparent that the top row of bricks **(1.)**, placed on the plastered course, was likely added after the main walls were completed. This additional row seems to have been specifically introduced to accommodate the roof construction.



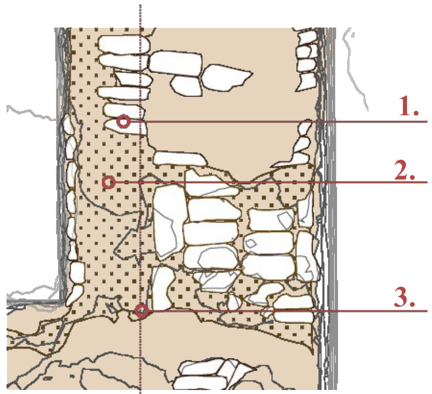
remaining structure of the slight step at the upper edge of the inner wall Y-KK_IW_NORTH

95 | Section



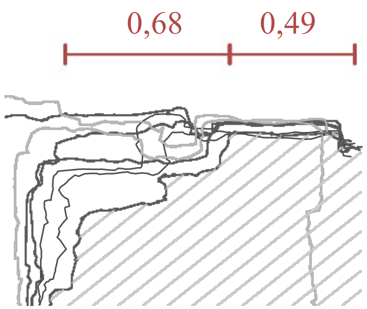
Upper part of interior wall Y-KK_IW_NORTH

96 | Snapshot 3D Model



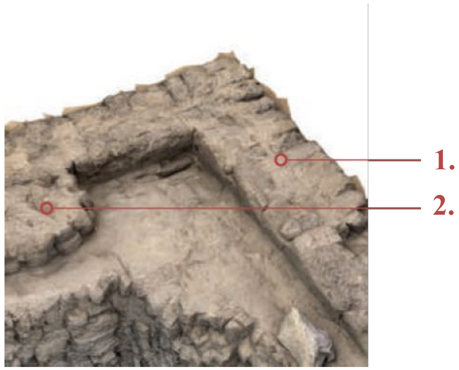
Y-KK_IW_NORTH (bordering Y-KK_IW_EAST)

97 | Plan View



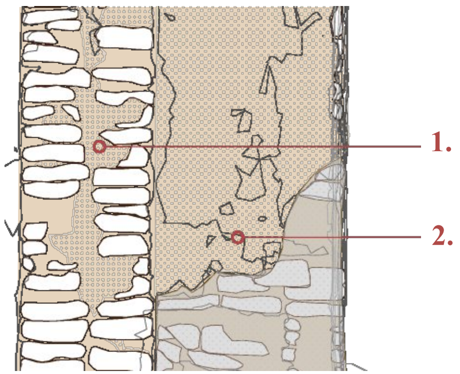
coping of
exterior wall
Y-KK_EW_
NORTH

98 | Section



Coping of
exterior wall
Y-KK_EW_
NORTH-WEST

99 | Snapshot



Plan View; of
exterior wall
Y-KK_EW_
SOUTH

100 | Plan View

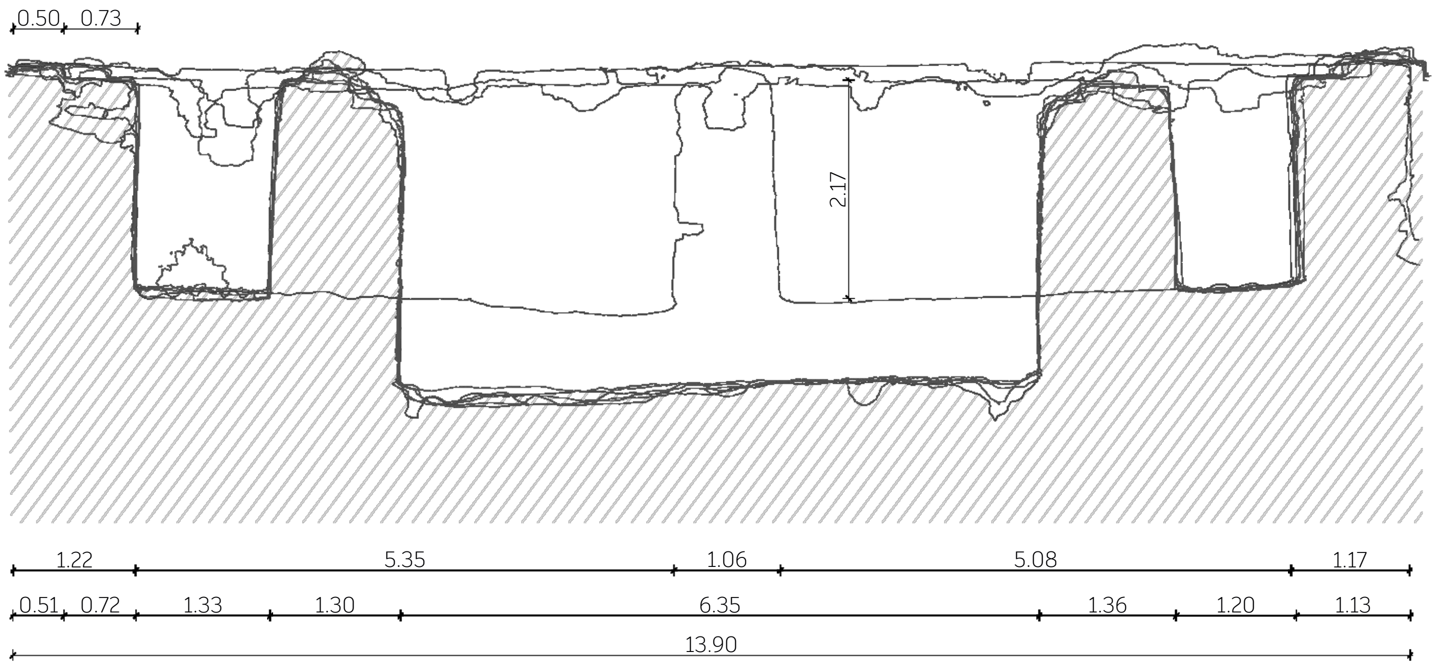
In contrast to the stepped profile of the interior wall, the construction of the exterior wall is better preserved. Its upper edge consists of the top part of the exterior wall itself, complemented by a brick edging.

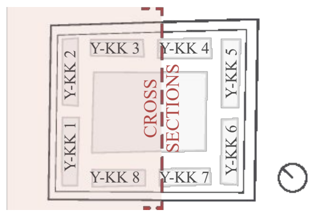
(1.) that was built along the outer edge of the exterior walls. This edging, measuring approximately half a meter in width, brings the total thickness of the wall to 1.25 meters.

(2.) The brick edging now stands as the highest regularly constructed element of the complex. While a few remaining fragments of the structure, originally intended to support the now-lost roof construction, rise above this level, this additional construction lacks any noticeable brick bond or structural integrity.

In some instances, the upper edge of the secondary embedding, along with the roof construction, appears to have been carefully aligned with the top of the outer brick edging, suggesting a deliberate adaptation during construction.

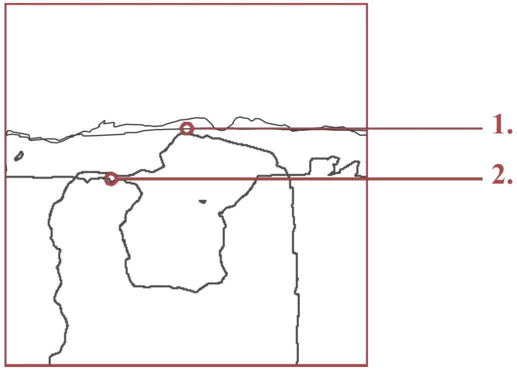
The height difference between the brick edging and the top edge of the interior wall is approximately 15 cm.. This level difference is mirrored within the interior walls, where the height of the inner edge of the exterior walls aligns with that of the outer edge of the interior walls. This consistency suggests a deliberate construction approach, potentially reflecting the functional requirements of the roof construction.


0.50
0.73
2.17
1.22
5.35
1.06
5.08
1.17
0.51
0.72
1.33
1.30
6.35
1.36
1.20
1.13
13.90


Y-KK 1
Y-KK 2
Y-KK 3
Y-KK 4
Y-KK 5
Y-KK 6
Y-KK 7
Y-KK 8
CROSS SECTIONS

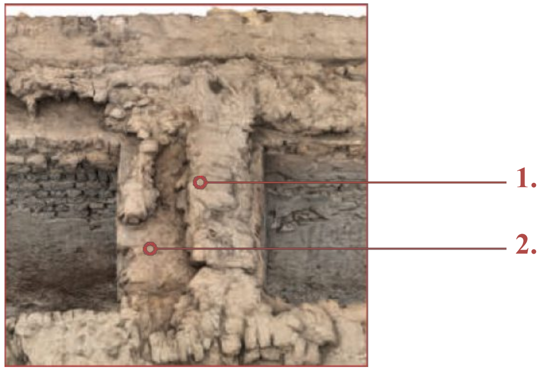
SCALE 1:75

Coping of intermediate wall Y-KK1-2_IMW



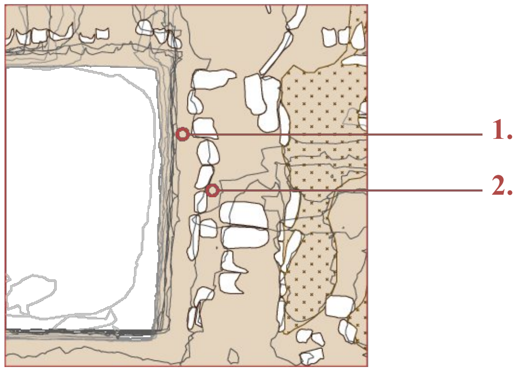
102 | Section

Coping of intermediate wall Y-KK1-2_IMW



103 | Snapshot 3D Model

Coping of intermediate wall Y-KK1-2_IMW



104 | Plan View

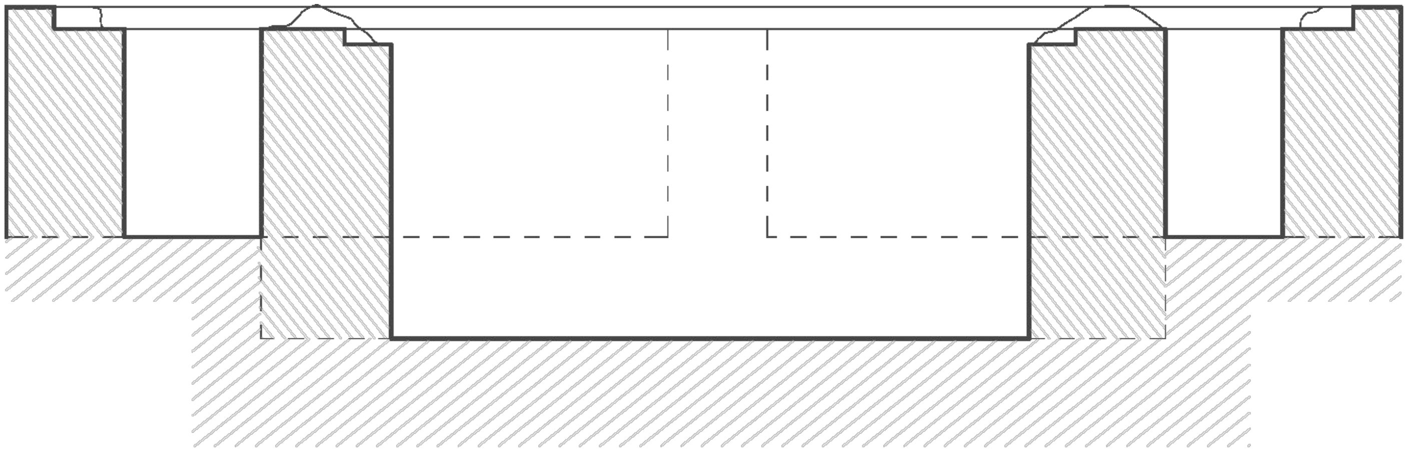
The structure of the interior and exterior walls observed in the longitudinal section is also repeated in the cross section. The stepped profiles of the upper edges in both the interior and exterior walls are consistent throughout, as are the wall thicknesses and heights of the construction.

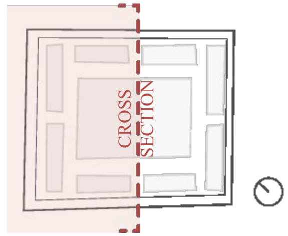
Additionally, the spatial layout remains the same, however, the length of the main chamber is now 6.36 m, which makes this side narrower than the opposite one. The total width of the structure measures 13.90 m, which is 2.5 m less than the length. Notably, this reduction is achieved solely by compressing the width of the interior space. The proportions, distances between the magazines, and the thicknesses of the walls remain identical to those observed in the longitudinal section.

It is also important to address how the intermediate walls are integrated into this system. As mentioned in the description of the interior wall construction, a secondary brick course can also be observed here.

This course is on top of the plaster coating of the wall and positioned on the upper edge of the walls. The plaster‘s upper edge aligns with the inner edge of the exterior walls‘ top, while the secondary brick course adjusts its height to match the upper edge of the additional brick edging of the exterior wall.

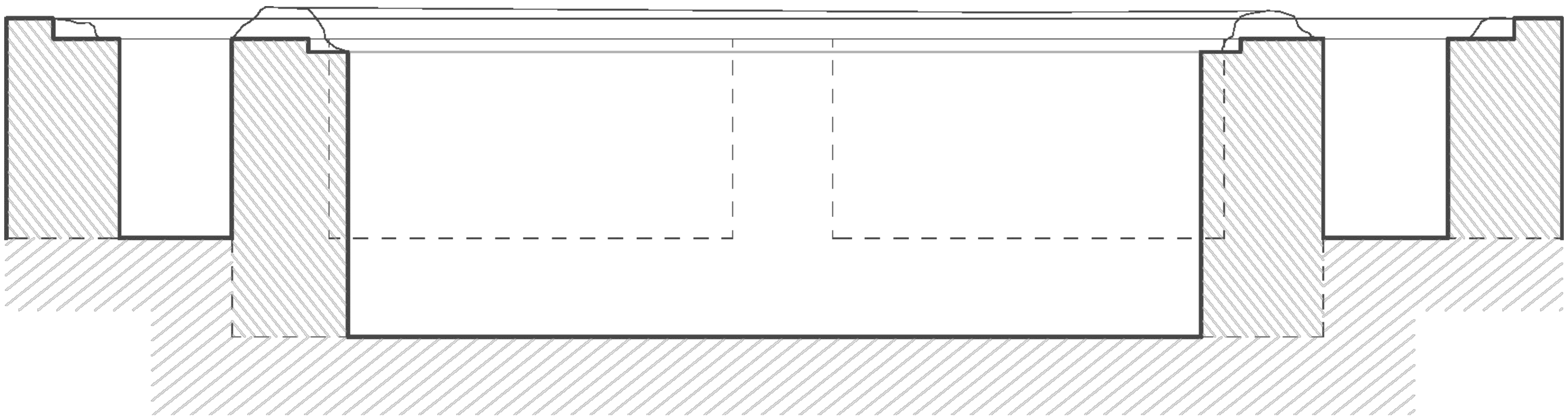
This integration demonstrates a recurring system that maintains consistent patterns and relationships across the structural elements, ensuring a unified approach in the construction.

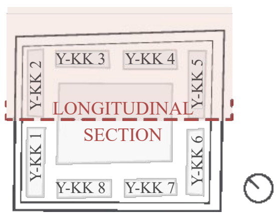




105 | simplified Illustration of Cross Section

SCALE 1:75





106 | simplified Illustration of Longitudinal Section

SCALE 1:75

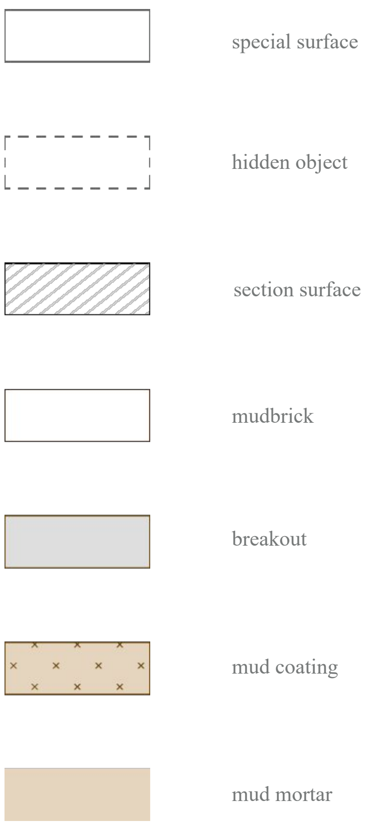
Summarizing these points of investigation and findings reveals several key aspects. The heights of the structural components are intentionally uniform within each type of construction element. Multiple stepped profiles are present at the upper part of the walls, either implemented into the primary wall construction or added later, most likely to accommodate the roof structure. Additionally, the structure is proportionally consistent in its overall design, with only the interior space being narrower along the East-West axis. The magazines along the South and North walls are longer but remain proportional in height and width to those on the other sides.
As previously mentioned, the structure is made of unbaked mudbricks and is very old. Therefore, a simplified illustration of the sections was created to provide a clear view of the structure, free from any distortions or missing elements.

In *Figure 105*, the cross section is shown, and in *Figure 106*, the longitudinal section. The illustrations are not merely sections, they also include dashed lines representing the magazines located behind the section, providing additional context to aid in understanding the construction.

6.5 Description of Methods Used

The following method of overlapping sections is consistently applied in the illustrations. Additionally, a map was created outlining the entire wall surfaces, color-coded according to their category. The legend include color codes for the mud mortar, mudbricks, holes or missing sections, and mud coating. Surface irregularities are further highlighted with lines. This mapping was designed to enable an analytical investigation of the masonry.

Since the bricks, mortar, and coating are all made of mud, identifying them can be challenging due to their homogeneous appearance. By actively categorizing and differentiating the elements, the construction becomes clearer. The analysis primarily relies on sections, snapshots from the 3D model, and plan views. Additionally, views and sections are combined to create what is known as a *folded section*. A folded section is a combination of a section and a view, where the section plane is *folded* exactly at the point where it intersects with the wall elevation.



107 | Legend for Mapping

This method effectively shows the structure at the intersection, allowing both the cross-sectional and the elevation details to be displayed in a single illustration, offering a clearer understanding of the constructional relationships.

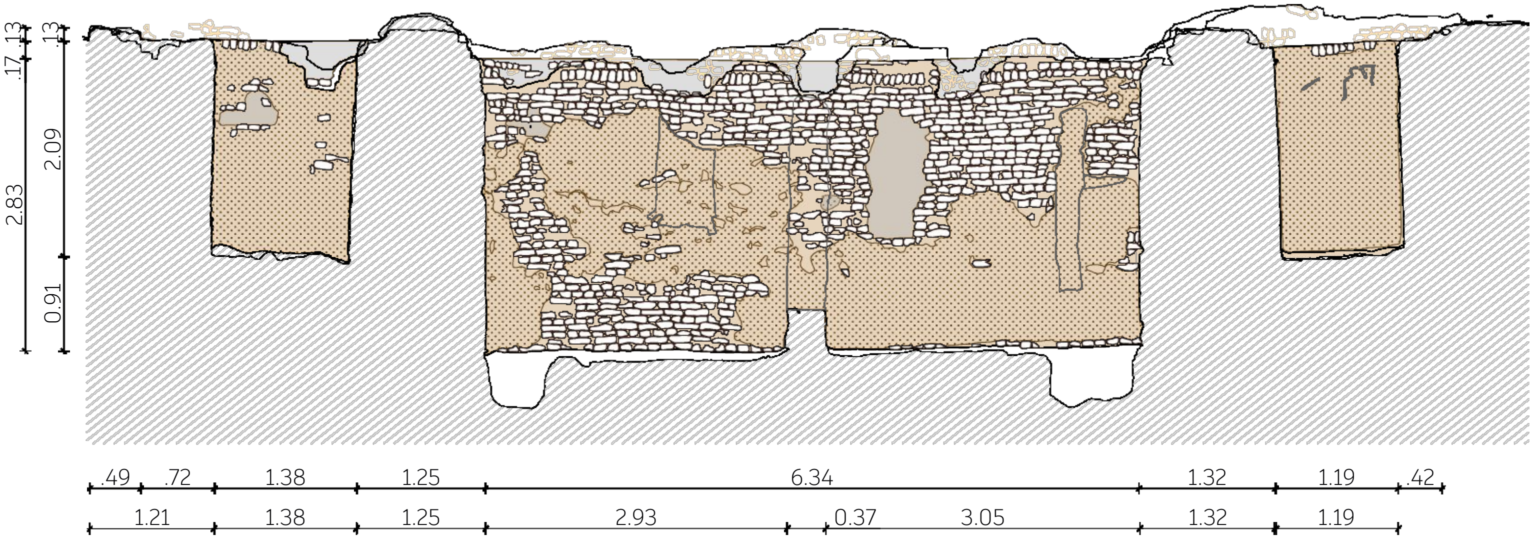
Finally, a masonry square meter was drawn for each interior wall, as the mud coating is missing in these areas. A masonry square meter is a selected section of the wall surface of a building which measuring one by one meter. It displays the materials used in the construction such as bricks, mortar and plaster. Through the scaled graphics, conclusions can be drawn about the quantities of materials and structural elements in the architecture and construction, as projected onto the entire wall surface.

In this case, each square meter of masonry as assigned a number and analyzed systematically. The designation consists of the prefix SM for *square meter of masonry*, followed by the assigned number. In the analysis, the dimensions of mortar joints and brick sizes are systematically recorded for each masonry square meter. Additionally, the courses of bricks are documented, and the bonding pattern is examind.

All this information is fed into a database, where the results from all masonry square meters are analyzed and subsequently extrapolated. This process determines an average brick size, and based on the analysis results, quantitative data is calculated. This includes, among other things, the total number of bricks in the structure, the total volume of bricks, and the volume of mortar used.

Since only parts of the masonry are visible, this method proves to be an efficient approach for comparing different types of masonry. It also facilitates extrapolations and estimations regarding material consumption and construction methods.
All these methods are applied to form a proposal for the construction. Different construction possibilities are suggested, and hypotheses are confirmed, refuted, or left open based on the analysis results.

108 | Section View 3D Model; Y-KK_IW_NORTH SCALE 1:75



109 | Section View Mapping; Y-KK_IW_NORTH SCALE 1:75

6.6 Data and Findings per Wall

6.6.1 Interior Wall NORTH (Y-KK_IW_NORTH):

Visible bricks: 793 bricks
Wall surface: 17.94 m²
Wall volume: 22.96 m³
Brick-laying technique: Stretcher, header, and rowlock courses;
brick courses to the top edge: 40
Visible courses:
Stretcher course: 17 courses
Header course: 22 courses
Rowlock course: 1 course

In *Figure 109*, the view of the north wall, along with the neighboring views of chambers Y-KK 3 and 8, is shown. The section cuts through the interior west and east walls. The interior wall has a length of 6.34 m, a height of 2.83 m, and an average depth of 1.28 m. This results in a visible wall surface area of 17.94 m² and a wall volume of 23 m³.

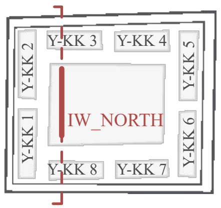
The surface displays partially black and reddish discolorations, which are indicative of fire damage. This suggests that surfaces without discoloration were likely covered, either by mud coating that has since fallen off or by objects that protected the surface.

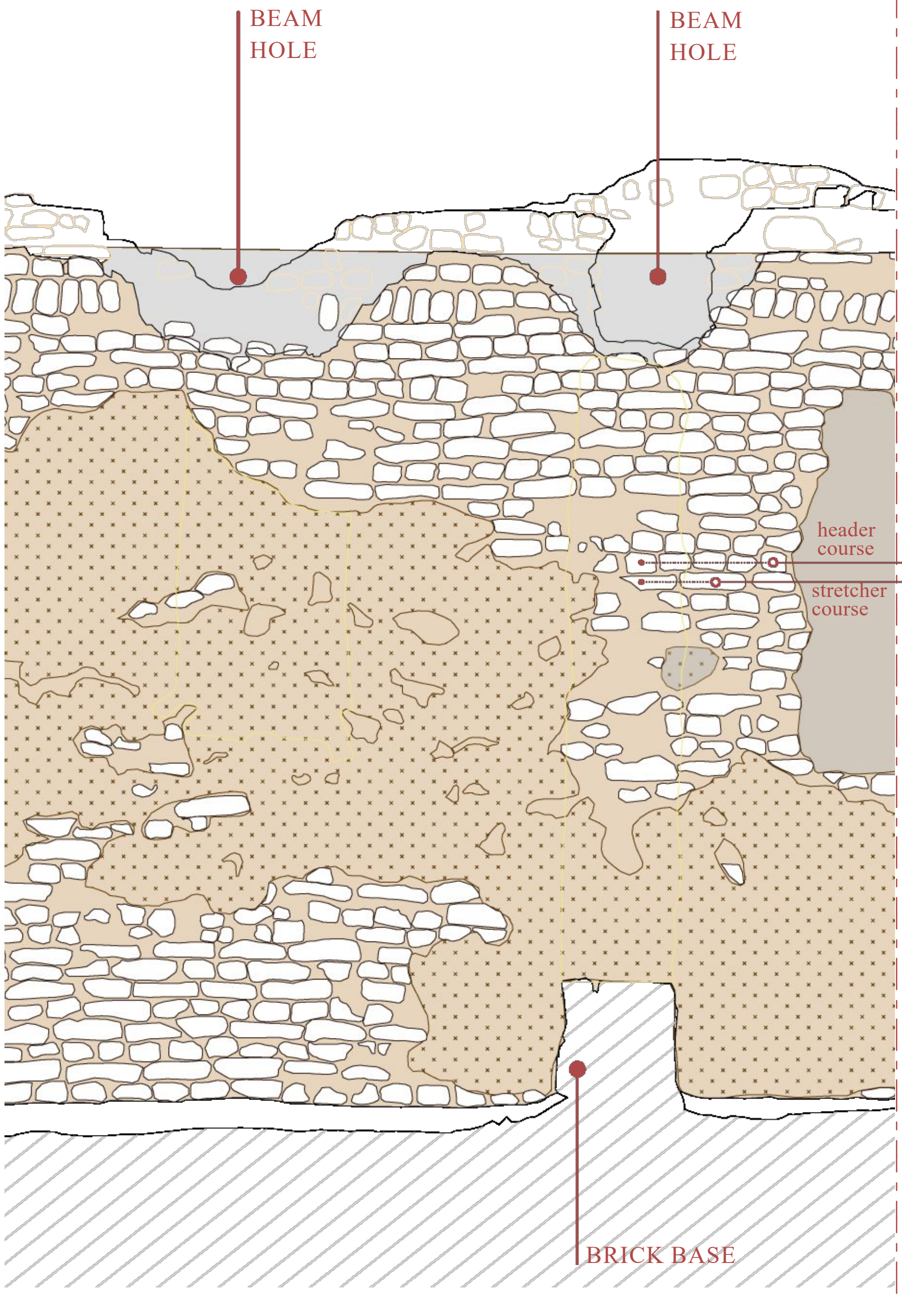
In total, 793 bricks are visible on the north wall, the rest remain covered with mud coating. There are three different laying techniques, which are examined step by step in the following analysis. But to briefly anticipate, in this case the course of the interior wall consists of 17 courses of stretcher + header course mix, 22 courses of header course, and one course of rowlock course. The second row is formed mostly by the rowlock course, while the other two types of courses alternate within the row. However, it is observed that the header course is laid in double courses three times, each occurring at regular intervals of 7–8 courses between the double courses.

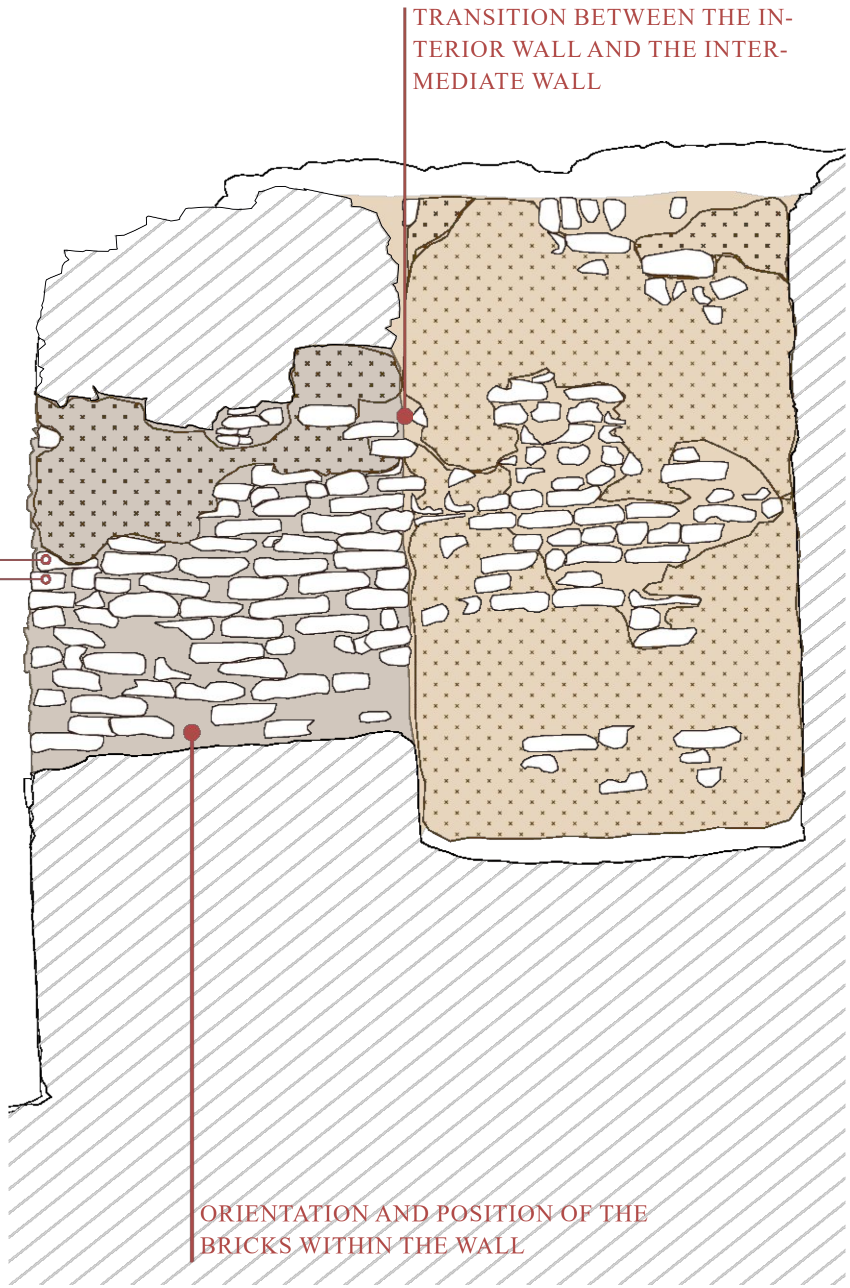
Furthermore several structural irregularities are evident. One is a hole, leading to magazine Y-KK 2, which appears unintentional.

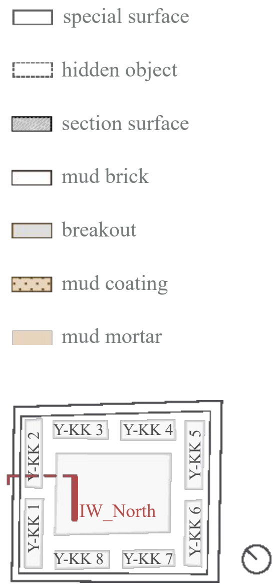
Y-KK_IW_NORTH

special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar





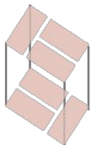




Elevation View (Y-KK_IW_NORTH)

Section (Y-KK_IW_NORTH)

SCALE 1:25



112 | Snapshot 3D Modell; Sockel

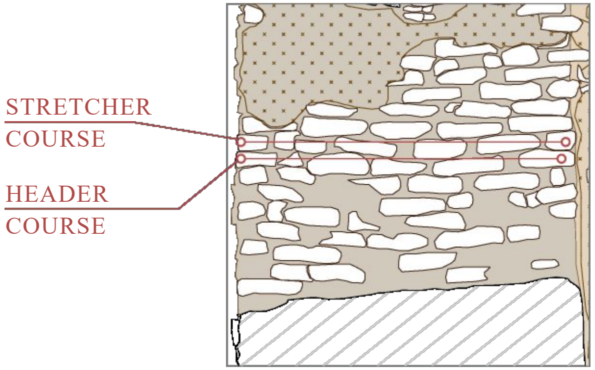
113 | Snapshot 3D Modell; Sockel

114 | Snapshot 3D Modell; Y-KK_IW_NORTH

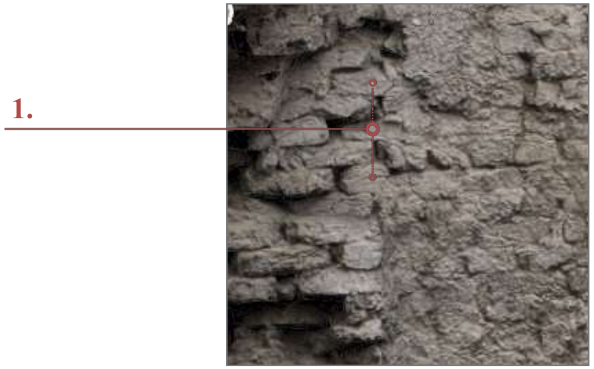
Additionally, at the upper edge of the wall, there are three evenly spaced voids, with the central void located precisely in the middle. Directly below this middle void, at floor level, there is a base with dimensions of 37 cm width by 38 cm height. This base is constructed of three bricks per course and is not interlocking with the wall.
Interestingly, these two components - the base and the evenly spaced void - are not only centrally aligned but also connected by a distinct discoloration in the mud coating. This lighter surface is also visible below the void on the left side and at approximately 60 cm distance from the east wall on the right. These vertical stripes stand out from the surrounding fire-related discolorations. Based on the alignment of the base, the regular positioned voids at the upper edge, and the traces of the differentiated mud coating surface, it can be hypothesized that this area was part of the roof structure. The base likely served as a foundation for a support post, which in turn carried a beam. This configuration appears to have been mirrored on the left and right sides. The visible remnants of plaster appear smoothed, suggesting that they represent the original finished surface of the wall.

The hole leading to magazine Y-KK 2 allows for important insights into the laying techniques within the wall. To investigate this, a folded section was created (*Figure 110, 111*), where part of the north wall view up to the section plane is visible, followed directly by the section itself. This reveals how the brick positions behave internally across the individual courses.

Interestingly, the internal bricks all align in one direction. In the case of the stretcher course, behind the brick with its long side facing outward, there is a row of four bricks rotated 90 degrees relative to the first and last bricks. Typically, a stretcher course (with the long side of the bricks visible) covers the surface and fills the space with bricks facing the same direction. In this case, however, it has been observed that the course consists of



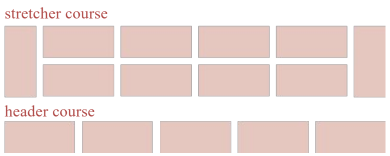
115 | Detail Section (Y-KK_IW_NORTH)



116 | Detail Snapshot 3D Modell (Y-KK_IW_NORTH)

117 | Snapshot 3D Model (Y-KK1-2_IMW)

stretchers positioned along the outer edge, while the interior is laid with headers. For the sake of simplicity, in this analysis, the term *stretcher course* refers specifically to this particular *stretcher-header mix*.

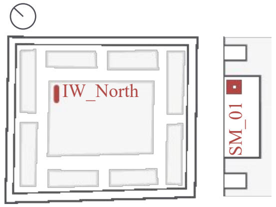


The internal structure of the header course is simpler, showing the bricks laid in a single row spanning the entire wall thickness. As already noted in the analysis of the masonry square meter, care was taken to stack the bricks directly on top of each other without creating an offset between the courses. However, due to the stretcher course, which does not begin with a full brick length but instead with a brick width, an offset occurs between the header course and the stretcher course. This offset is advantageous as it enhances the stability and cohesion of the masonry. While the visible arrangement may initially seem structurally unfavorable due to the lack of staggered joints, the internal configuration adequately compensates for this.

(1.) Furthermore, a few bricks can be identified here that appear to form a transition between the interior wall and the intermediate wall Y-KK1-2_IMW. These bricks seem to belong to the course with the stretcher course. However, since only a few bricks are visible and the rest are still covered with mud coating, few conclusions can be drawn due to the lack of sufficient evidence. Nevertheless, it is clear that there appears to be an indication of an interlocking connection between the interior wall and the intermediate wall in this area.

(2.) Interestingly, directly on the opposite side of the intermediate wall Y-KK1-2_IMW, a visible gap can be observed between the interior wall and the intermediate wall. This suggests that these might be separate structural elements.

SM_01



118 | Masonry Square Meter (SM_01); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**6 header and 9 stretcher courses** **header: 67 + (4) = 71 bricks** **stretcher: 28 + (2) = 30 bricks**
3.	brick height:	**50 - 73 mm**
4.	brick length (stretcher):	**204 - 268 mm**
5.	brick length (header):	**89 - 122 mm**
6.	joint thickness (horizontal):	**0 - 7 mm**
7.	joint thickness (vertical)	**0 - 11 mm**
8.	number of brick courses per 1m²:	**15**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1.28 m**

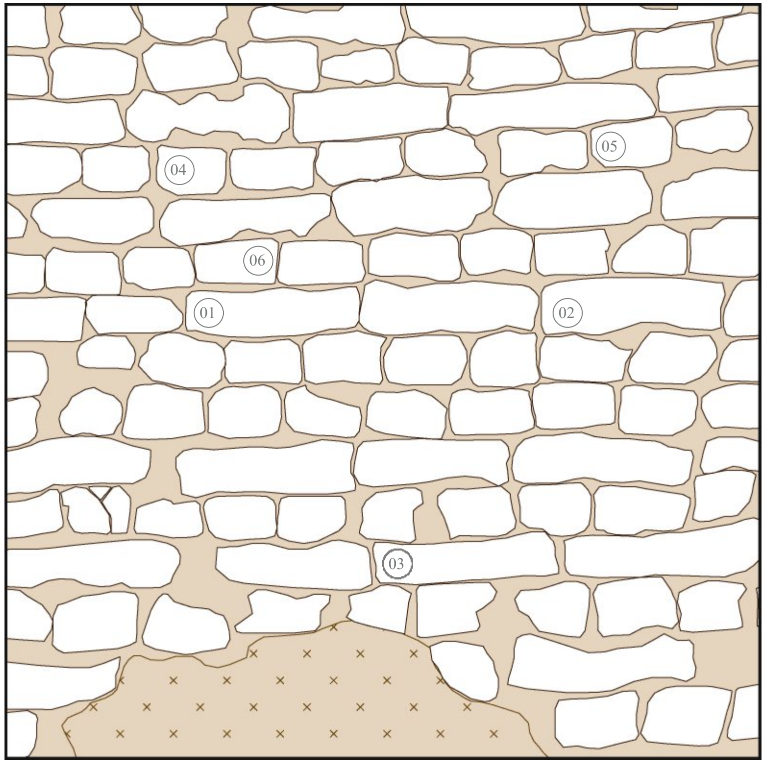
The masonry square meter consists of a total of 95 visible bricks. If the areas covered by the mud coating are reasonably supplemented with bricks, the total amounts to 101 bricks per square meter. These bricks are laid in different orientations. While 9 courses are laid with the header side visible, the remaining 6 courses are laid with the long side (stretcher) visible. The courses alternate, except for one double course of header course.
The vertical joints of the bricks mostly align with each other, with only a slight offset in some cases. In the header course, every second vertical joint aligns with the positioning of the stretcher course.

The bricks have dimensions varying in height between 5.4 and 7.3 cm, a length measured from the stretcher course of 20.4–26.8 cm, and a width measured from the header course of 9.1–12.2 cm. This indicates that the height of the bricks varies by 19 mm, or nearly two centimeter. The length shows a difference of 6.4 cm, while the width exhibits a difference of 3.1 cm. These variations may explain the slight offsets between the courses. In particular, the length of the bricks varies the most and could cause such discrepancies during the laying process.

The mud mortar joints are barely visible in the view. Between the courses, they are virtually nonexistent, and within the courses themselves, there are only minimal gaps between the bricks where mud mortar is occasionally visible.

The selected bricks, numbered 1–6, fall within the average range of dimensions, with the greatest variation observed in their heights.

These dimensions are entered into a dedicated database and contribute to calculating the dimensions of an average brick.



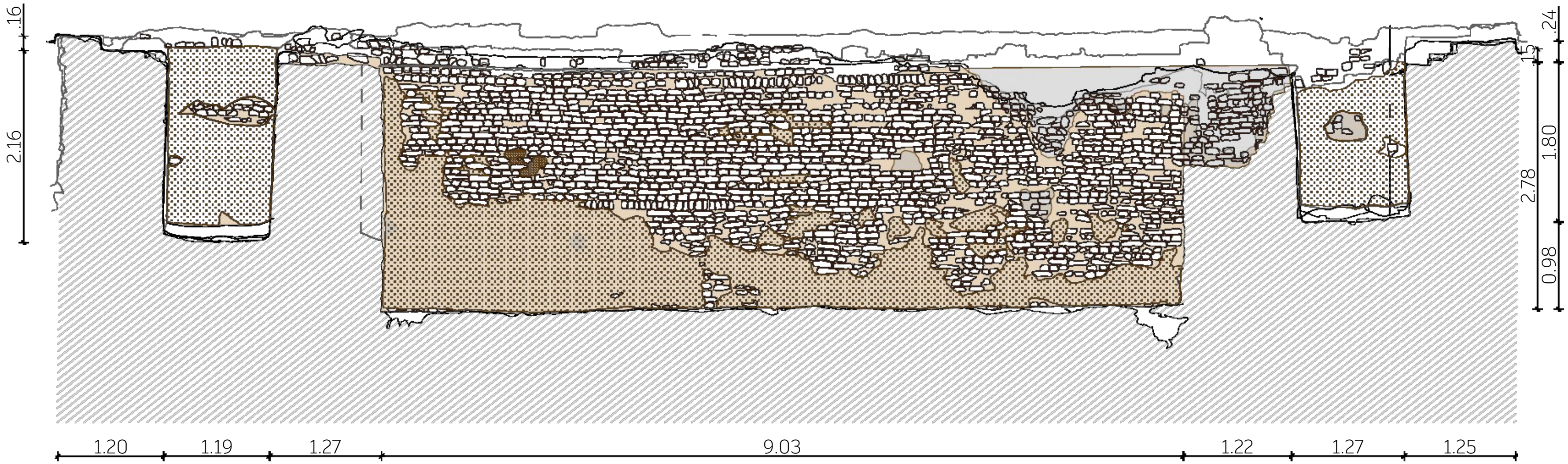
119 | Masonry Square Meter (SM_01); Mapping SCALE 1:10

No.	LENGTH	WIDTH	HEIGHT
1	22,7	-	6,1
2	23,7	x	7,3
3	23,6	x	5
4	x	9	6,1
5	x	10,7	6,2
6	x	11,4	5,4

120 | Measurements Bricks 1-6

121 | Elevation View (Y-KK_IW_North); 3D Model

122 | Section View 3D Model; Y-KK_IW_EAST SCALE 1:75



123 | Section View Mapping; Y-KK_IW_EAST SCALE 1:75

6.6.2 Interior Wall EAST (Y-KK_IW_EAST):

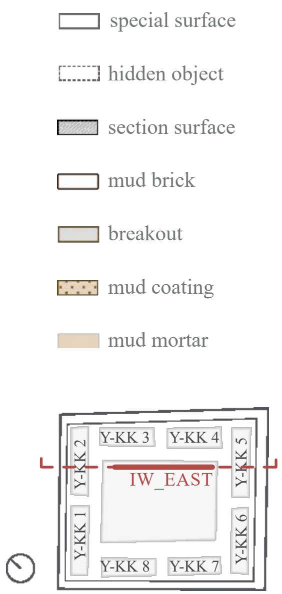
Visible bricks: 1598 bricks
Wall surface: 25.1 m²
Wall volume: 34.1 m³
Brick-laying technique: Stretcher, header, and rowlock courses; brick courses to the top edge: 33 visible + 7 additional
Visible courses:
Stretcher course: 14 + (3) courses
Header course: 18 + (4) courses
Rowlock course: 1 course
Non-visible courses: 7 courses

The figure illustrates the intrior east wall along with views of magazines Y-KK 2 and 5. The wall has a length of 9.03 m, a depth of 1.36 m, and a height of 2.78 m, resulting in a visible wall surface area of 25.1 m² and a wall volume of 34.1 m³.

Mud coating is still present in the lower portion of the wall and along the northern side. The upper edge on the southern side is heavily damaged, as also revealed by the section through the south wall, where significant portions are missing.

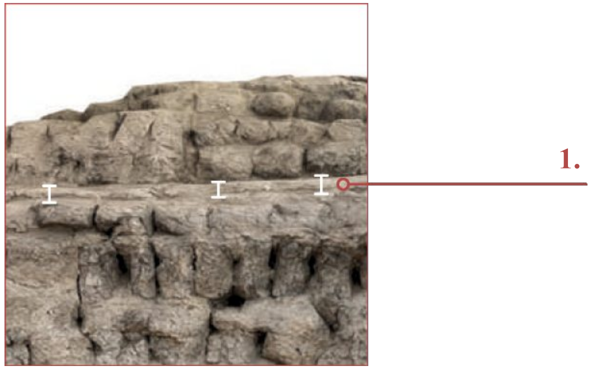
In the areas not covered by mud coating or where it has fallen off, the brick masonry becomes visible. Overall, the discoloration is not as pronounced as on the north wall regarding fire damage. The most extensive reddish-black discolorations are concentrated in the lower portion of the wall. Notably, some of the bricks - not just the mud coating - are red, indicating that they were directly exposed to the fire.
The large breakout on the southern side suggests significant damage and is too extensive to have served as a beam socket or similar feature. In contrast to the north wall, no base or obvious beam sockets are present here.

A total of 1598 bricks are visible, arranged across 40 courses. In some areas, only fragments of courses are

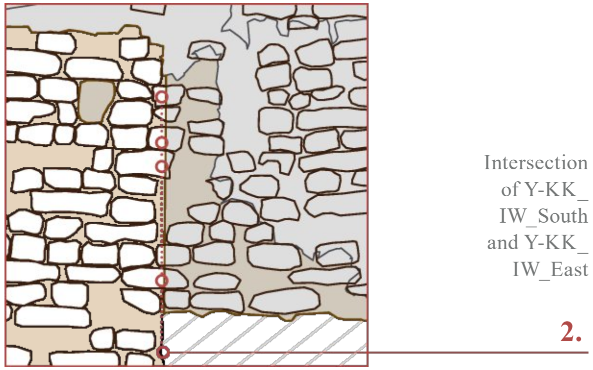


visible as they are covered by the mud coating. Nevertheless, it can be assumed that this laying technique extends across the entire length of the wall, as there is no reason to suggest that the bonding patterns would change within the same plane, except in rare cases. Generally, the courses remain consistent. These comprise 17 courses (14 visible + three extended) of stretcher course, 22 courses (18 visible + four extended)of header course, and one course of rowlock course. It should be noted here that, fundamentally, a header-rowlock mix occurs twice. This means a rowlock course runs over into a header course. However, in total, they collectively form one header course and one rowlock course.

Due to the considerable length of the wall, slight variations in course types occur - specifically with the header and rowlock courses - though no changes are observed in the stretcher courses. It is possible that rowlock courses were occasionally inserted as leveling courses, given that they are taller than a single brick height but shorter than a double brick course. Similar to the north wall, double courses of the header course are also present, occurring at regular intervals of every seven courses, except near the upper section.



124 | Detail; Snapshot 3D Model



125 | Detail; Elevation View

2.

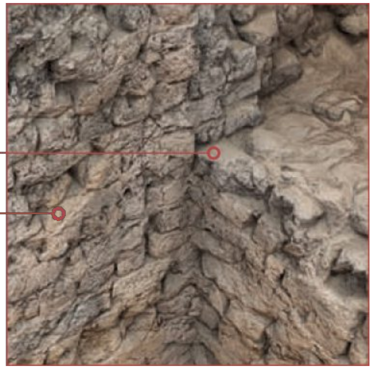
Intersection of Y-KK_ IW_South and Y-KK_ IW_East

126 | Detail; 3D Model Snapshot

3.

STRETCHER

STRETCHER COURSE



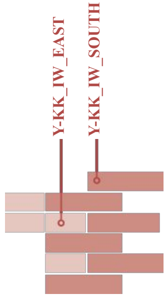
127 | Detail; 3D Model Snapshot

3.

Y-KK_IW_SOUTH

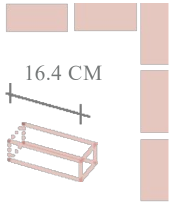
Y-KK_IW_EAST

128 | Detail; Elevation View



(1.) Of particular note is the clear visibility of the stepped structure of the interior wall along the upper edge, as well as the mud coating applied to this section. In this area, the thickness of the mud coating ranges between 2 and 3 cm.
The breakouts at the junctions of the east and south interior walls provide valuable insights into how the interlocking of the walls may have been executed. In the corner area of the interior east and south walls, partial indications can be observed of how the respective courses meet.

(2.) Firstly, it becomes apparent that the course of the east interior wall continues into the outermost course. This is more evident in the header courses, where the continuation is clearly visible.

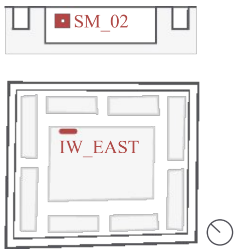


(3.) The stretcher courses are less distinct; however, there is a noticeable overlap at the corner where the two walls intersect. In one course of stretcher courses, the first brick of the south wall measures 16.4 cm in length - this is shorter than the typical dimensions of a stretcher.

Therefore, it can be assumed that this brick is interlocked with the adjacent wall, providing a theoretical basis for corner connections in stretcher courses. It is appears that the inner course of one wall continues until it meets the course of the other wall.

The bricks identified as stretchers in the graphic (*Figure 128*) are, in fact, headers from the south interior wall. In this area, a regular offset can also be observed, indicating that the same system was consistently applied per course when the walls intersected.

SM_02

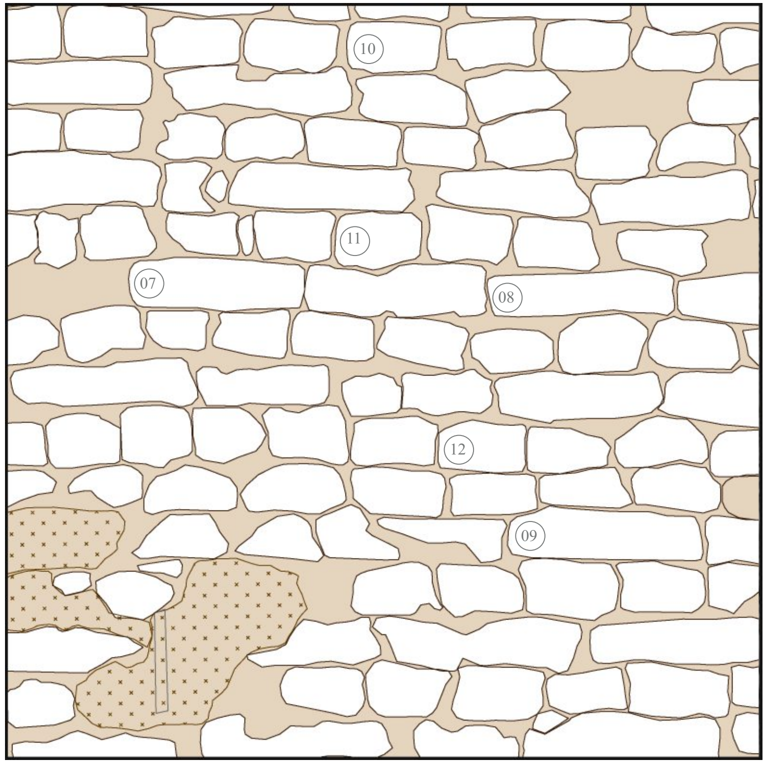


129 | Masonry Square Meter (SM_02); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**7 header and 8 stretcher course** **header: 64 + (5) = 69 bricks** **stretcher: 28 + (1) = 29 bricks**
3.	brick height:	**49 - 74 mm**
4.	brick length (stretcher):	**206 - 259 mm**
5.	brick length (header):	**94 - 126 mm**
6.	joint thickness (horizontal):	**0 - 6 mm**
7.	joint thickness (vertical)	**0 - 20 mm**
8.	number of brick courses per 1m²:	**15**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1, 36m**

The masonry square meter on the east wall consists of a total of 98 visible bricks, including 29 bricks laid with the stretcher side visible (28 directly observed plus one reconstructed) and 69 bricks laid with the header side visible (64 observed plus five reconstructed). There are no rowlock courses present in this area, and the courses are arranged in an alternating pattern throughout.
In the lower-left section, a small portion is still covered with mud coating. In this area, six bricks were logically reconstructed based on the surrounding pattern. A double layer of header courses is located near the middle, consistent with the arrangement observed on the north wall. A total of 15 courses are visible within this square meter. The dimensions of the bricks vary: stretcher bricks have lengths between 20.6 cm and 25.9 cm, headers range from 9.4 cm to 12.6 cm in length, and the height of the bricks spans 4.9 cm

to 6.9 cm. Some bricks are broken or illegible, and in these cases, they were typified and got dimensions assigned based on averages.
The mud mortar joints are rarely visible, with almost no gaps between the courses. Within the courses, only minimal spaces are present between the bricks, where traces of mud mortar can occasionally be observed.
Both walls display a similar structure, with alternating header and stretcher courses and occasional double header courses. The ratio between the number of header and stretcher courses is slightly higher in the east wall. The regular use of double header courses in both walls suggests a deliberate design choice of consistency. The similarities in the layout support a standardized approach, while slight variations in the number and type of courses reflect minor differences because of the building process



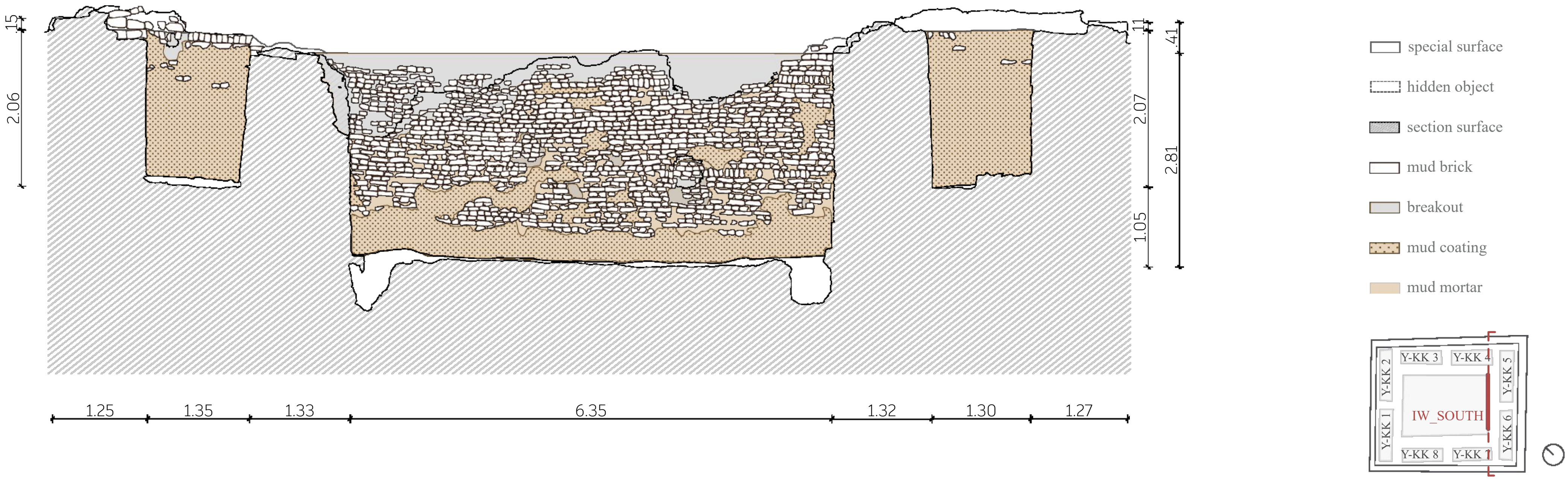
130 | Masonry Square Meter (SM_02); Mapping

No.	LENGTH	WIDTH	HEIGHT
7	23,3	x	6,9
8	24,1	x	5,2
9	25,4	x	6,2
10	x	12,1	6,5
11	x	11,1	7,4
12	x	11,7	6,6

131 | Measurements Bricks 7-12

132 | Elevation View (Y-KK_IW_East); 3D Model

133 | Section View 3D Model; Y-KK_IW_SOUTH SCALE 1:75



134 | Section View Mapping; Y-KK_IW_SOUTH SCALE 1:75

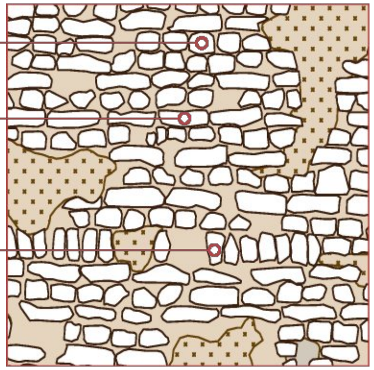
6.6.3 Interior Wall SOUTH (Y-KK_IW_SOUTH):

Visible bricks: 1146 bricks
Wall surface: 17.8 m²
Wall volume: 22.5 m³
Brick-laying technique: Stretcher, header, and rowlock courses;
brick courses to the top edge: 35 visible + 5 additional
Visible courses:
Stretcher course: 15 + (3) courses
Header course: 19 + (2) courses
Rowlock course: 1 course
Non-visible courses: 5 courses

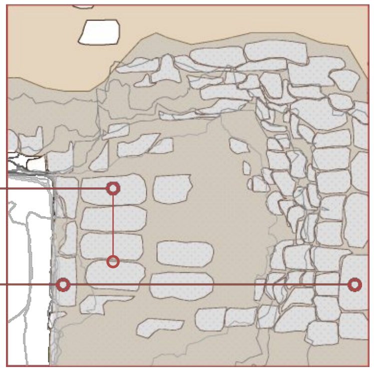
The figure illustrates the interior south wall, featuring a total of 1146 visible bricks. The wall has a height of 2.81 m, a length of 6.35 m, and an average depth of 1.26 m, resulting in a visible wall surface area of 17.8 m² and a wall volume of 22.5 m³. The brick-laying technique incorporates stretcher, header, and rowlock courses.
To the top edge, 35 brick courses are visible, with an additional 5 courses partly covered with mud. Among the visible courses, there are 15 stretcher courses, with three reconstructed, 19 header courses, with two reconstructed, and one rowlock course.

The interior wall on the South side is heavily damaged at the top. Nevertheless, the missing sections at the top, as well as a hole in the right middle area of the wall, clearly reveal the brick-laying technique. The mud coating in magazines Y-KK 7 and Y-KK 4 is still very well preserved, so no conclusions regarding the brick bond pattern can be drawn. The brick courses consist of sequential courses of header and stretcher courses. It is highly likely that this pattern was also repeated in the foundation area covered by mud or in sections that are no longer preserved.

135 | Elevation View; Y-KK_IW_SOUTH



136 | Elevation View; Y-KK_IW_SOUTH



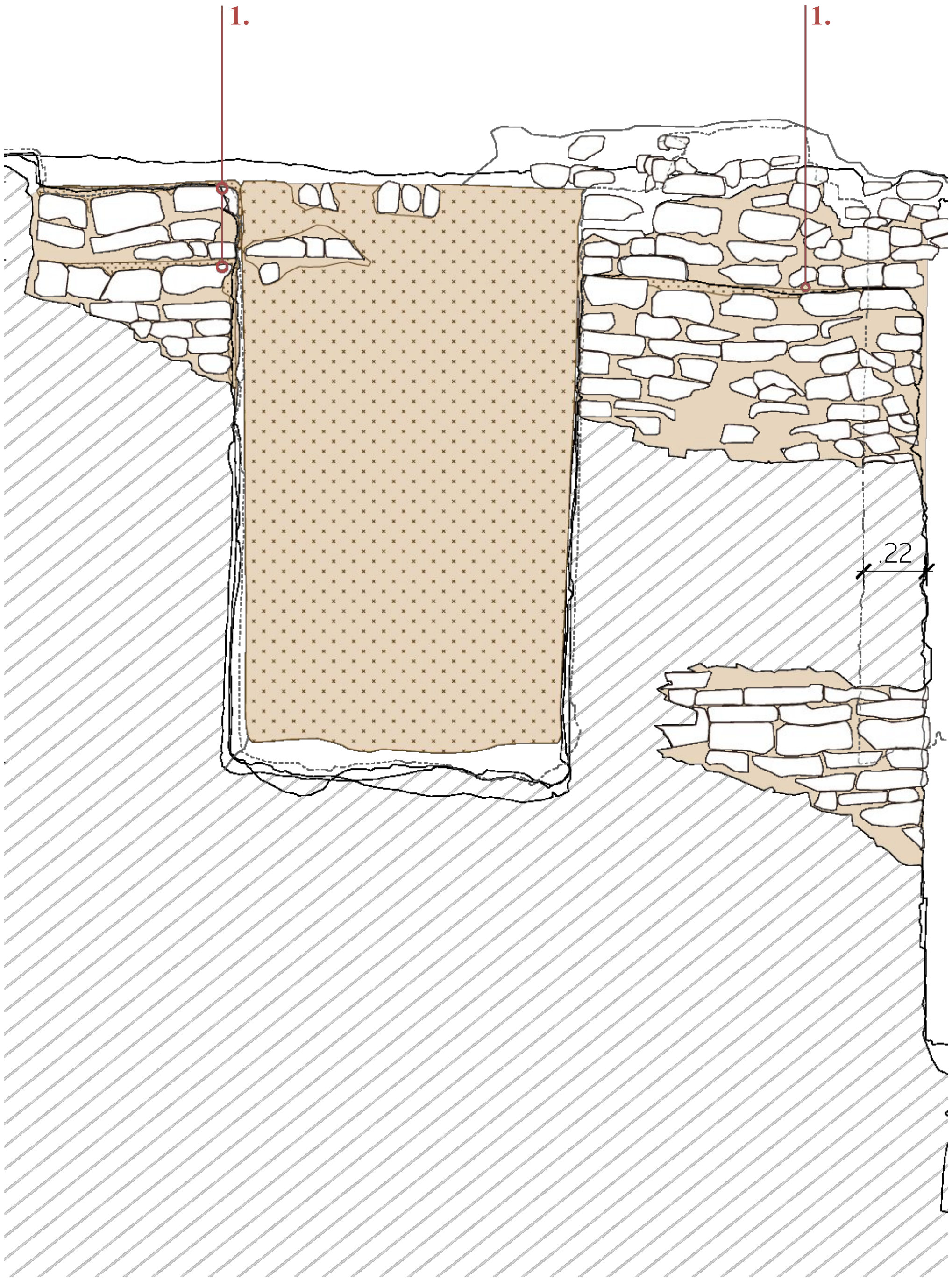
137 | Plan View; Y-KK_IW_SOUTH

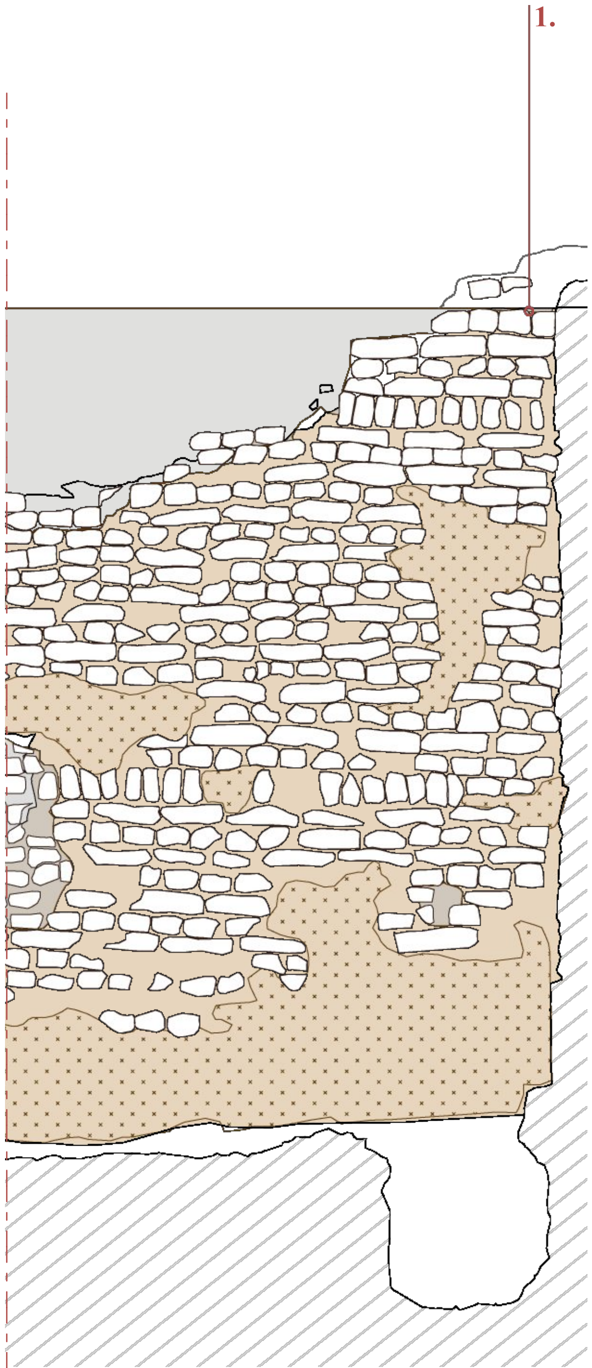
Primarily, only these header and stretcher courses are used, arranged in an alternating pattern. However, header courses are occasionally laid twice in succession, whereas stretcher courses do not appear directly on top of one another. The arrangement and spacing of the courses, as well as the joints between the bricks, appear regular and uniform.

The bricks are tightly placed together, with minimal mortar courses visible. Since the course joints are only partially offset and frequently align vertically, it seems that the intention was to create a masonry bond with aligned course joints.
The rowlock course technique is used in only two specific locations: in the fifth row from the top on the right side and once near the middle, also on the right side. In both instances, the rowlock course does not continue across the entire wall but transitions to a header course.

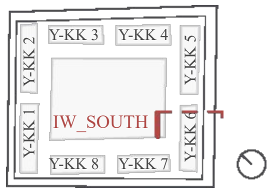
While the top edge frequently features a rowlock course, the presence of a rowlock course in the middle is relatively rare and likely served a constructive purpose. It is plausible that the ground was uneven or that the construction materials settled significantly, necessitating the addition of a leveling course to maintain the overall alignment of the structure.

In *Figure 137*, the top view of the 17th course is exposed because of the damage. It is a continuous course with a stretcher course, as visible in the wall elevation. This laying technique is now also evident in a top view, confirming the previously drawn conclusions. As now apparent, the first row does not repeat itself. In the subsequent rows, the bricks are rotated by 90 degrees, resulting in the brick-laying technique of the following rows transitioning into a header course.



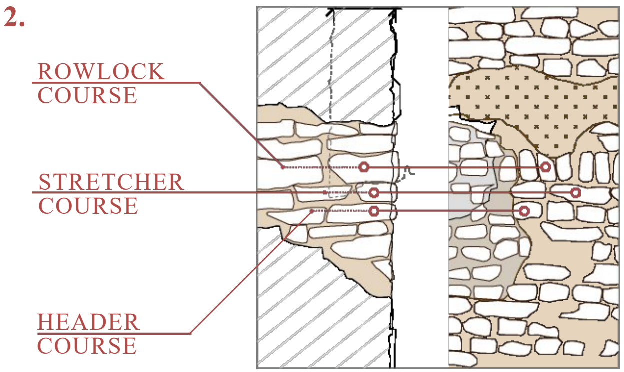


special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar



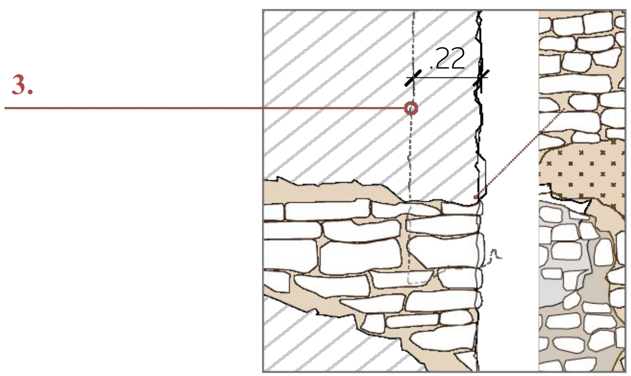
 Section View; Y-KK_IW_SOUTH SCALE 1:25

 Elevation View Y-KK_IW_SOUTH



140 | Folded Section; Y-KK_IW_SOUTH

141 | Plan View; Y-KK_IW_SOUTH



142 | Detail Folded Section; Y-KK_IW_SOUTH

(1.) In the section, the remnants of the mud coating are still visible at the upper edge of the wall. The thickness of this layer measures up to approximately 2.7 cm. Interestingly, this coating is not only present along the topmost edge but has also been identified at a height of 1.78 (from the floor of the magazine) on both the exterior wall and the south interior wall.

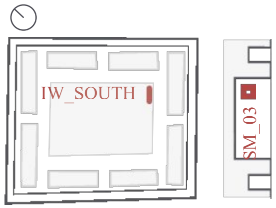
This observation could provide insight into the construction phases. It suggests that the walls might have been erected and coated first, followed by the necessary adaptations for additional structural elements, including the roof construction.

(2.) Not only in sections but also partially in the top view, the brick bond within the walls can be observed. In areas such as Y-KK_IW_SOUTH, where a significant portion of the wall's upper edge is missing, it becomes evident again that the inner bricks are all oriented in the same direction, regardless of the course.

Additionally, the offset between the stretcher course and the header course is occasionally visible, highlighting the consistent alignment and the relationship between the courses within the masonry.

(3.) During the creation of the plan graphics for the section, a cut through magazines Y-KK6 and Y-KK7 was also made and marked with a gray line. It is now evident that the continuation of the south interior wall into the intermediate wall Y-KK6-7_IMW aligns with the exterior side of the south wall but is offset by 22 cm on the interior side. This offset corresponds to the length of a single brick.

SM_03



143 | Masonry Square Meter (SM_03); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**6 header and 9 stretcher course** **header: 67 + (9) =76 bricks** **stretcher: 20 + (4) = 24 bricks**
3.	brick height:	**49 - 74 mm**
4.	brick length (stretcher):	**222 - 261 mm**
5.	brick length (header):	**86 - 120 mm**
6.	joint thickness (horizontal):	**0 - 9 mm**
7.	joint thickness (vertical)	**0 - 19 mm**
8.	number of brick courses per $1m^2$:	**15**
9.	mortar:	**mud coating**
10.	plaster type:	**mud**
11.	wall thickness:	**1,36m**

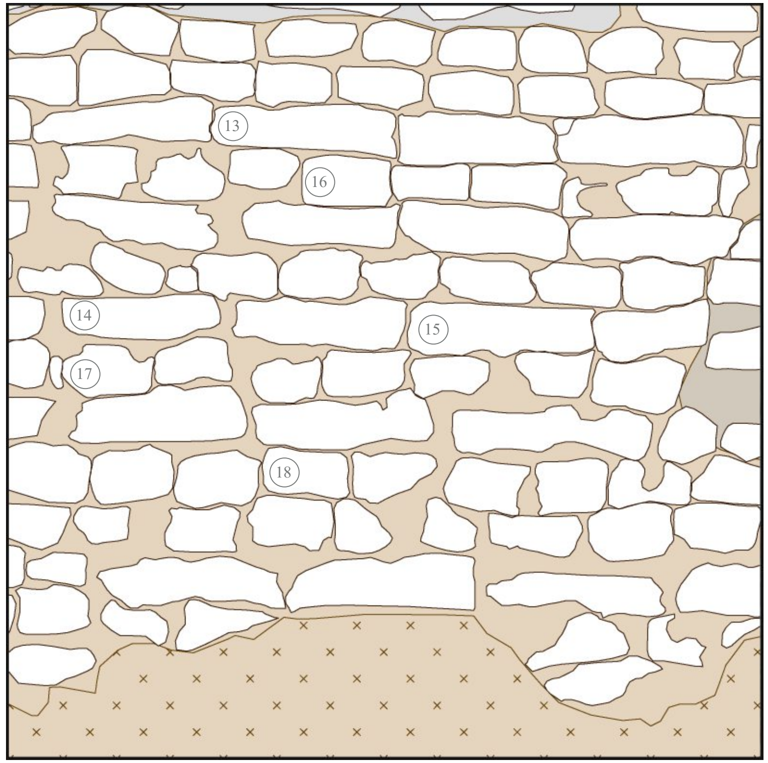
The masonry square meter on the south wall consists of a total of 100 bricks, with 87 visible and 13 reconstructed in areas where the mud coating still covers the surface. This square meter includes 15 courses arranged in an alternating stretcher-header pattern, reflecting a consistent and methodical construction approach.

Of the total bricks, 67 visible headers and 9 reconstructed headers can be identified, alongside 20 visible stretchers and four reconstructed ones. No rowlock courses are present in this section. The brick distribution aligns with the observed pattern.

Notably, two double layers of header courses are present within this section. One is located in the upper area, while the other can be observed in the middle to lower portion of the wall. The laying concept features a stretcher brick positioned below two headers, a pattern that is generally consistent but occasionally shows slight offsets, likely due to minor adjustments during the laying process.

The dimensions of the bricks vary, with stretcher bricks measuring between 22.2 and 26.1 cm in length and headers ranging from 8.6 to 12 cm. The brick height spans from 4.9 to 7.4 cm. The mud mortar joints are relatively narrow, with a maximum thickness of 1.9 cm.

The remaining mud coating in the lower portion of the wall obscures part of the courses, but the reconstructed bricks in these areas follow the same logical arrangement observed in the visible sections.



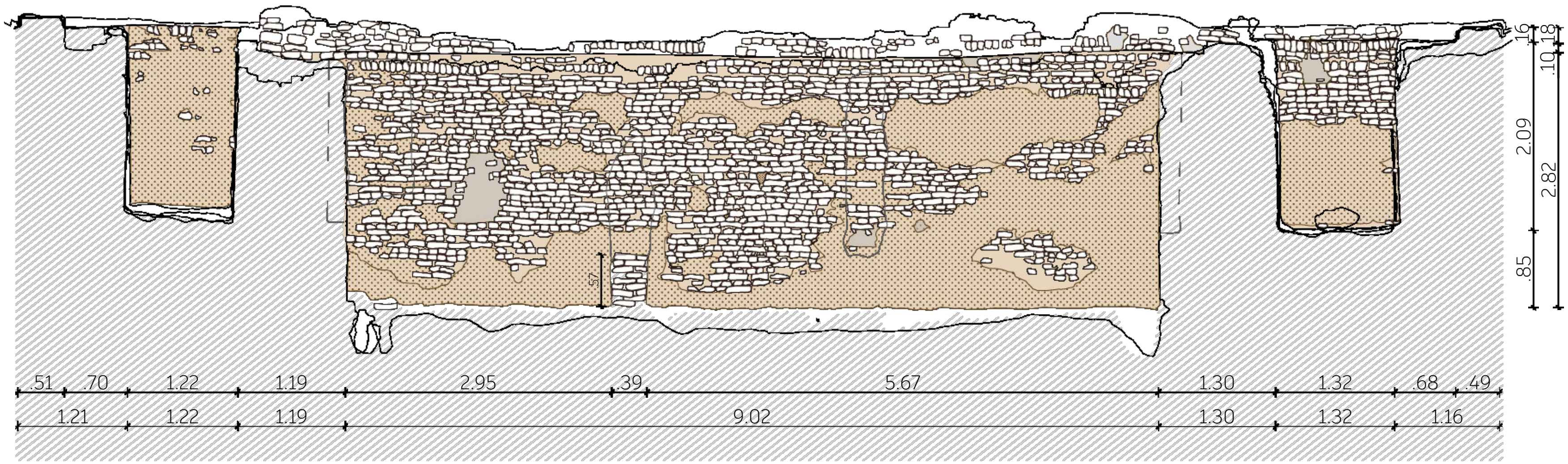
144 | Masonry Square Meter (SM_03); Mapping

No.	LENGTH	WIDTH	HEIGHT
13	24,06	x	5,89
14	20	x	5,7
15	24,2	x	5,7
16	x	11,7	6,87
17	x	11,95	7,2
18	x	11,28	6,12

145 | Measurements Bricks 13-18

146 | Elevation View (Y-KK_IW_South); 3D Model

147 | Section View 3D Model; Y-KK_IW_WEST SCALE 1:75



148 | Section View Mapping; Y-KK_IW_WEST SCALE 1:75

6.6.4 Interior Wall WEST (Y-KK_IW_WEST):

Visible bricks: 1474 bricks
Wall surface: 25.4 m²
Wall volume: 32.0 m³
Brick-laying technique: Stretcher, header, and rowlock courses
brick courses to the top edge: 36 visible + 4 additional
Visible courses:
Stretcher course: 16 + (2) courses
Header course: 19 + (2) courses
Rowlock course: 1 course
Non-visible courses: 4 courses

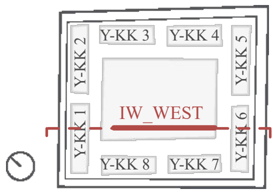
The figure illustrates the interior west wall, comprising a total of 1 474 visible bricks. The wall has a height of 2.82 m, a length of 9.02 m, and an average depth of 1.26 m, resulting in a visible wall surface area of 25.4 m² and a wall volume of 32.0 m³. The brick-laying technique features stretcher, header, and rowlock courses. To the top edge, 36 courses are visible, with an additional four courses reconstructed in the obscured sections. The visible courses include 16 stretcher courses with two reconstructed, 19 header courses with two reconstructed, and one rowlock course.

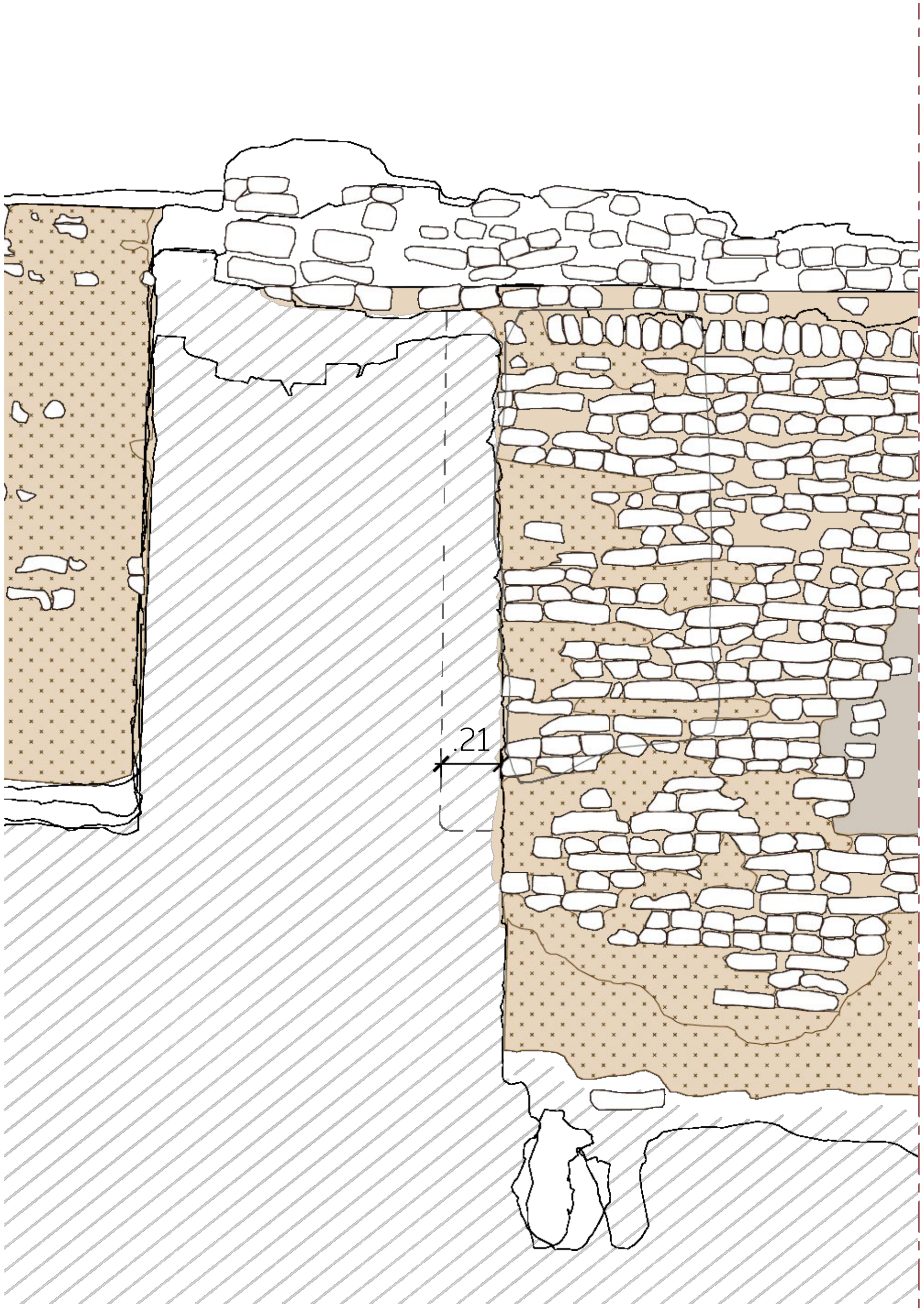
The most significant surface discolorations caused by fire damage are located on the right side, in the northwest corner. This area also retains the largest amount of mud coating.
In some sections, the surface of the mud coating appears to be very smoothly finished, suggesting that it originally served as the final layer. In contrast, the lower part of the wall has a rougher mud coating, indicating that a thin layer may already be missing. Despite this, the masonry itself is not yet visible in these areas.

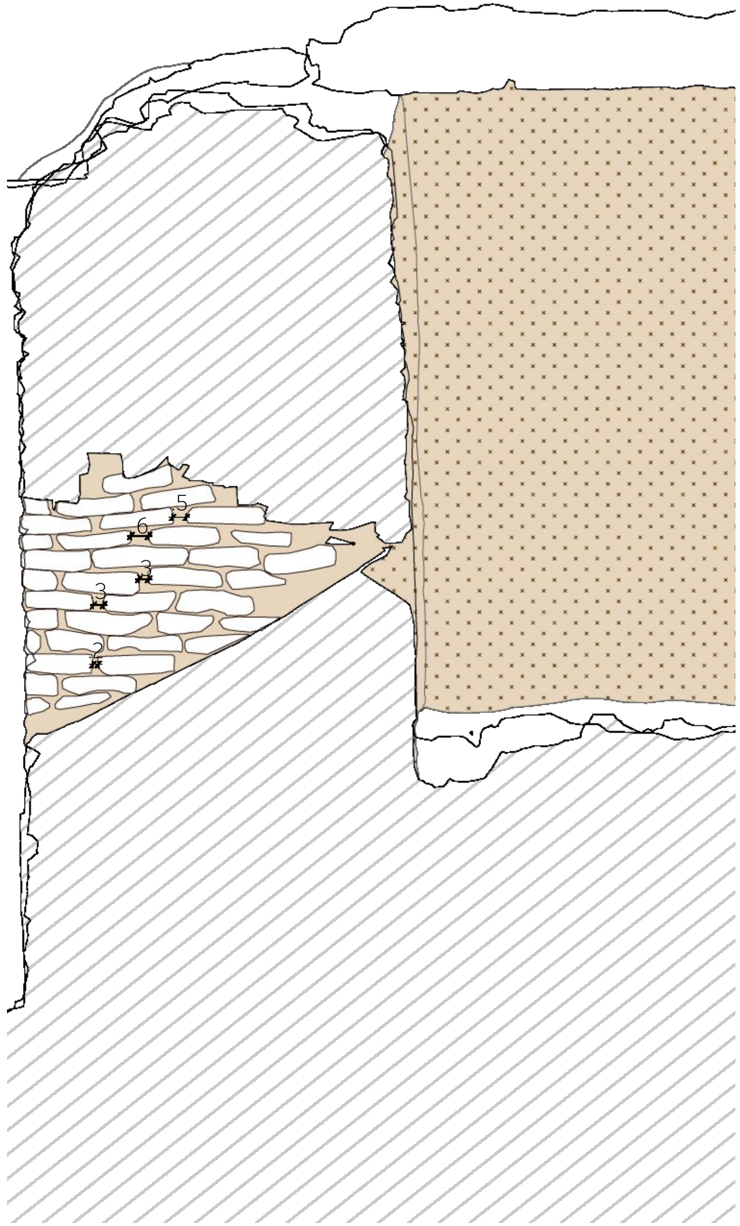
Along this wall, small surface irregularities can be observed, but no large breakouts that could be identified as beam sockets. However, as seen on the north wall, a brick base is present in front of the west interior wall. This base is slightly larger, measuring 57 cm by 39 cm, and consists of 9 brick courses. It is constructed in the same manner as the one found on the north wall.

The base is positioned 2.95 m from the south wall and 5.67 m from the north wall. On the

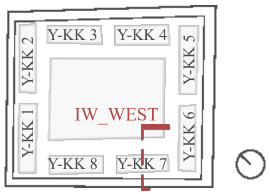
special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar



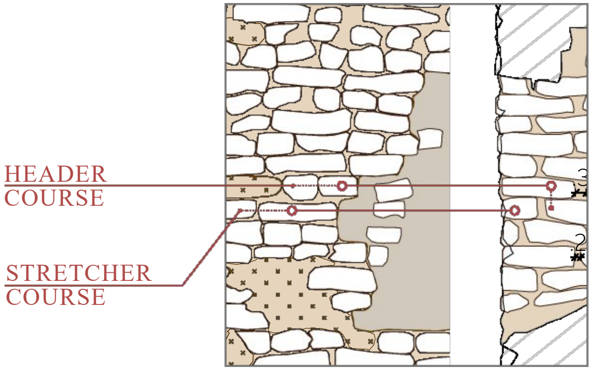




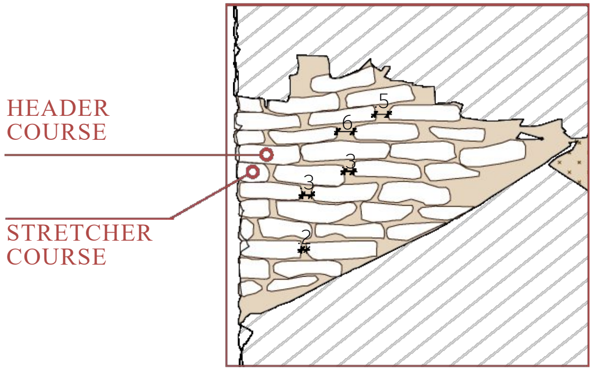
special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar



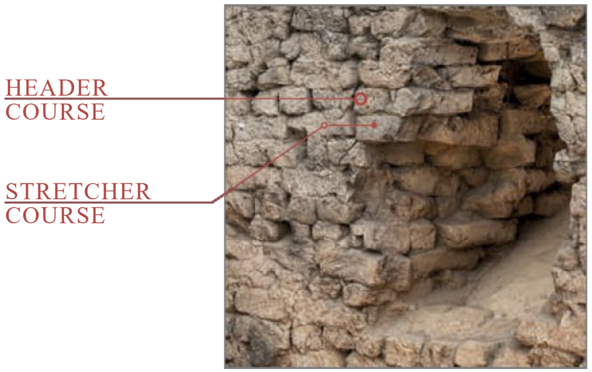
SCALE 1:25



151 | folded section; Y-KK_IW_WEST

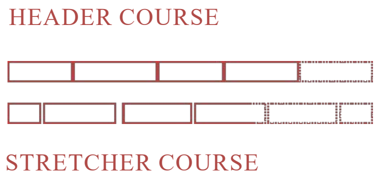


152 | Section; Y-KK_IW_WEST



153 | Snapshot; Break out Y-KK_IW_WEST

north wall, the base is similarly located three meter from the wall‘s edge. Above the base, the surface is noticeably lighter, showing no signs of fire damage. This lighter surface forms a stripe that runs directly above the base and matches its width.



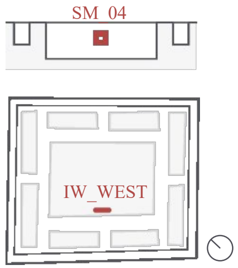
Additional vertical stripes are visible, including one at the corner near the south wall and another, 2.6 m to the right of the base (center-to-center distance). While no base is present at this second location, the stripe‘s width aligns with that of the existing base, suggesting that another support structure might logically have been positioned here. This alignment hints at a systematic arrangement, likely related to the structural support of the wall and its associated elements. In the folded section, many features which were already observed in the other walls can be identified once again.

In the opening present in Y-KK_IW_WEST, the brick-laying techniques of the various courses are clearly visible. Since the opening extends deep into the wall, it is evident that the header courses consist of five brick lengths, while the stretcher courses include two brick widths plus four brick lengths.

It is also apparent that the mud mortar joints within the section and the interior are significantly larger than those visible on the surface of the wall. The interior joints range from 2 cm to as much as 6 cm in width. Notably, none of these wider joints are aligned directly above one another. The offset of the bricks is consistently maintained, ensuring stability throughout the masonry.

In conclusion, the courses of the interior west wall (Y-KK_IW_WEST) remain consistent throughout, reflecting a standardized construction approach. The difference in wall width, with the intermediate wall Y-KK6-7 being 21 cm narrower than the interior west wall, corresponds to the same relationship observed in other transitions between interior walls and intermediate walls. Additionally, the brick-laying technique observed within the wall, visible through the openings, aligns with the patterns identified in other sections, further supporting the uniformity of masonry methods across the structure.

SM_04



154 | Masonry Square Meter (SM_01); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**8 header and 7 stretcher course header: 28 bricks stretcher: 70 bricks**
3.	brick height:	**38 - 80 mm**
4.	brick length (stretcher):	**216 - 245 mm**
5.	brick length (header):	**92 - 116 mm**
6.	joint thickness (horizontal):	**0 - 7 mm**
7.	joint thickness (vertical)	**0 - 12 mm**
8.	number of brick courses per $1m^2$:	**15**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,26 m**

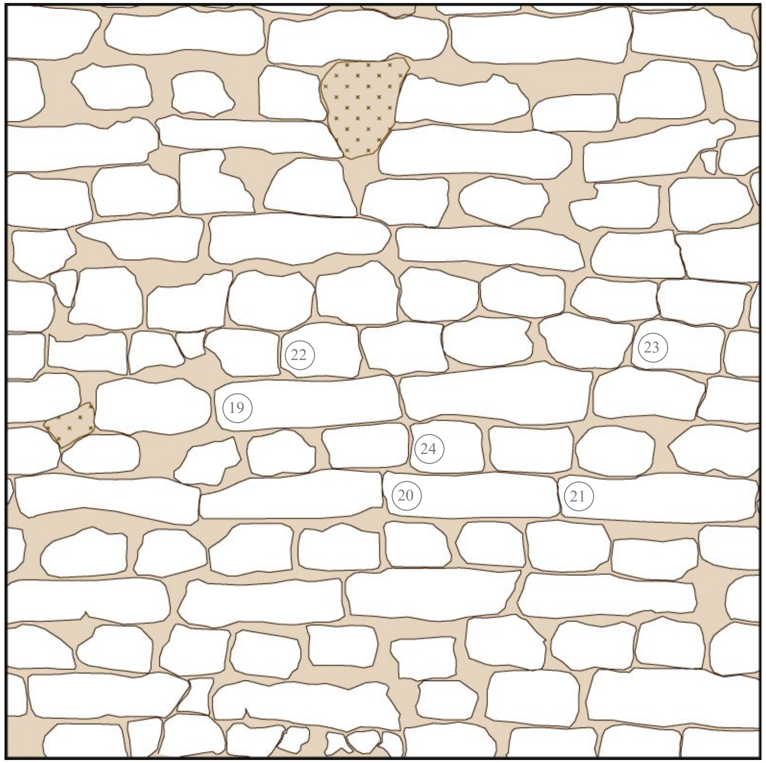
The masonry square meter on the west wall is constructed entirely of visible air-dried mudbricks, providing a complete view of the arrangement and structure. The wall consists of alternating header and stretcher courses, with a total of 28 header bricks and 70 stretcher bricks within this square meter.

The dimensions of the bricks vary, with stretcher bricks measuring between 216 and 245 mm in length and headers ranging from 92 to 116 mm. Brick heights range from 38 to 80 mm. The joints are thin, with horizontal joints measuring between 0 and 7 mm and vertical joints between 0 and 12 mm. A total of 15 courses are visible per meter, reflecting a consistent layering pattern. The stretcher courses (of the third and fifth row from the top) are notable due to the unusually low height of the bricks used. In this case, some stretcher bricks measure less than 4 cm in height,

which is exceptionally small compared to the standard dimensions.
The general laying technique follows a stretcher brick positioned beneath two headers. However, this stacked arrangement is less distinctly visible compared to other masonry square meters. While the pattern is not as pronounced here, it is occasionally observed in isolated areas.

The wall has a thickness of 1.26 m and is covered with mud coating as a plaster layer. The use of mud mortar in the joints is only slightly visible, with minimal traces observed between the bricks. This masonry section exhibits a more pronounced offset between courses, contributing to a slightly irregular appearance compared to other sections, though still adhering to the overall standardized construction approach.

SCALE 1:10

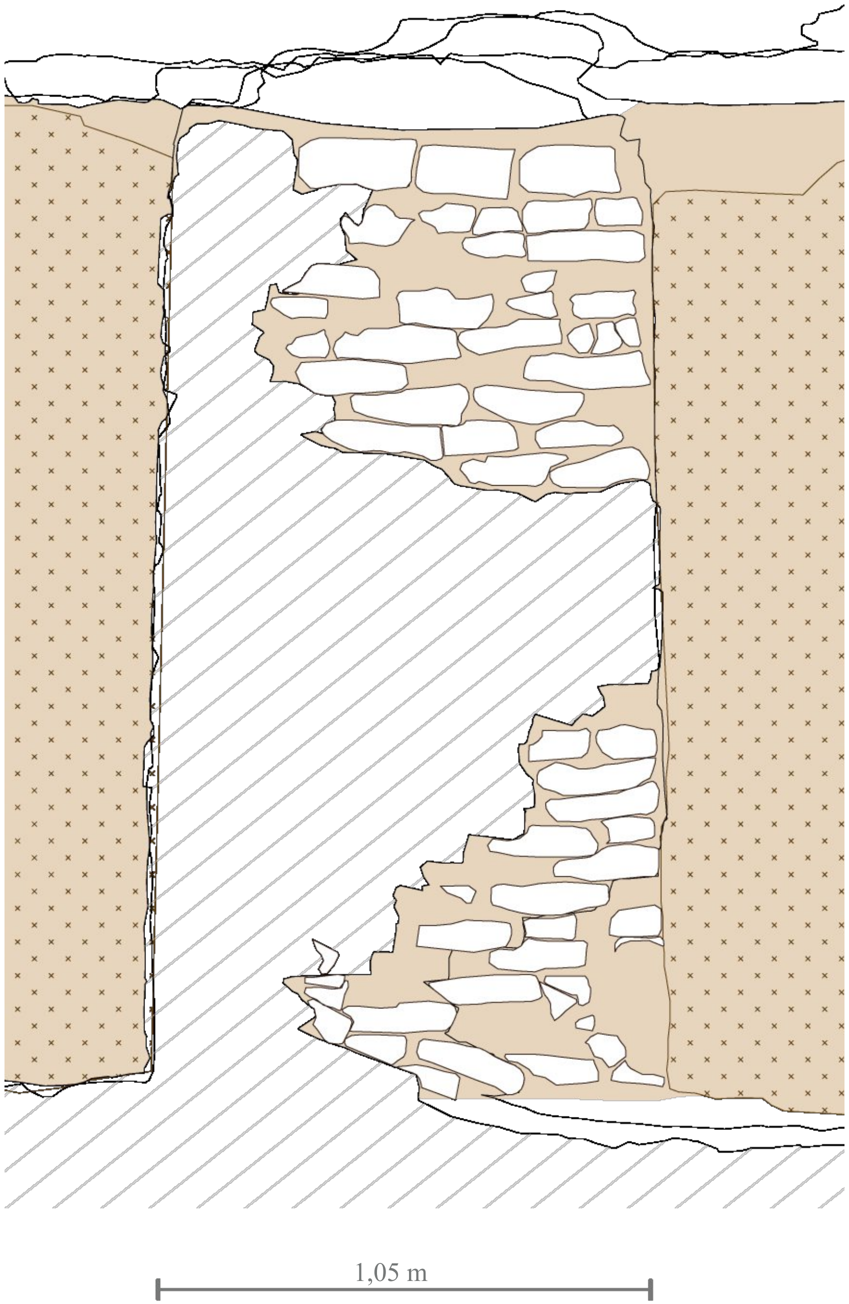


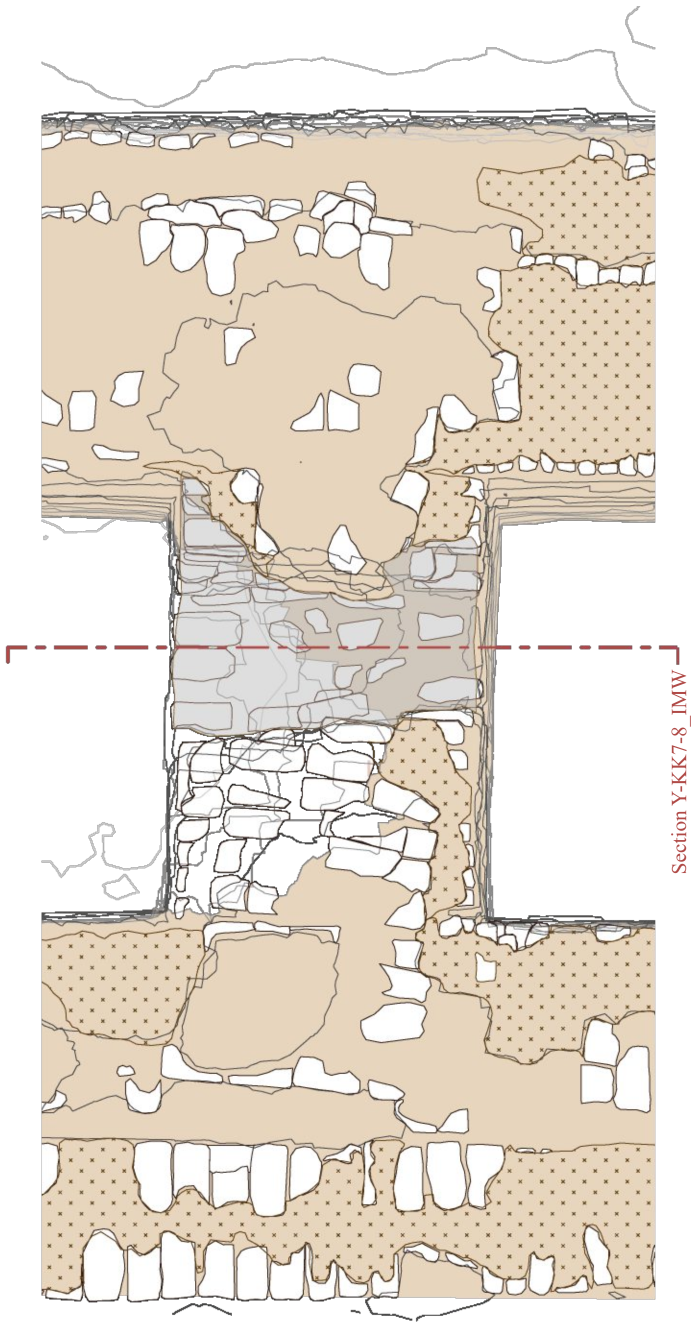
155 | Masonry Square Meter (SM_02); Mapping

No.	LENGTH	WIDTH	HEIGHT
19	24,1	x	5,7
20	22,5	x	6,1
21	25,9	x	6,4
22	x	10,5	6,7
23	x	11,8	6,7
24	x	9,2	6,7

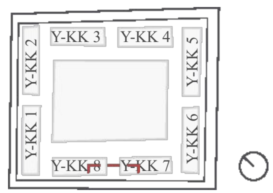
156 | Measurements Bricks 19-24

157 | Elevation View (Y-KK_IW_East); 3D Model





- special surface
- hidden object
- section surface
- mud brick
- breakout
- mud coating
- mud mortar

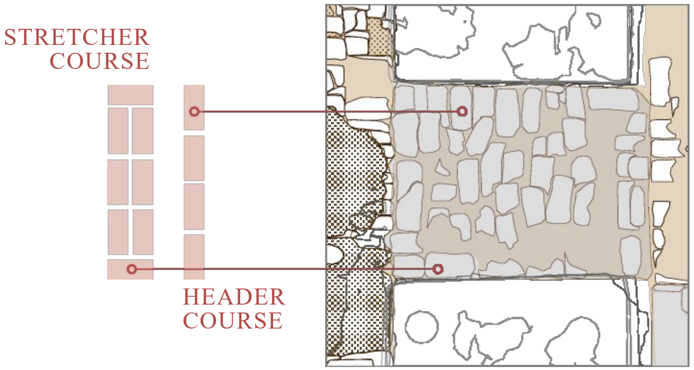


Y-KK7-8_IMW

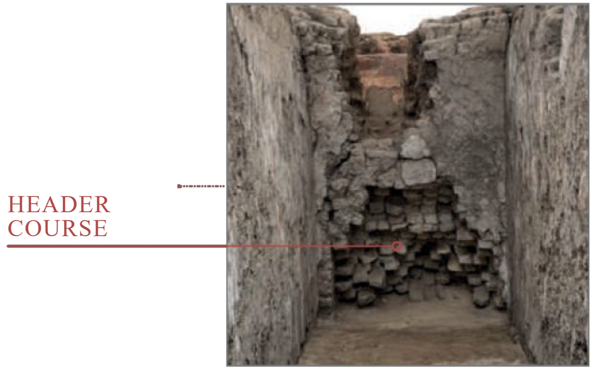
 | Section View; Y-KK7-8_IMW

 | Plan View; Y-KK7-8_IMW

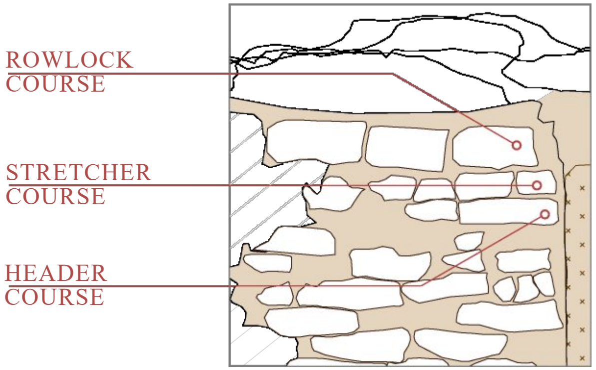
SCALE 1:25



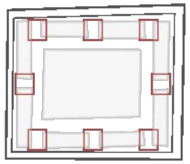
160 | Plan View ; Y-KK5-6_IMW



161 | Snapshot ; Y-KK7-8_IMW



162 | Detail Section; Y-KK7-8_IMW



In total, there are four intermediate walls positioned centrally between the respective interior and exterior walls, serving as connectors. Additionally, there are four intermediate walls located at the corners where two interior walls meet, linking them to the exterior wall.

The condition of the intermediate walls (IMW) is generally very good. Most of them are still covered with mud coating and show minimal damage. However, to study the construction in more detail, IMW 7-8 and Y-KK 1 provide the most insights. Y-KK7-8_IMW reveals significant details due to its damaged state, which includes two large holes that expose the interior of the wall. Similarly, Y-KK1 offers additional insights, as the top of the wall has less mud coating, making its construction more visible. While the interior and exterior walls generally have a thickness of 1.20 m (equivalent to five brick lengths), the depth of the intermediate walls is reduced by one brick length, averaging 1 m (equivalent to four brick lengths).

As seen in the section of Y-KK7-8_IMW, each course typically consists of four to five bricks in depth. Not all bricks are visible due to some being cut in the section, but when the brick-laying system is extended further, this becomes clear. This pattern is also evident in the plan view of Y-KK5-6_IMW. In *Figure 160*, due to the breaks along the top edge, it is possible to identify the types of courses used.
On one hand, the header course is visible, and on the other, the stretcher course can also be observed.

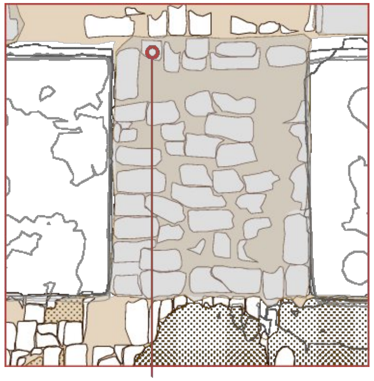
Based on the data from both walls, it is apparent that the same brick-laying technique used for the other walls is applied here. Here, as has often been observed with other walls, the topmost course was constructed using the rowlock course. The only difference is that one brick is omitted within the arrangement, resulting in the reduced wall thickness.

(1.) Especially in the case of the intermediate walls positioned between the interior and exterior walls, large gaps can be observed, such as those in Y-KK7-8_IMW. These gaps suggest that there may not be a structural connection between the individual building components.

(2.) However, there are also indications that some level of interlocking might exist. For instance, in the case of wall Y-KK5-6_IMW, where the upper section is damaged, it becomes apparent that parts of bricks connect the building components. This observation suggests a partial structural integration despite the gaps seen in other areas.

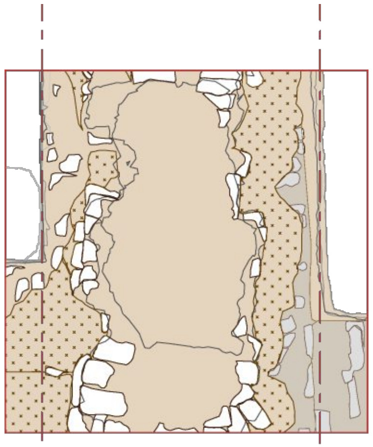
(3.) The dashed line represents the inner edges of the interior wall Y-KK_IW_WEST. A comparison was conducted to analyze the positioning of the bricks precisely in the regions where the line intersects. The bricks are laid using conventional techniques along the wall, with no observable changes in these areas. This suggests that an internal interlocking occurs, indicating a specific corner configuration where two interior walls intersect with an intermediate wall and an exterior wall.

163 | Detail Snapshot; Y-KK7-8_IMW

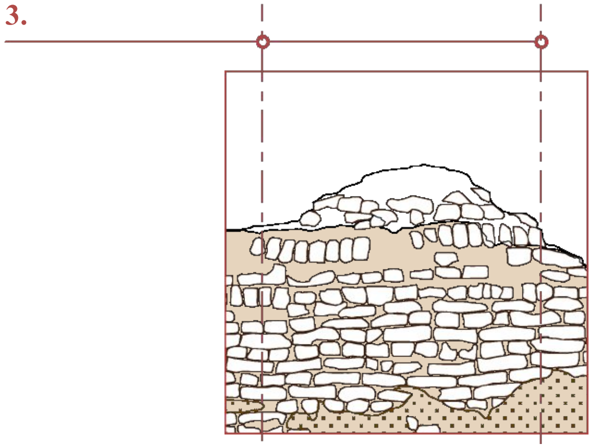


164 | Detail Plan View; Y-KK5-6_IMW

165 | Detail Snapshot; Y-KK5-6_IMW



166 | Plan View; Y-KK_IW_WEST



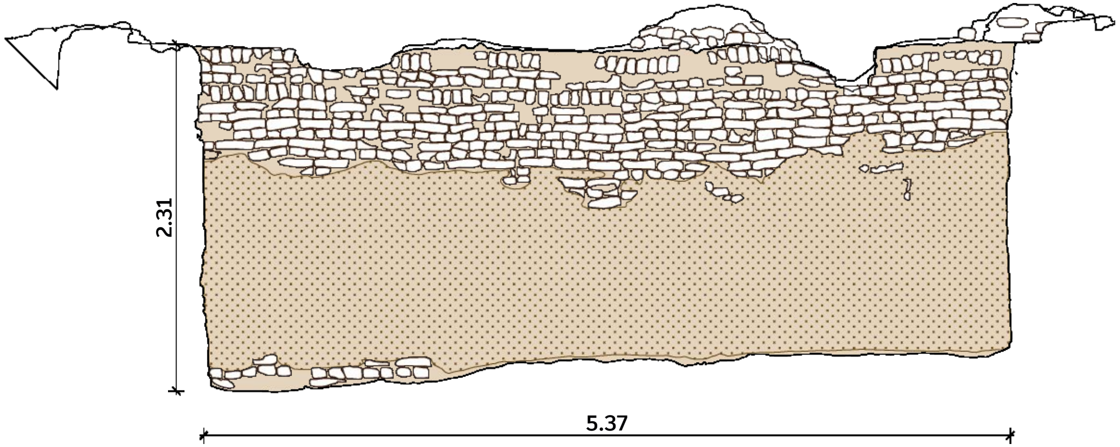
167 | Elevation View; Y-KK1_IMW_Y-KK8

If the structural components had been built sequentially, a clear termination of the wall would likely be visible. However, in this case, the outermost layer of bricks appears continuous, with no edges or terminations evident, further supporting the hypothesis of integrated construction.

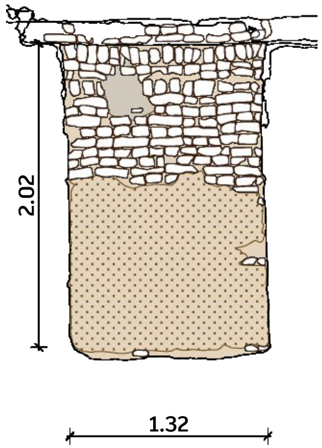
The intermediate walls placed at the corners of the interior walls are likely connected in some way. The outer visible bricks, at least in the observable areas, appear to be continuous. However, the exact nature of the connection between the intermediate wall and the exterior wall remains unclear. The relatively good condition of these walls could support the theory of interlocking, as one would expect to see damage patterns such as gaps or cracks if no structural connection existed. This suggests that the walls may have been intentionally integrated to enhance stability.

The connection between the intermediate walls positioned in the middle between the exterior and interior walls remains also ambiguous. On one hand, there are some indications that they are interlocked and form a cohesive unit. On the other hand, significant surface irregularities and even visible gaps at the transitions suggest otherwise.

Due to the well-preserved condition of the magazine wall surfaces, with minimal mud coating loss, drawing conclusions about these connections is challenging. The limited evidence available provides conflicting interpretations, making it difficult to determine the exact construction technique.

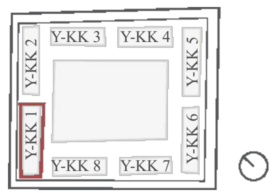


168 | Elevation View; Y-KK 1_IMW_Y-KK 8



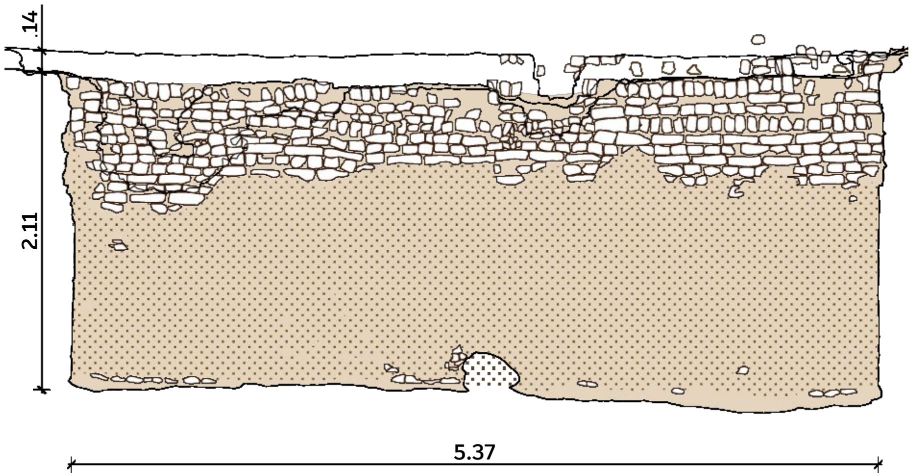
169 | Elevation View; Y-KK 1_IW_WEST

special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar

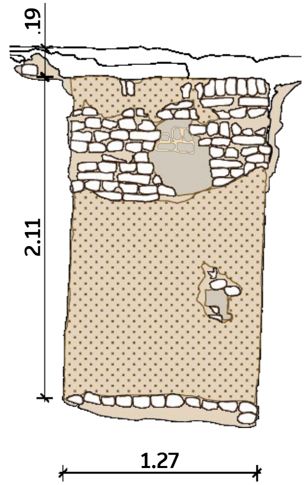


170 | Plan View of magazine Y-KK 1

SCALE 1:50



171 | Elevation View; Y-KK 1_IW_North

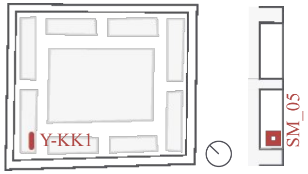


172 | Elevation View; Y-KK 1_IMW_Y-KK 2

6.6.5 Y-KK_1:

The magazine that reveals the most of the brick structure is Y-KK 1, located at the northwest corner of the burial complex. The mud coating on the upper half of the walls has fallen off, exposing a brick structure similar to the interior wall. The magazine has a length of 5.4 m, which corresponds to approximately 23 brick lengths, and a width of 1.3 m, roughly equal to 5 brick lengths.
The height ranges between 2.1 and 2.3 m, corresponding to approximately 30 brick courses. As in most cases, the topmost layer of the wall is formed by a rowlock course, marking the upper edge. Below this, an alternating pattern of stretcher and header courses is evident, precisely stacked so that a stretcher lies beneath two headers.
In this instance, a second continuous rowlock course is visible, positioned at the fourth course from the bottom. This arrangement means that one stretcher and one header course are placed between the first and second rowlock layers. This configuration has not been observed in the interior walls.

SM_05



173 | Masonry Square Meter (SM_05); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**7 header, 5 stretcher and 1 rowlock courses** **header: 32 + (11) = 43 bricks** **stretcher: 14 + (8) = 22 bricks** **rowlock: 11 + (3) = 14 bricks**
3.	brick height:	**49 - 71 mm**
4.	brick length (stretcher):	**215 - 262 mm**
5.	brick length (header):	**84 - 113 mm**
6.	joint thickness (horizontal):	**0 - 9 mm**
7.	joint thickness (vertical)	**0 - 17 mm**
8.	number of brick courses per 1m²:	**13**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,03 m**

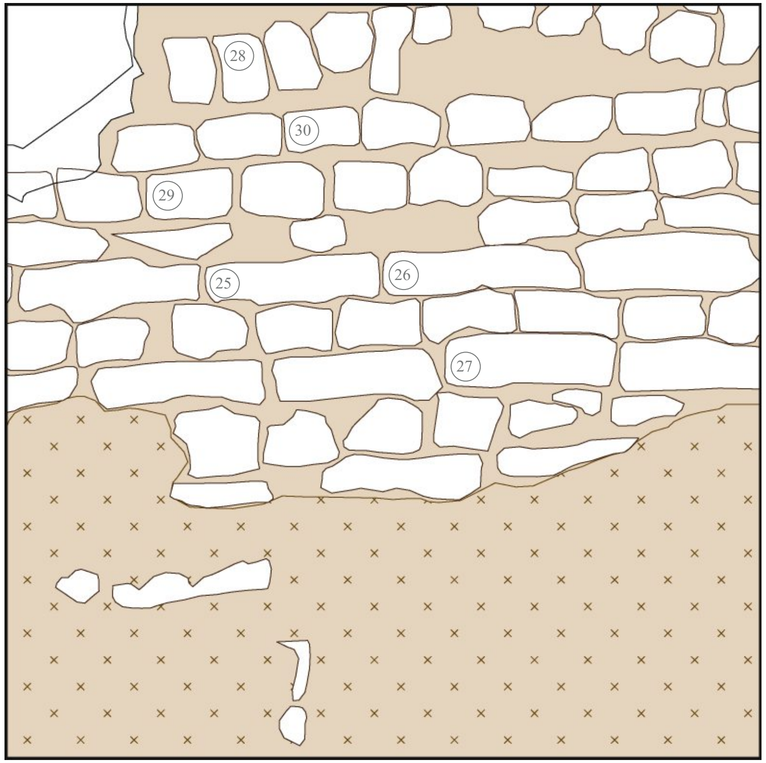
Unfortunately, the intermediate walls are largely covered in mud coating, leaving few areas where the underlying masonry is fully exposed. Consequently, many aspects of the wall structure had to be inferred. However, several sections of the coating have fallen off along the wall, exposing enough bricks to allow for a logical reconstruction of the remaining areas.

The masonry square meter of the intermediate walls is constructed using air-dried mudbricks and consists of a combination of header, stretcher, and rowlock courses. The distribution includes 43 header bricks (32 visible and 11 reconstructed), 22 stretcher bricks

(14 visible and 8 reconstructed), and 14 rowlock bricks (11 visible and three reconstructed).

The dimensions of the bricks vary, with stretcher bricks measuring between 215 and 262 mm in length, and headers ranging from 84 to 113 mm. Brick heights are between 49 and 71 mm. The horizontal spacing between bricks is negligible, while vertical joints can measure up to 2 cm.
The upper edge of the wall is constructed using rowlock bricks, following a non-consistent system where the rowlock course is typically succeeded by three header courses. The wall has a thickness of 1.03 m and uses mud mortar for bonding.

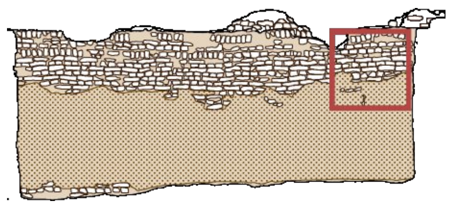
SCALE 1:10



174 | Masonry Square Meter (SM_05); Mapping

No.	LENGTH	WIDTH	HEIGHT
25	23,1	x	6,1
26	26,1	x	5,6
27	22,4	x	6,6
28	x	8,8	5,7
29	x	11,1	6,3
30	x	9,6	4,7

175 | Measurements Bricks 25-30



176 | Elevation View (Y-KK 1_IMW_Y-KK 8); 3D Model

 Perspective; Snapshot 3D Model; Exterior Walls manually attached

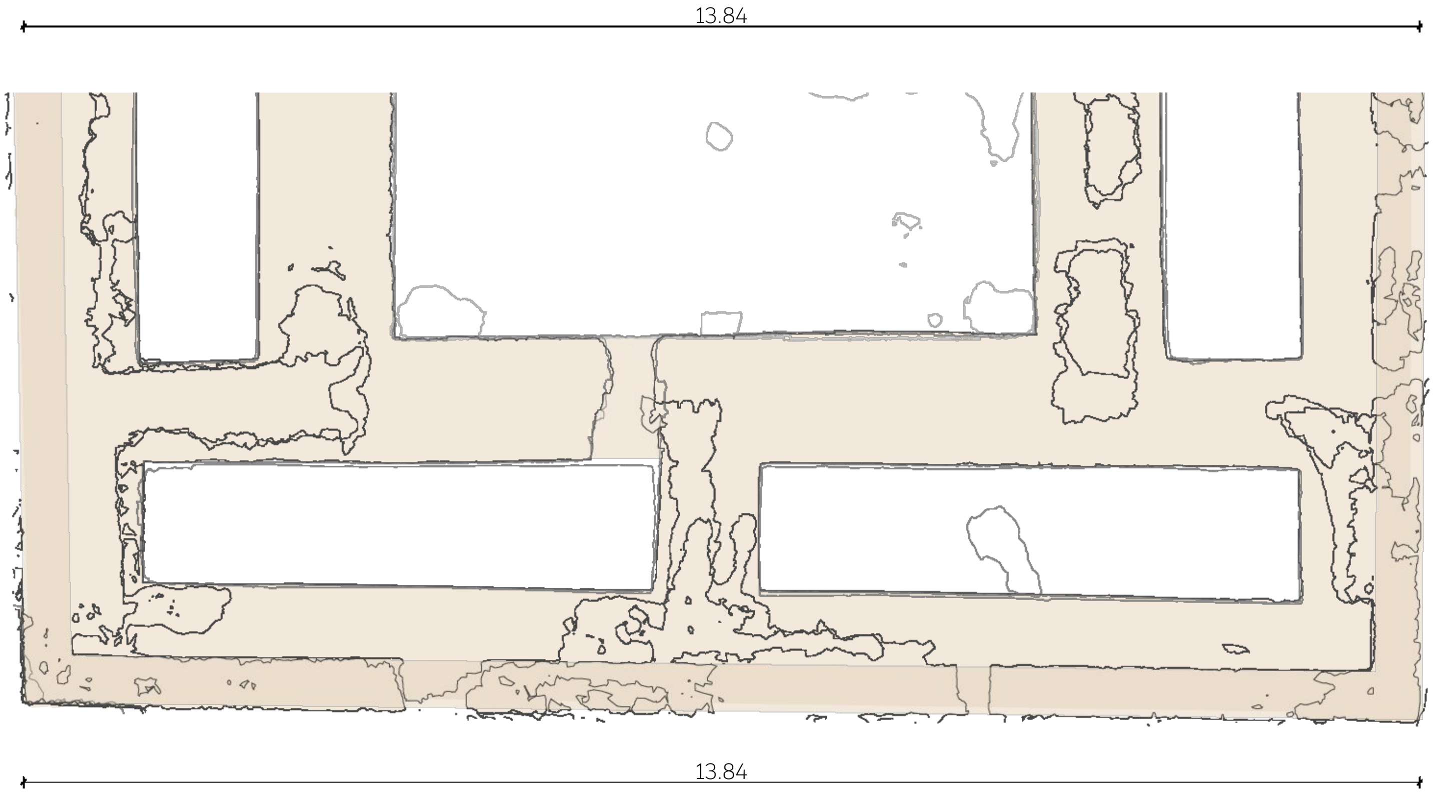
without scale

The photogrammetric survey of the exterior walls was conducted during the spring campaign in April 2024. Although the alignment process of the photogrammetry data for the exterior walls has not yet been fully completed, components are already available that provide meaningful insights into the condition of the masonry and its construction techniques. Therefore, the images of the 3D model are shown with limited resolution.

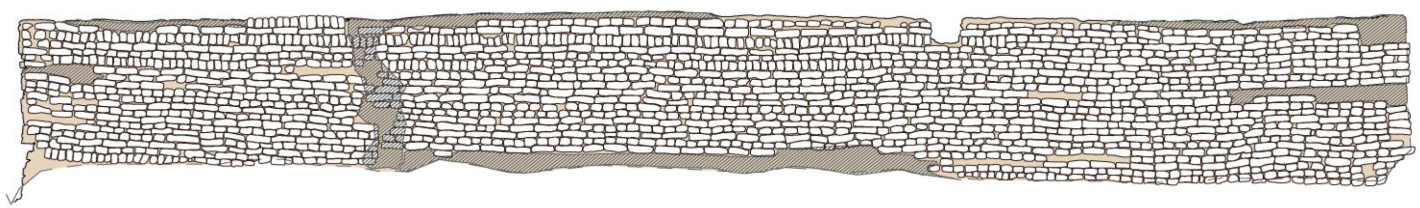
In *Figure 177*, the components of the exterior walls are currently positioned manually in their correct locations. The connection of the individual components to the main tomb has not yet been completed. Additionally, small isolated areas with missing data still remain; these areas have been explicitly marked in the elevation views.

The exterior walls were not coated with mud, making the masonry courses particularly visible in this area. Fundamentally, it mirrors the construction of the interior and intermediate walls. Since only parts of the wall have been uncovered, and the processing is not yet complete, the exact heights of the exterior walls cannot yet be determined. However, the east wall has been completely exposed, and its height matches the inner side of the exterior wall (measured from the magazine dimensions).

Therefore, it can be assumed that the height of the exterior walls on the inside corresponds to the height of the exterior walls on the outside.



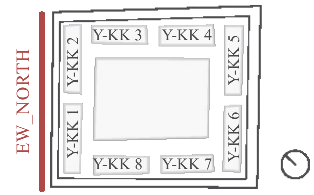
178 | Plan View; Area Y-KK_EW_NORTH



179 | Elevation View; Y-KK_EW_NORTH (measurements with reservations)

Scale 1:75

special surface
hidden object
section surface
mud brick
breakout
mud coating
mud mortar



6.6.6 Exterior Wall NORTH (Y-KK_EW_NORTH):

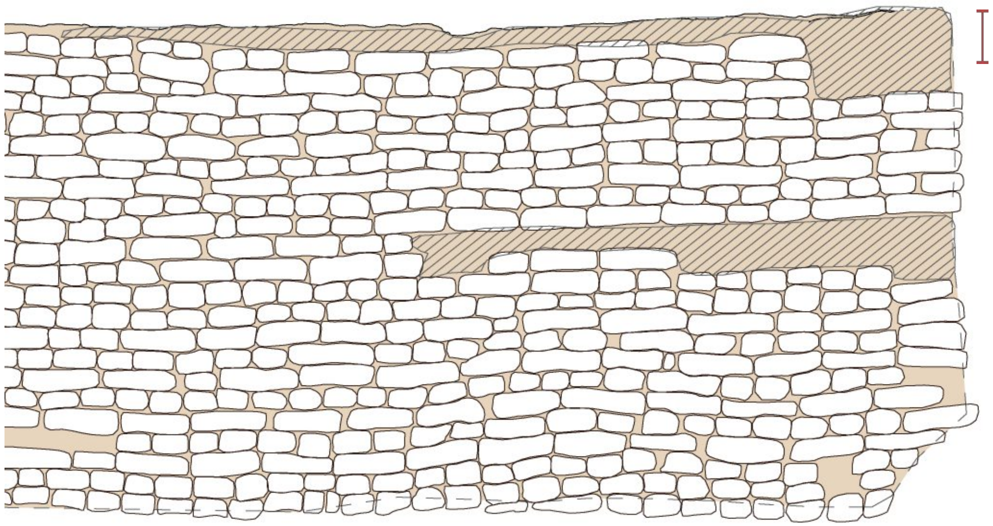
Visible bricks: 1728 bricks
Wall surface: 28.2 m²
Wall volume: 34.4 m³
Brick-laying technique: Stretcher, header, and rowlock courses;
brick courses to the top edge: 22 visible + 6 additional
Visible courses:
Stretcher course: 9 + (3) courses
Header course: 11 + (3) courses
Rowlock course: 2 courses
Non-visible courses: 6 courses

The exterior north wall (Y-KK_EW_NORTH) spans a length of 13.84 m, a height of 2.04 m (without the mudbricks edge), and an average depth of 1.22 m, resulting in a visible wall surface area of 28,23 m² and a wall volume of 34,44 m³. The brick-laying technique combines stretcher, header, and rowlock courses. To the top edge, 22 courses are visible, with an additional 6 courses reconstructed in obscured sections. Among the visible courses, nine stretcher courses with three reconstructed, eleven header courses with three reconstructed, and one rowlock course are identifiable. A total of six courses remain concealed. This configuration reflects a consistent construction approach, with alternating stretcher and header courses forming the primary pattern.

On the left side, up to four rowlock courses have been incorporated, while none are present on the right side. These rowlock courses were consistently inserted with intermediate layers in between.

The exterior walls consist of a mudbrick edging that forms the outer wall structure. The analysis focuses on understanding the composition of the outer wall and how the masonry ring integrates with the rest of the wall construction.

180 | Plan View; Y-KK_EW_NORTH connected to Y-KK_EW_WEST



181 | Elevation View; Y-KK_EW_NORTH

SCALE 1:25

special surface

hidden object

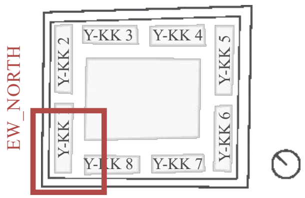
section surface

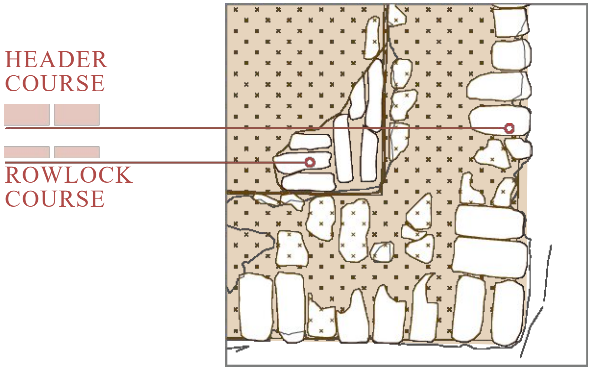
mud brick

breakout

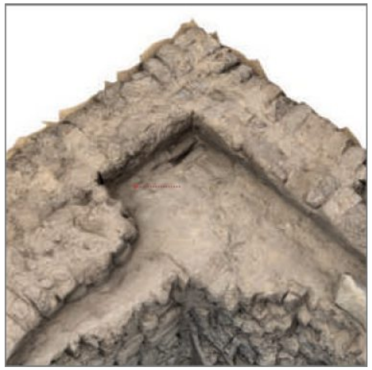
mud coating

mud mortar

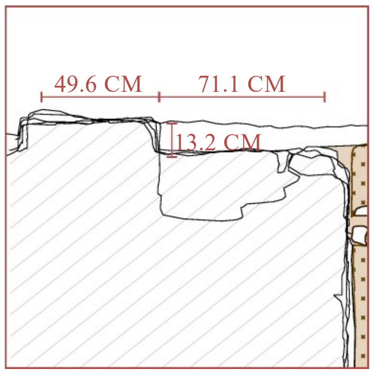




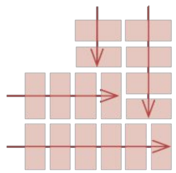
182 | Plan View; Y-KK_EW_NORTH-WEST



183 | Snapshot; Y-KK_EW_NORTH-WEST

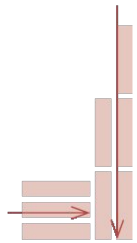


184 | Section; Y-KK_EW_SOUTH



At the northwest corner, it becomes clear that the topmost layer of the masonry ring is a header course. The outermost bricks of the north wall extend fully to the edge, while the second row ends one brick length earlier. A similar pattern is observed on the west wall, though here the outermost row ends one brick length short, and the second row ends two brick lengths earlier.

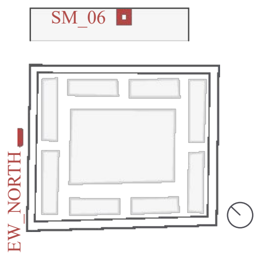
In the view of the north wall, the top layer of the mudbrick edging is revealed to be a header course, followed by an alternating pattern of header and stretcher courses. The inner edge of the wall‘s top is formed by a rowlock course.



Interestingly, the bricks in the rowlock course are oriented with their long sides facing the outer edges, rather than the short sides. On the visible northern side, three rowlock bricks are observed, positioned two rowlock widths away from the inner step of the wall. On the west side, two rowlock bricks are visible.

When comparing these layers with the exterior view of the north wall, it becomes evident that no rowlock course is present on the outer face. This discrepancy indicates that a transition in the brick-laying technique occurs within the interior of the wall.

SM_06



185 | Masonry Square Meter (SM_06); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**5 header, 6 stretcher and 2 rowlock courses** **header: 40 bricks** **stretcher: 24 bricks** **rowlock: 26 bricks**
3.	brick height:	**60 - 80 mm**
4.	brick length (stretcher):	**223 - 268 mm**
5.	brick length (header):	**95 - 122 mm**
6.	joint thickness (horizontal):	**0 - 13 mm**
7.	joint thickness (vertical)	**0 - 17 mm**
8.	number of brick courses per 1m²:	**13**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,22 m**

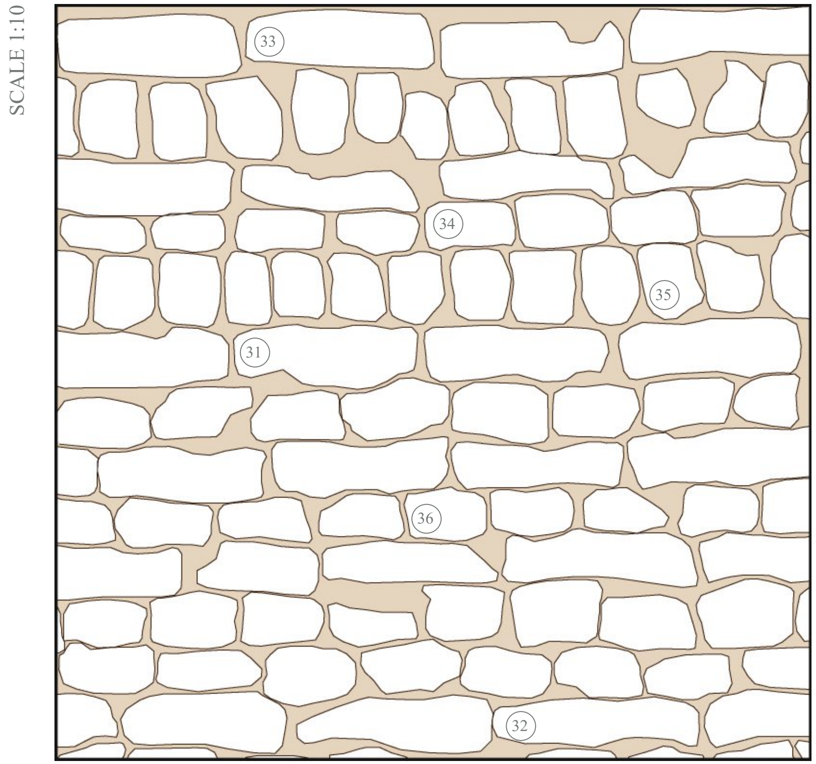
The masonry square meter on the north exterior wall consists of 13 courses, including five header, six stretcher, and two rowlock courses. The distribution includes 40 header bricks, 24 stretcher bricks, and 26 rowlock bricks.

The brick dimensions are as follows: stretcher bricks range from 223 to 268 mm in length, headers from 95 to 122 mm, and brick heights vary between 60 and 80 mm. Joint thicknesses measure up to 13 mm horizontally and up to 17 mm vertically.

Unlike the interior walls, the exterior walls are not covered with mud coating, allowing the brick structure to be fully visible. This visibility reveals a consistent arrangement of bricks, with stretcher and header courses alternating. Notably, a double layer of header courses is present, as well as two rowlock layers near the upper section, separated by only two courses. This configuration is not observed in the interior walls.

In the rowlock courses, there are typically three and a half bricks per stretcher length, further reflecting the uniformity of the construction. The dimensions and arrangement of the bricks are similar to those found in the interior walls, demonstrating a standardized building technique across the structure, with specific adaptations for the exterior walls.

The wall thickness measures 1.22 m, the use of mortar is just slightly visible in the narrow joint layers.

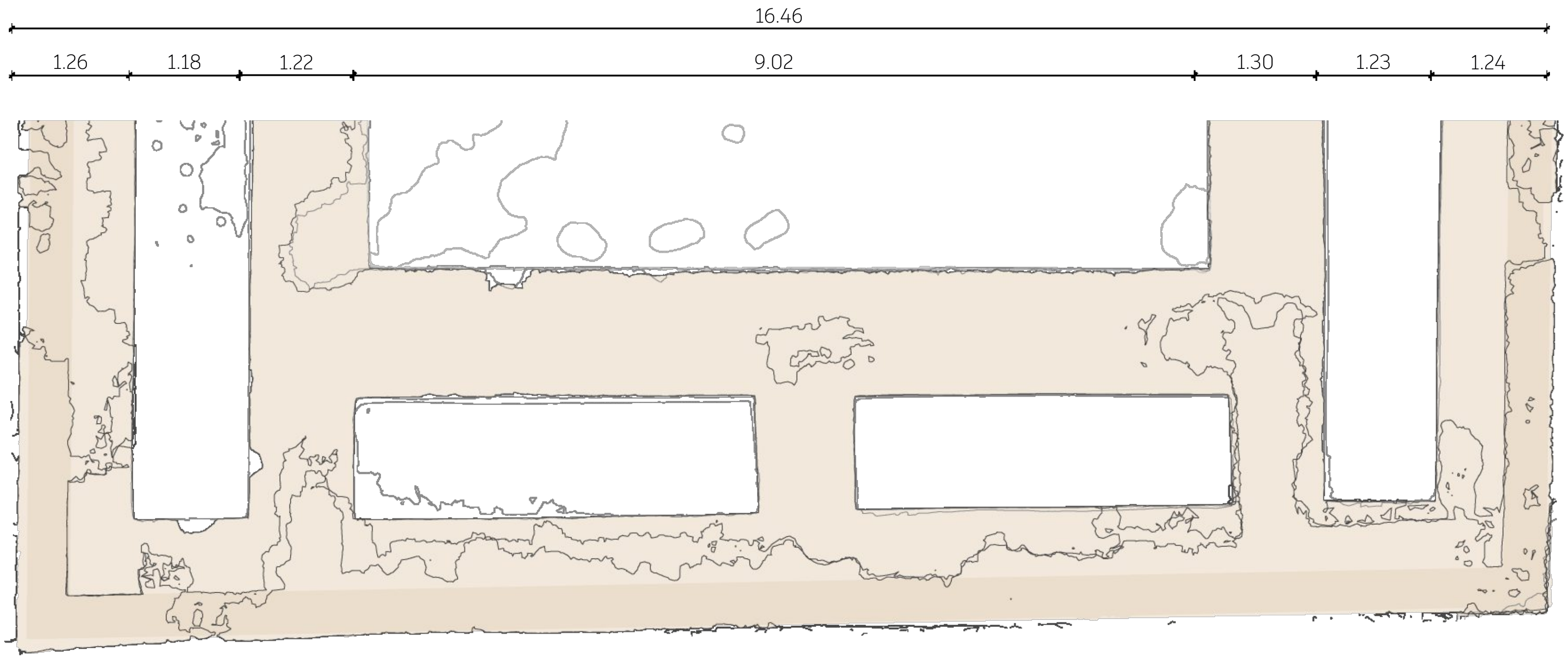


186 | Masonry Square Meter (SM_06); Mapping

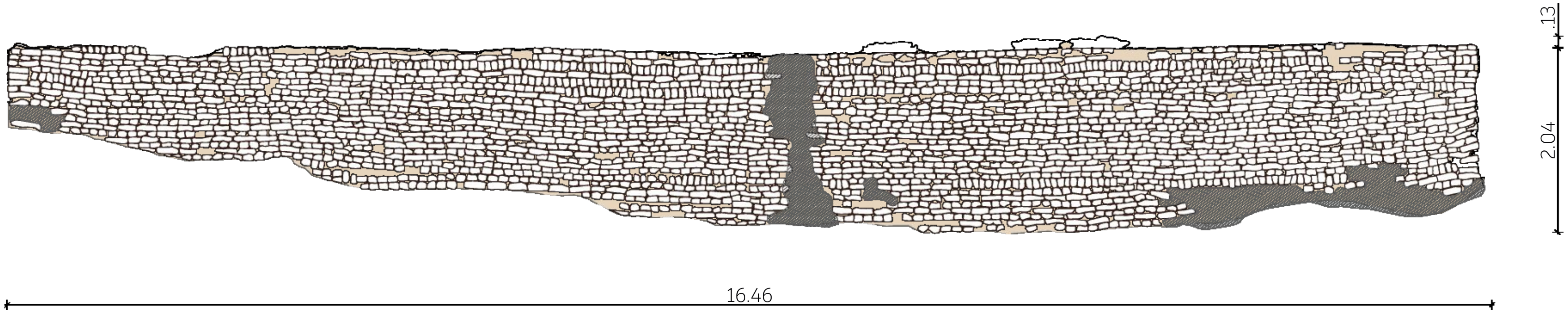
No.	LENGTH	WIDTH	HEIGHT
31	24,2	x	6,3
32	27,1	x	6
33	25,1	x	6,9
34	x	11,8	5,8
35	x	10	7,2
36	x	10,1	6,8

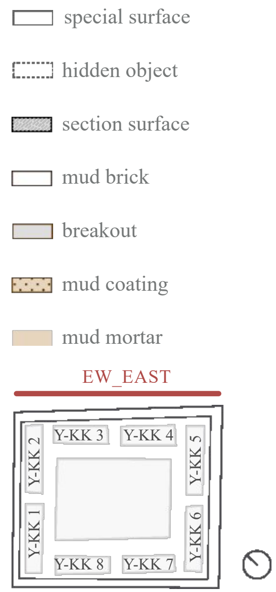
187 | Measurements Bricks 31-36

188 | Elevation View (Y-KK_EW_North); 3D Model



189 | Plan View; Area Y-KK_EW_EAST





190 | Elevation View; Y-KK_EW_EAST (measurements with reservations)

Scale 1:75

6.6.7 Exterior Wall EAST (Y-KK_EW_EAST):

Visible bricks: 2507 bricks
Wall surface: 33.58 m²
Wall volume: 43.32 m³
Brick-laying technique: Stretcher, header, and rowlock courses;
brick courses to the top edge: 28

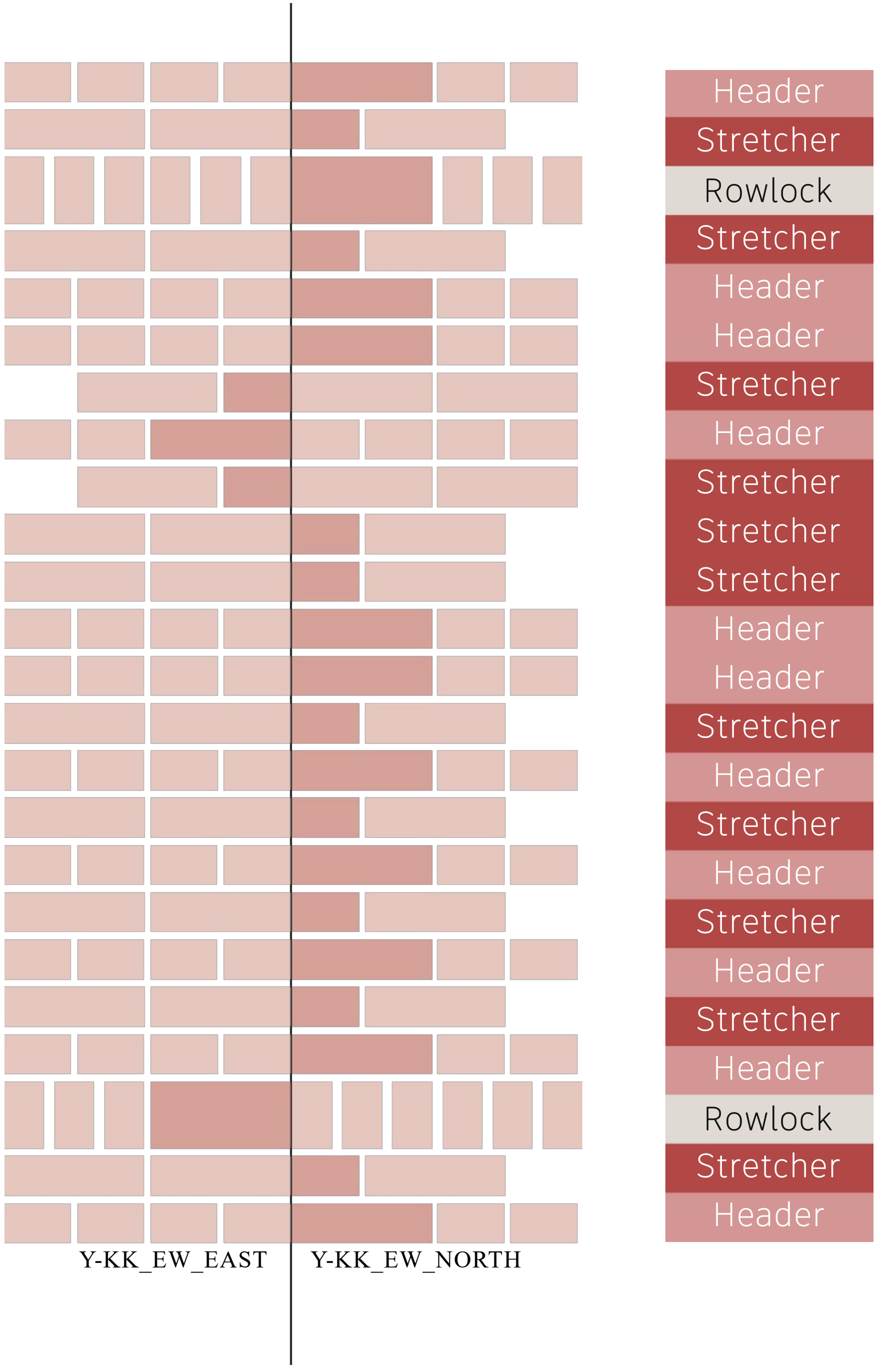
Visible courses: 28
Stretcher course: 13 courses
Header course: 13 courses
Rowlock course: 2 courses
Non-visible courses: 0

The exterior east wall (Y-KK_EW_EAST) measures 16.46 m in length, 2.04 m in height (excluding the mudbrick edging), and has an average depth of 1.29 m. These dimensions result in a visible wall surface area of 33.58 m² and a wall volume of 43.32 m³. The brick-laying technique integrates stretcher, header, and rowlock courses, with a total of 28 visible courses. Among these, 13 are stretcher courses, 13 are header courses, and two are rowlock courses.

This wall, fully excavated to its base, served as a reference for determining the height of the remaining walls. The third row consists of a rowlock course, meaning that the first two rows form the mudbrick edging, and from the third row onward, the wall reaches its full depth.

It is now clear that the first row on the inner edge and the third row on the outer edge are part of the same course. This observation aligns with findings from the interior walls and magazines, where rowlock courses were often used as termination or top edge elements of the wall. However, the bond is not continuous.

Beyond this row, the sequence alternates between stretcher and header courses, with occasional double layers of headers observed. Rowlock courses, apart from the shared first/third row, are introduced sporadically but are limited to short sections rather than running continuously.



Graphic; Intersection Exterior Walls East and North

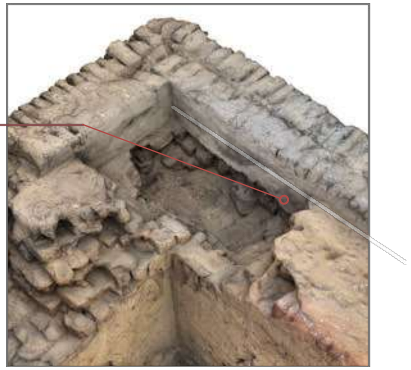
1.

THE COURSE REMAINS CONSISTENT, BUT THE FIRST/ LAST BRICK IS DIFFERENT.

192 | Snapshot 3D; Corner Y-KK_EW_NORTH-EAST

2.

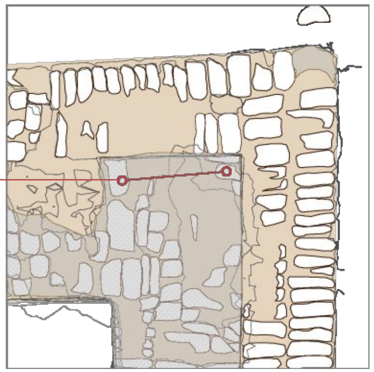
MUD COATING EXTENDS UP TO BELOW THE TOP EDGE OF INNER SIDE EXTERIOR WALL



193 | Snapshot; Y-KK_EW_SOUTH-EAST

3.

INDICATION FOR INTERLOCKING



194 | Plan View; Y-KK_EW_SOUTH-EAST

(1.) Observing the corner where the north wall and the east wall intersect reveals how the corner arrangement of the exterior walls was resolved.

It is evident that the configuration of the courses remains consistent up to the edge, meaning the course is laid fully to the boundary. As a result, a stretcher appears in the header course, a header appears in the stretcher course, and a shiner appears in the rowlock course.

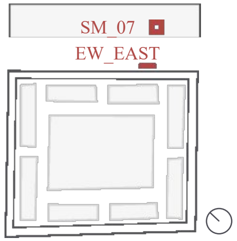
In this corner, it appears that no particular attention was given to the arrangement of the final brick in each course. As shown in *Figure 191*, most of the final bricks were laid in line with the edge of the east wall. Therefore, the starting brick of the north wall is often different from the brick type of the course itself. However, this was likely unnecessary, as the stacked arrangement of the bond ensures that the overall stability of the structure remains unaffected.

(2.) In the southeast corner, the upper section of the inner wall is visibly damaged. This reveals that the mud coating of the masonry ring extends just below the top edge of the wall. It is now uncertain whether the masonry ring is a construction two layers thick and two brick rows wide, resting on the exterior wall, or if the wall actually consists of two walls arranged one behind the other.

(3.) However, some of the exposed bricks in the damaged areas contradict this theory, as they are positioned precisely at the inner edge of the ring, centrally aligned. If these parts were separate structures, a clear division between the components would be visible.

SM_07

195 | Masonry Square Meter (SM_07); 3D Model



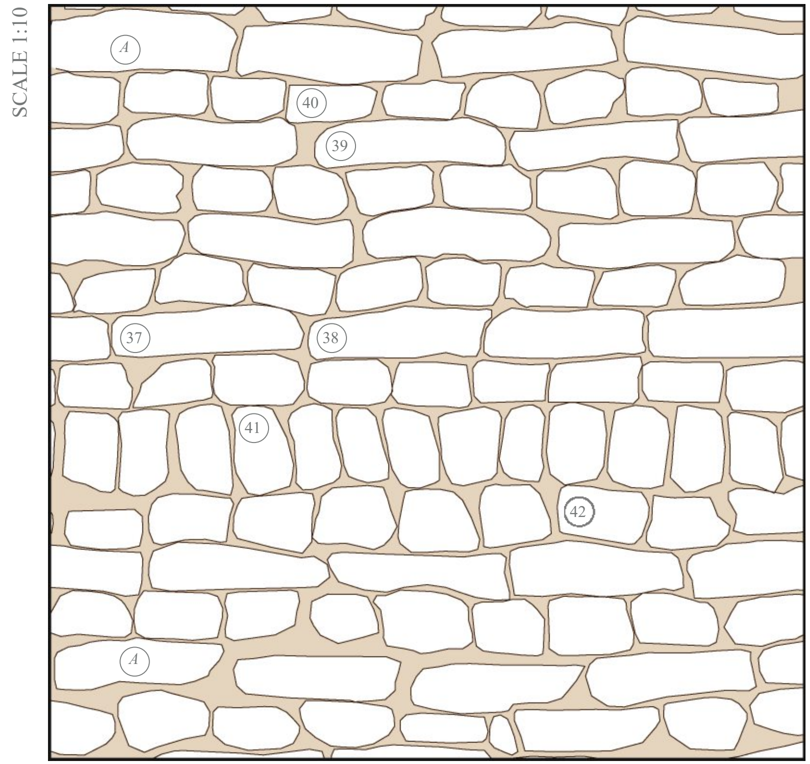
1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**7 header, 6 stretcher and 1 rowlock courses** **header: 60 bricks** **stretcher: 24 bricks** **rowlock: 14 bricks**
3.	brick height:	**48 - 74 mm**
4.	brick length (stretcher):	**207 - 253 mm**
5.	brick length (header):	**96 - 113 mm**
6.	joint thickness (horizontal):	**0 - 6 mm**
7.	joint thickness (vertical)	**0 - 2 mm**
8.	number of brick courses per 1m^2:	**14**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,29 m**

The masonry square meter on the east exterior wall is comprising 14 courses in total. These include seven header courses, six stretcher courses, and one rowlock course. The distribution consists of 60 headers, 24 stretchers, and 14 rowlock bricks. The bricks vary in size, with stretcher bricks measuring between 207 and 253 mm in length, headers ranging from 96 to 113 mm, and heights between 48 and 74 mm. The joints are particularly narrow, with horizontal joints up to 6 mm and vertical joints reaching a maximum of 2 mm.

The layering alternates between headers and stretchers, with a rowlock course positioned centrally, flanked by header courses above and below. This pattern adds a distinctive characteristic to the overall arrangement.

A notable irregularity is present in the alignment of certain sections. In the first course, and at the beginning of courses 12 and 13, a shift by the width of a single header is evident. While stretcher and header courses typically align in a straight plane, this area shows significant displacement.

Despite these deviations, the general construction method aligns with the standardized practices used in the masonry. The wall, measuring 1.29 m in thickness.

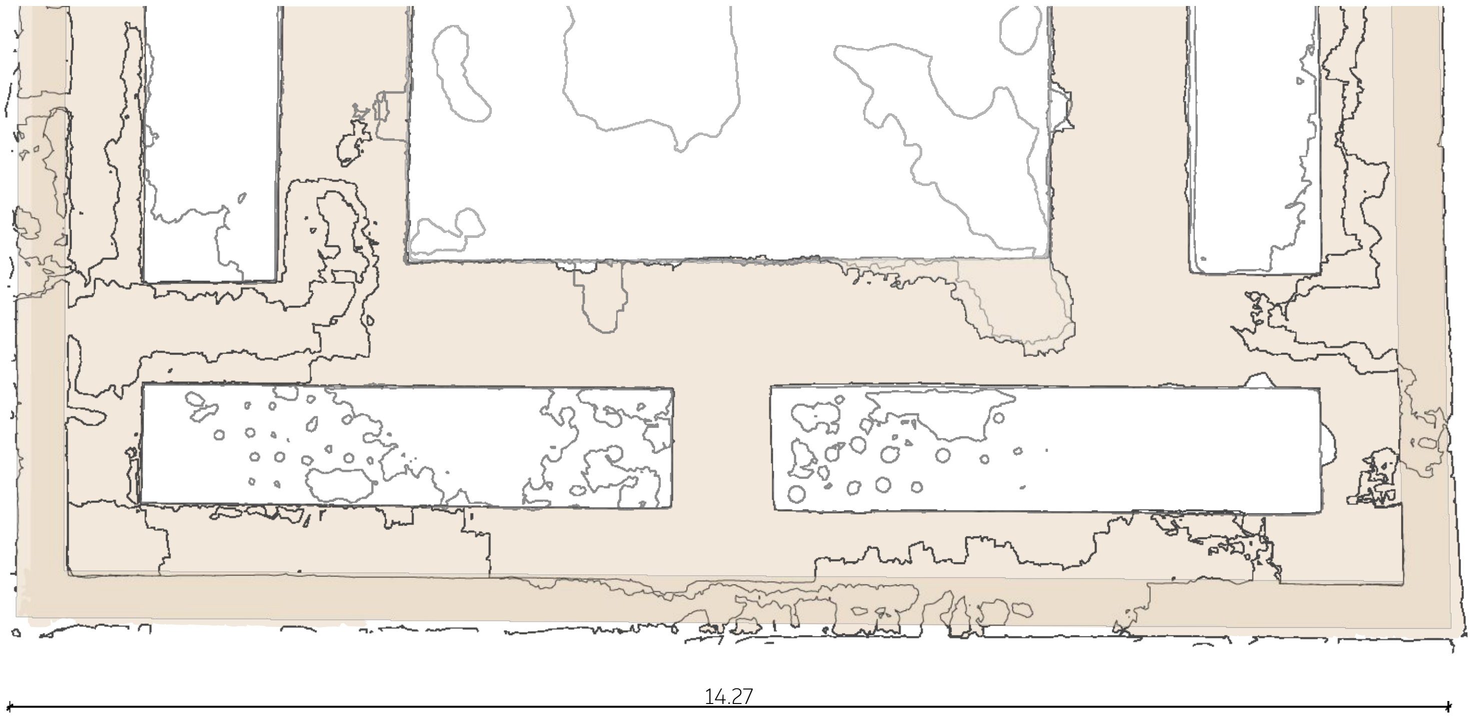


196 | Masonry Square Meter (SM_07); Mapping

No.	LENGTH	WIDTH	HEIGHT
37	15,15	x	5,99
38	22,54	x	6,77
39	25,28	x	5,47
40	x	11,33	4,56
41	x	11,60	5,99
42	x	11,68	6,12

197 | Measurements Bricks 37-42

198 | Elevation View (Y-KK_EW_East); 3D Model



199 | Plan View; Area Y-KK_EW_SOUTH

special surface

hidden object

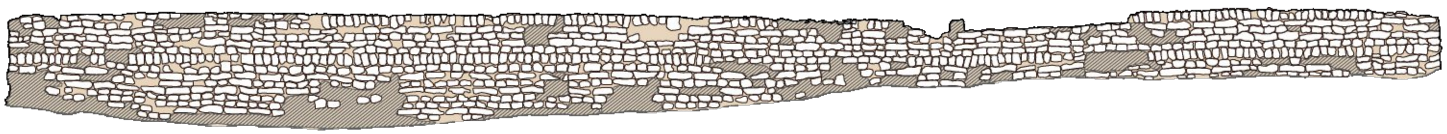
section surface

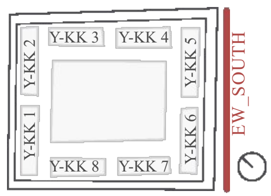
mud brick

breakout

mud coating

mud mortar





200 | Elevation View; Y-KK_EW_SOUTH (measurements with reservations)

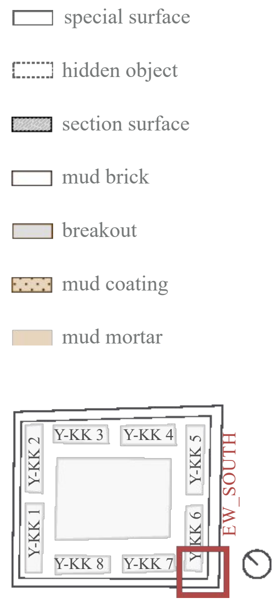
Scale 1:75

6.6.8 Exterior Wall SOUTH (Y-KK_EW_SOUTH):

Visible bricks: 987 bricks
Wall surface: 29.11 m²
Wall volume: 35.52 m³
Brick-laying technique: Stretcher, header, and rowlock courses
brick courses to the top edge: 14 visible + 14 additional.
Visible courses:
Stretcher course: 5 + (7) courses
Header course: 7 + (7) courses
Rowlock course: 2 courses
Non-visible courses: 14 courses

The exterior east wall (Y-KK_EW_SOUTH) measures 14.27m in length, assumed height of 2.04 m, and has an average depth of 1.22 m. These dimensions result in a visible wall surface area of 29.11 m² and a wall volume of 35.52 m³.
The brick-laying technique alternates between stretcher, header, and rowlock courses, with a total of 14 visible courses and an additional 14 reconstructed courses in concealed sections. The visible courses include five stretcher courses (seven reconstructed), seven header courses (seven reconstructed), and two rowlock courses.
The first rowlock course forms mainly the topmost layer of the masonry ring. The second rowlock course is located in the sixth row from the top (including the rows of the masonry ring), while the remaining rows alternate between stretcher and header courses.

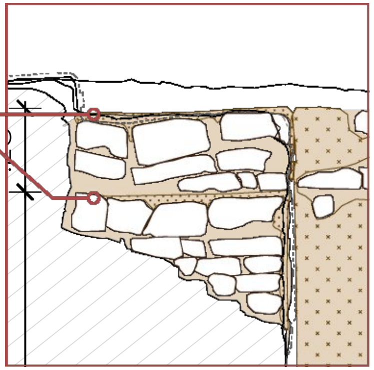
(1.) In the southwest corner, portions of the mud coating have fallen off, and part of the upper edge of the wall is damaged. This has partially revealed how the different courses intersect.
In the upper interior section of the wall, mainly parts of the header course are visible. Here, it becomes apparent that the western side extends to the inner edge of the mudbricks edging, while the southern side ends before reaching it.



 | Plan View; Area Y-KK_EW_SOUTH and Y-KK_EW_WEST

SCALE 1:20

1.



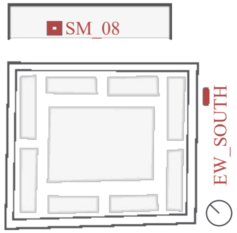
202 | Section; Y-KK_EW_EAST

203 | Snapshot; Y-KK_EW_WEST

The mudbrick edging consists of two rows of rowlock courses on the western side, while the southern side features a header course. The header course extends fully to the outer edge, whereas the rowlock course is set back by the length of one brick.

(2.) Similar to wall Y-KK_EW_East, there are indications that the mud coating on the inner side of the mudbrick edging extends just below the inner top edge of the wall. This is also evident here; due to more significant damage, both the layers and the coating are partially visible. It can now be observed on the inner side that the mud coating in this area extends down to the 6th row from the top (including the mudbrick edging). As the mud coating stops at the 6th row, this row becomes visible, revealing the type of course within the mudbrick edging. Bricks in a rowlock course are discernible, indicating that the 6th course is uniform and continuous across the structure, maintaining alignment throughout.
The 6th row forms a rowlock layer, visible both on the interior and exterior, indicating a single course and thus a unified structural element. In the interior section, rows three through five (a total of three rows) create a structure that appears to have been added secondarily. This three-row and three-brick deep construction rests on the mud coating and is not anchored to the mudbrick edging. Furthermore, only the exterior edge reveals a rowlock course in both the first and sixth rows. The rowlock course of the third row is not present on the exterior wall, indicating a divergence in construction between the interior and exterior layers.

SM_08



 Masonry Square Meter (SM_08); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**7 header, 4 stretcher and 2 rowlock courses** **header: 58 bricks** **stretcher: 16 + (1) =17 bricks** **rowlock: 27 bricks**
3.	brick height:	**48 - 78 mm**
4.	brick length (stretcher):	**193 - 245 mm**
5.	brick length (header):	**99 - 125 mm**
6.	joint thickness (horizontal):	**0 - 1 mm**
7.	joint thickness (vertical)	**0 - 19 mm**
8.	number of brick courses per 1m²:	**13**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,22 m**

The masonry square meter on the south exterior wall features mudbricks arranged in a total of 13 courses.

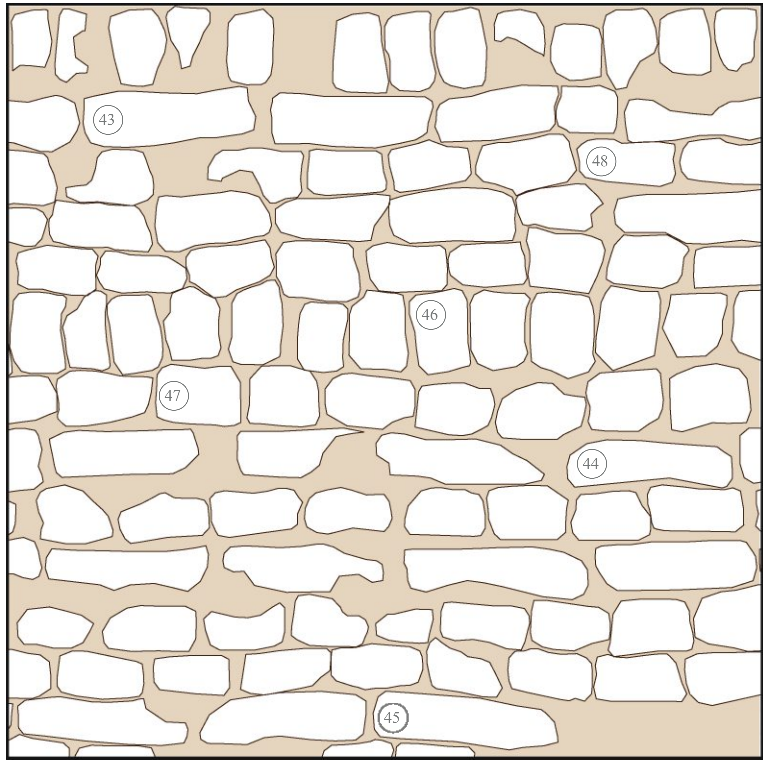
These include seven header courses, four stretcher courses, and two rowlock courses, distributed as 58 headers, 17 stretchers (16 directly visible and one reconstructed), and 27 rowlock bricks.

The dimensions of the bricks vary, with stretcher bricks ranging in length from 193 to 245 mm, headers between 99 and 125 mm, and heights spanning from 48 to 78 mm. Horizontal joints are nearly imperceptible at up to 1 mm, while vertical joints can reach up to 19 mm in thickness. The courses generally alternate between headers and stretchers, though certain stretcher bricks are unusually short, appearing more compact than the typical length of two headers.

One rowlock layer is located near the top of the wall, framed by header courses above and below. The uppermost rowlock course is bordered by a stretcher course underneath. A double header layer is also present in the lower part of the masonry.

The wall has a thickness of 1.22 m, with mud mortar that seems to be seeping partially from the joints.

SCALE 1:10

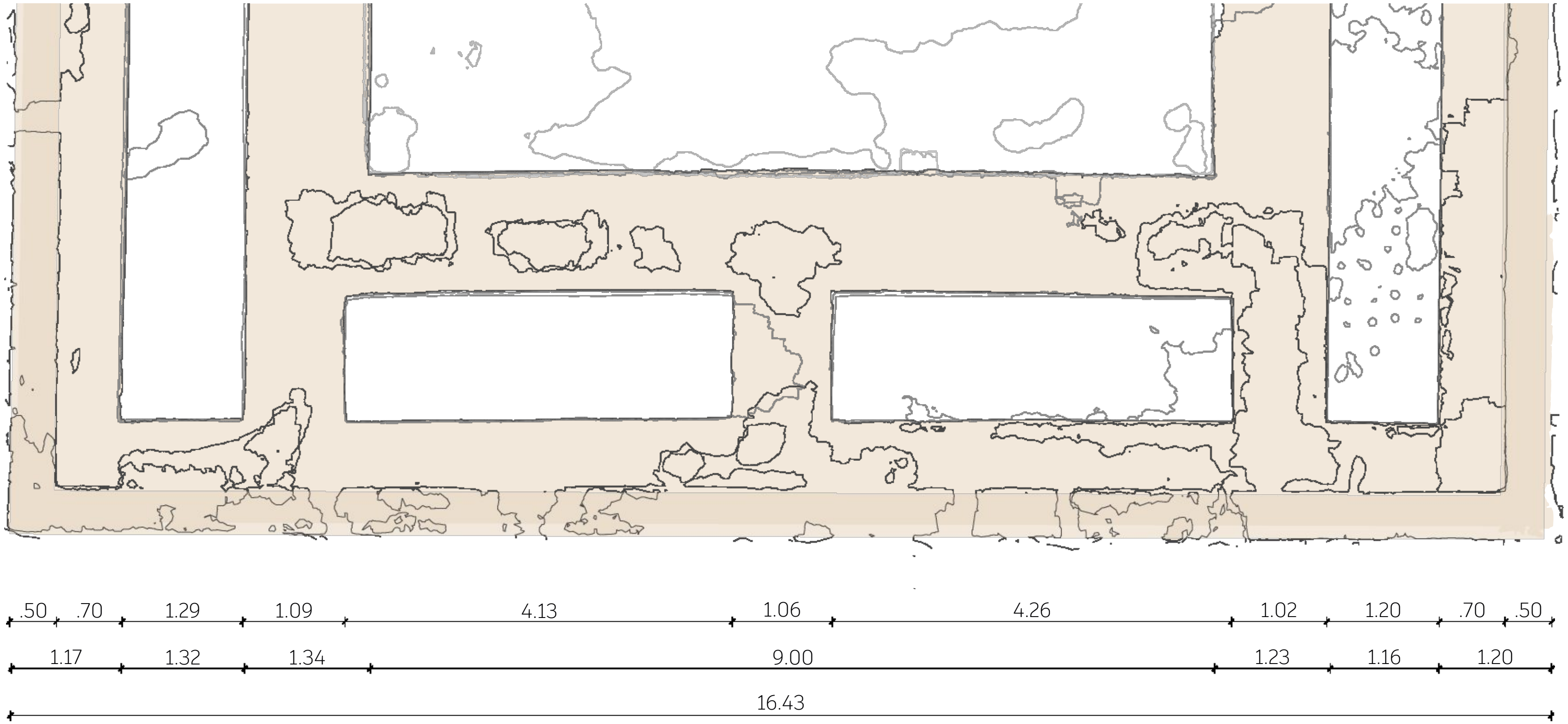


205 | Masonry Square Meter (SM_08); Mapping

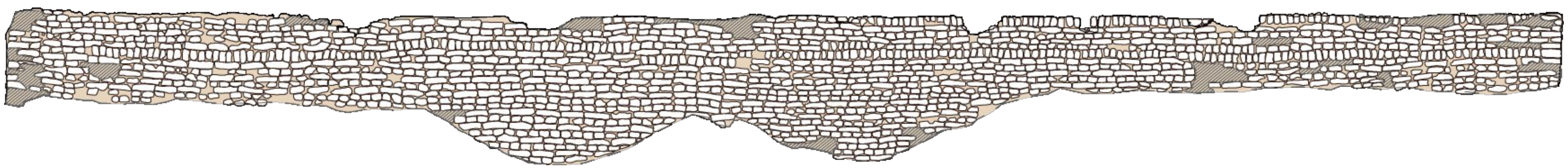
No.	LENGTH	WIDTH	HEIGHT
43	22,74	x	6,75
44	21,95	x	5,6
45	24,1	x	5,81
46	x	10,68	6,67
47	x	11,33	7,42
48	x	12,77	5,73

206 | Measurements Bricks 43-48

207 | Elevation View (Y-KK_EW_South); 3D Model

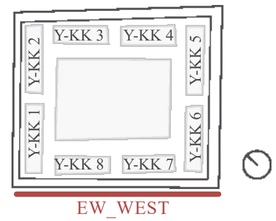


208 | Plan View; Area Y-KK_EW_WEST Scale 1:75



209 | Elevation View; Y-KK_EW_WEST (measurements with reservations) Scale 1:75

- special surface
- hidden object
- section surface
- mud brick
- breakout
- mud coating
- mud mortar



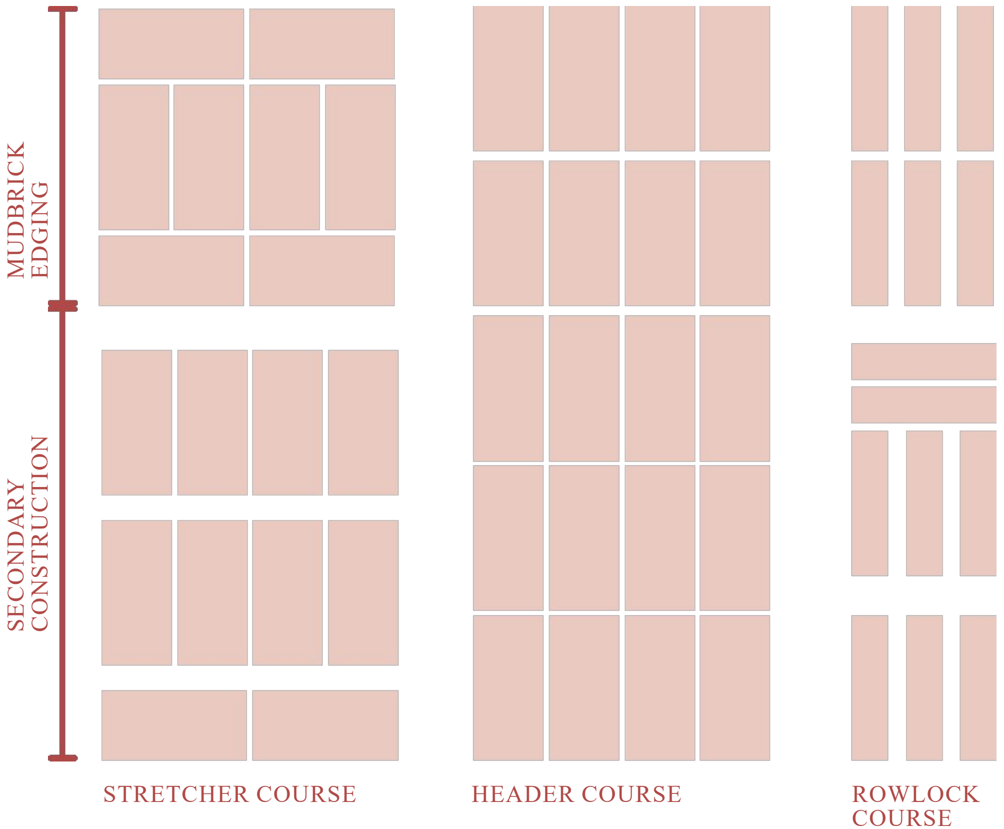
6.6.9 Exterior Wall WEST (Y-KK_EW_WEST):

Visible bricks: 1591 bricks
Wall surface: 33.33 m²
Wall volume: 40.67 m³
Brick-laying technique: Stretcher, header, and rowlock courses; brick courses to the top edge: 23 visible + 5 additional
Visible courses:
Stretcher course: 10 + (2) courses
Header course: 11 + (3) courses
Rowlock course: 2 courses
Non-visible courses: 5 courses

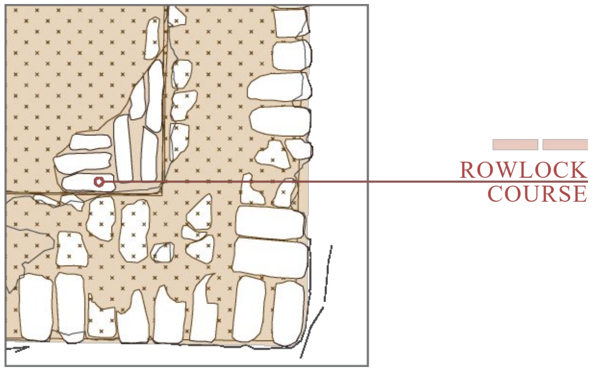
The west exterior wall (Y-KK_EW_WEST) spans 16.34 m in length, stands 2.04 m in height (as inferred from the east wall), and has an average depth of 1.22 m. These proportions give the wall a total visible surface area of 33.33 m² and a volume of 40.67 m³.
The brickwork is composed of stretcher, header, and rowlock courses. A total of 23 courses are visible, with an additional five reconstructed courses in areas where the masonry is obscured. Among the visible courses, there are ten stretcher courses (including two reconstructed), eleven header courses (with three reconstructed), and two rowlock courses.

At the exterior west wall, near magazine Y-KK 8, a deep breakout is visible at the upper edge of the wall, exposing the internal construction. This provides further evidence supporting the hypothesis that a secondary construction rests atop the sixth row. The brick-laying technique for this secondary construction can be clearly observed in this area.
The mudbrick edging appears to be five brick heights tall and sits on the sixth row, which forms a rowlock course. In *Figure 209*, it is evident that the lower courses extend beneath the mudbrick edging. Above this lies a secondary construction, measuring three brick heights and three brick lengths in depth.

COURSE ARRANGEMENT OF SECONDARY CONSTRUCTION
THE FIRST THREE ROWS ON THE INSIDE OF EXTERIOR WALL

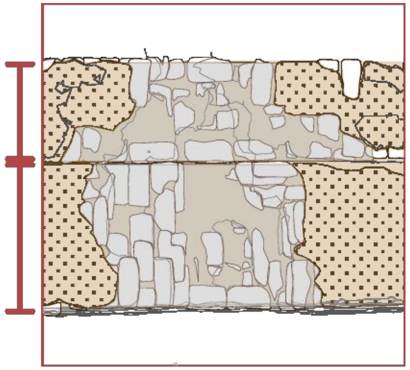


Illustration; Secondary Construction Exterior Wall

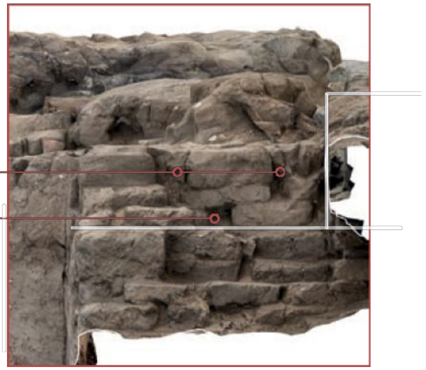


Detail; Exterior Wall South and West

212 | Snapshot; Y-KK_EW_WEST



213 | Plan View; Y-KK_EW_WEST



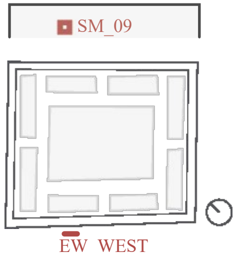
214 | Section Snapshot; Y-KK_EW_WEST

The breakout has only removed the first row of the mudbrick edging, revealing the stretcher courses within. In this construction, two stretcher bricks - one on the interior and one on the exterior - are separated by the length of one brick. The header bond, which is also visible in other top views, consists of two rows of bricks placed with their headers facing the exterior edge, similar to the rowlock course, except that here the bricks are positioned upright.

The secondary construction shows no significant differences in the application of the header courses compared to the continuous masonry, maintaining a consistent layout. This results in the mudbrick edging comprising two brick lengths, while the secondary construction adds another three brick lengths, for a total depth of five brick lengths from the outer edge to the inner edge of the exterior wall. However, differences are apparent in the other course types. In the stretcher course, a stretcher is positioned against the inner edge of the exterior wall, while the two interior header bricks, extending to the inner edge of the mudbrick edging, are placed with large gaps between them, resulting in mortar joints of up to 9 cm.

In the rowlock course, the mortar joints are also notably wide. In this case, two rowlock bricks are placed consecutively, as is typical, but two additional rowlock bricks are rotated 90 degrees, with their long sides oriented toward the inner edge of the mudbrick edging. This unique arrangement was previously analyzed at the corner of the northwest exterior walls.

SM_09



215 | Masonry Square Meter (SM_09); 3D Model

1.	predominant material:	**Mudbrick (air-dried)**
2.	bond/masonry type:	**6 header, 7 stretcher and 1 rowlock courses** **header: 45 bricks** **stretcher: 29 bricks** **rowlock: 13 bricks**
3.	brick height:	**50 - 78 mm**
4.	brick length (stretcher):	**227 - 277 mm**
5.	brick length (header):	**103 - 144 mm**
6.	joint thickness (horizontal):	**0 - 1 mm**
7.	joint thickness (vertical)	**0 - 16 mm**
8.	number of brick courses per 1m²:	**14**
9.	mortar:	**mud**
10.	plaster type:	**mud coating**
11.	wall thickness:	**1,22 m**

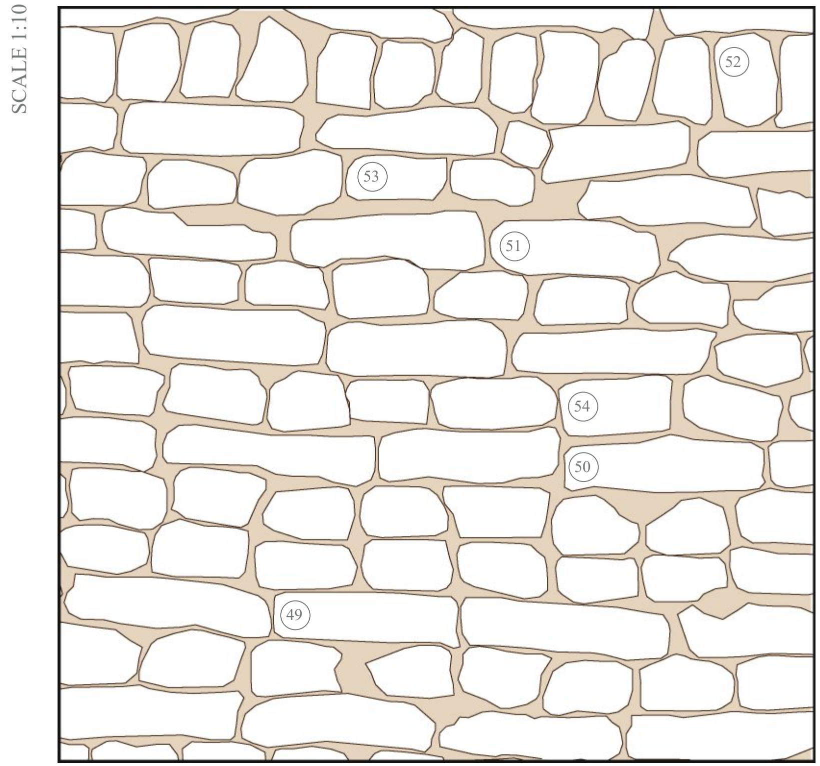
The masonry square meter on the west exterior wall is constructed with air-dried mudbricks arranged in 14 courses, consisting of six header courses, seven stretcher courses, and 1 rowlock course. The distribution includes 45 headers, 29 stretchers, and 13 rowlock bricks.

The brick dimensions show variations, with stretcher bricks measuring between 22.7cm and 27.7 cm in length, headers ranging from 10.3 cm to 12.6 cm, and heights spanning 5.0 cm to 7.1 cm. Horizontal joints are minimal, measuring up to 1 mm, while vertical joints can reach up to 1.6 cm. In some areas, the mud mortar appears to seep slightly from the joints, contributing to the texture of the wall surface.

The rowlock course is located at the top of the wall, bordered by stretcher courses above and below. The fourth course shows a rare instance where headers appear to transition into stretchers, a highly unusual occurrence in this masonry type.

Some bricks in this section exhibit particularly low heights, further adding to the variation. A double layer of header courses is present. The headers are precisely aligned directly above one another, while the stretchers, though generally aligned, occasionally show a slight offset by the width of a single header brick.

This wall reflects a largely consistent construction method, with minor deviations. The wall has a thickness of 1.22 m.



216 | Masonry Square Meter (SM_09); Mapping

No.	LENGTH	WIDTH	HEIGHT
49	24,13	x	6,43
50	26,54	x	6,91
51	22,36	x	7,56
52	x	11,42	7,72
53	x	13,03	5,79
54	x	14,32	7,4

217 | Measurements Bricks 49-54

218 | Elevation View (Y-KK_EW_West); 3D Model

MUD BRICK VOLUME					
SM	WALL	No.	LENGTH	WIDTH	HEIGHT
SM_01	Y-KK_IW_NORTH	1	22,7	x	6,1
SM_01	Y-KK_IW_NORTH	2	23,7	x	7,3
SM_01	Y-KK_IW_NORTH	3	23,6	x	5
SM_01	Y-KK_IW_NORTH	4	x	9	6,1
SM_01	Y-KK_IW_NORTH	5	x	10,7	6,2
SM_01	Y-KK_IW_NORTH	6	x	11,4	5,4
SM_02	Y-KK_IW_EAST	7	23,3	x	6,9
SM_02	Y-KK_IW_EAST	8	24,1	x	5,2
SM_02	Y-KK_IW_EAST	9	25,4	x	6,2
SM_02	Y-KK_IW_EAST	10	x	12,1	6,5
SM_02	Y-KK_IW_EAST	11	x	11,1	7,4
SM_02	Y-KK_IW_EAST	12	x	11,7	6,6
SM_03	Y-KK_IW_SOUTH	13	24,0	x	5,9
SM_03	Y-KK_IW_SOUTH	14	20,0	x	5,7
SM_03	Y-KK_IW_SOUTH	15	24,2	x	5,7
SM_03	Y-KK_IW_SOUTH	16	x	11,7	6,9
SM_03	Y-KK_IW_SOUTH	17	x	11,9	7,2
SM_03	Y-KK_IW_SOUTH	18	x	11,3	6,1
SM_04	Y-KK_IW_WEST	19	24,1	x	5,7
SM_04	Y-KK_IW_WEST	20	22,5	x	6,1
SM_04	Y-KK_IW_WEST	21	25,9	x	6,4
SM_04	Y-KK_IW_WEST	22	x	10,5	6,7
SM_04	Y-KK_IW_WEST	23	x	11,8	6,7
SM_04	Y-KK_IW_WEST	24	x	9,2	6,7
SM_05	Y-KK1-8_IMW	25	23,1	x	6,1
SM_05	Y-KK1-8_IMW	26	26,1	x	5,6
SM_05	Y-KK1-8_IMW	27	22,4	x	6,6
SM_05	Y-KK1-8_IMW	28	x	8,8	5,7
SM_05	Y-KK1-8_IMW	29	x	11,1	6,3
SM_05	Y-KK1-8_IMW	30	x	9,6	4,7
SM_06	Y-KK_EW_NORTH	31	24,2	x	6,3
SM_06	Y-KK_EW_NORTH	32	27,1	x	6
SM_06	Y-KK_EW_NORTH	33	25,1	x	6,9
SM_06	Y-KK_EW_NORTH	34	x	11,8	5,8
SM_06	Y-KK_EW_NORTH	35	x	10	7,2
SM_06	Y-KK_EW_NORTH	36	x	10,1	6,8
SM_07	Y-KK_EW_EAST	37	25,2	x	5,99
SM_07	Y-KK_EW_EAST	38	22,54	x	6,77
SM_07	Y-KK_EW_EAST	39	25,28	x	5,47
SM_07	Y-KK_EW_EAST	40	x	11,33	4,56
SM_07	Y-KK_EW_EAST	41	x	11,6	5,99
SM_07	Y-KK_EW_EAST	42	x	11,68	6,12
SM_08	Y-KK_EW_SOUTH	43	22,74	x	6,75
SM_08	Y-KK_EW_SOUTH	44	21,95	x	5,6
SM_08	Y-KK_EW_SOUTH	45	24,1	x	5,81
SM_08	Y-KK_EW_SOUTH	46	x	10,68	6,67
SM_08	Y-KK_EW_SOUTH	47	x	11,33	7,42
SM_08	Y-KK_EW_SOUTH	48	x	12,77	5,73
SM_09	Y-KK_EW_WEST	49	24,13	x	6,43
SM_09	Y-KK_EW_WEST	50	26,54	x	6,91
SM_09	Y-KK_EW_WEST	51	22,36	x	7,56
SM_09	Y-KK_EW_WEST	52	x	11,42	7,72
SM_09	Y-KK_EW_WEST	53	x	13,03	5,79
SM_09	Y-KK_EW_WEST	54	x	14,32	7,4

6.7 Results of Findings

Through the detailed analysis of masonry square meters SM_01 to SM_09, a comprehensive dataset has been generated, providing critical insights into the material dimensions. As part of this analysis, six bricks were systematically measured for each masonry square meter, consisting of three stretcher bricks and three header bricks. These measurements were meticulously recorded to establish a reliable dataset for determining the average brick dimensions.

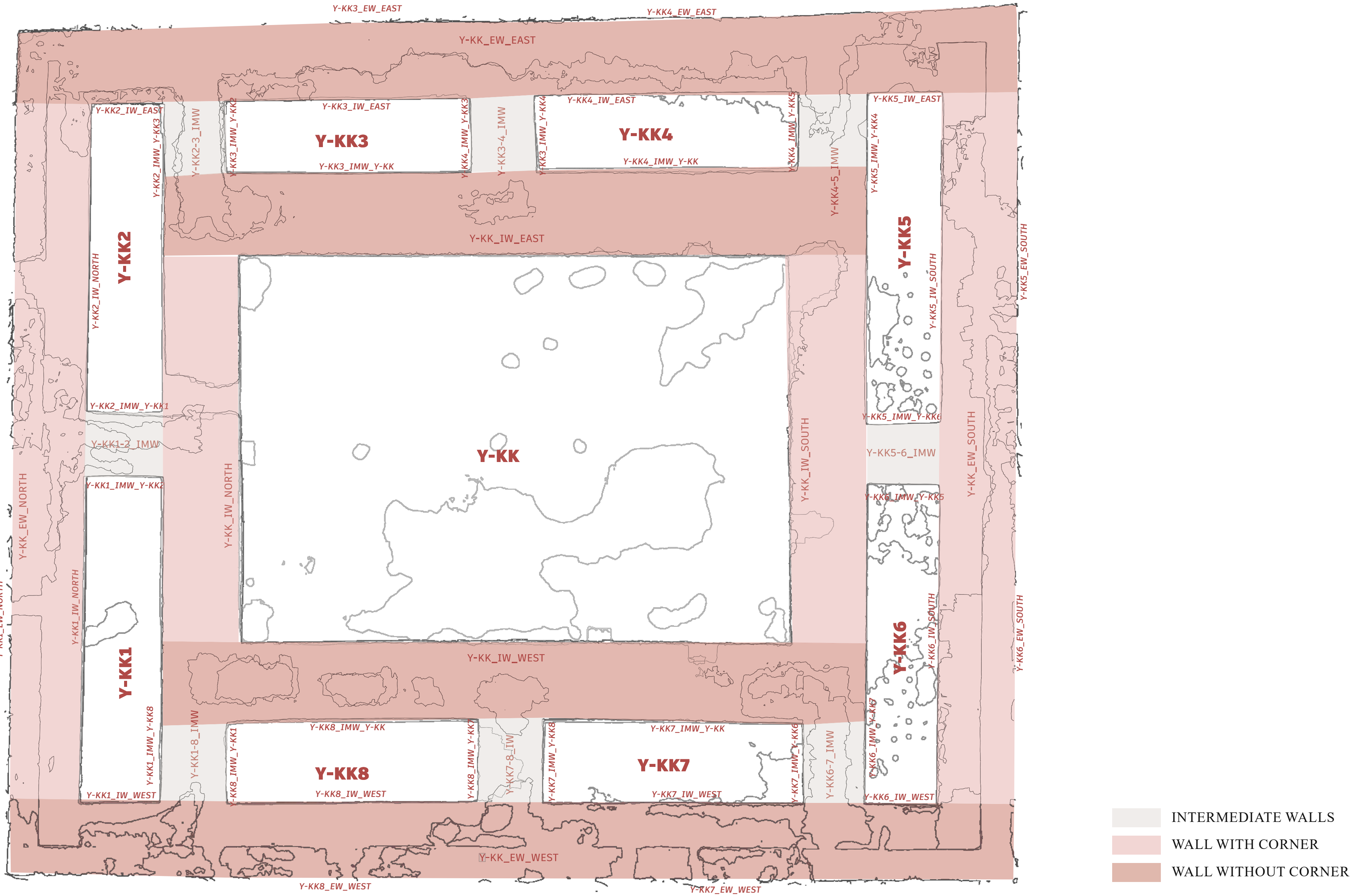
In total, data from 54 individual bricks were analyzed, forming a robust statistical basis for further calculations and interpretations. These average dimensions serve as a reference for extrapolating the material quantities required for the entire structure. Furthermore, this dataset is instrumental in supporting digital simulations, enabling accurate modeling and analysis of the architectural form and structural behavior of the building.

The findings revealed an average brick length of 23.94 cm, a width of 11.18 cm, and a height of 6.28 cm. This equates to an average brick volume of 1680.82 cm³ or approximately 0.0017 m³.

In addition to recording the dimensions of six bricks per masonry square meter, the distribution of header, stretcher, and rowlock bricks was also documented. To simplify calculations, the tomb was initially divided into distinct sections.

AVERAGE VOLUME OF ONE MUD BRICK				
LENGTH	WIDTH	HEIGHT	in cm^3	in m^3
23,94	11,18	6,28	1680,83	0,0017

220 | Data; Volume Average Mudbrick



 | Plan View with assigned Areas

without scale

As illustrated in *Figure 221*, the exterior and interior east walls, as well as the exterior and interior west walls, were extended to the edges of the structure, including the corner masses. Since the corner areas are already accounted for within the long walls, the north and south walls were defined as the remaining areas for calculation.

The intermediate walls were estimated by using data from one wall as a reference and multiplying it by eight, while the mudbrick edging was calculated separately and added to the totals along with the mud coating.

For the calculations, the average dimensions of the mudbricks from the masonry square meters, along with the recorded counts and types of bricks, were compiled into a detailed list. The total surface area and volume of the components were then computed. In the case of stretcher bricks, it was considered that a stretcher course typically includes a double row behind it, consisting of four headers in each row, which is then enclosed by another stretcher. This arrangement results in a total depth of 10 bricks for stretcher courses. Similarly, header and rowlock courses consist of 5 bricks aligned consecutively in depth.

After scaling up the masonry square meter, not only the number of visible bricks but also the number of bricks in depth per square meter was determined. This data was then extrapolated to the entire structural component, resulting in the total number of bricks per component.

To calculate the volume of bricks and mortar, the results of the calculated average brick dimensions were applied and scaled accordingly. By subtracting the total volume of the bricks (determined by multiplying the brick count by the average brick volume) from the total volume of the structural mass, the volumes of both the bricks and mortar were determined. This calculation includes the contribution of the mudbrick edging.

VOLUME WALL, BRICKS, MORTAR	COUNT number of bricks of square meter			MEASUREMENT WALLS				Number of mud bricks (per wall)		
Wall	stretcher course	header course	rowlock course	length (m)	height (m)	depth (m)	Surface Area	stretcher course	header course	rowlock course
Y-KK_IW_NORTH	30	69	0	6,34	2,83	1,28	17,9	538	1 238	0
Y-KK_IW_EAST	29	69	0	11,52	2,78	1,36	32,0	929	2 210	0
Y-KK_IW_SOUTH	24	76	0	6,35	2,81	1,26	17,8	428	1 356	0
Y-KK_IW_WEST	28	70	0	11,51	2,82	1,26	32,5	909	2 272	0
Y-KK1-8_IMW	*22*	*43*	*14*	*1,28*	*2,04*	*1,03*	*2,6*	*57*	*112*	*37*
Y-KK_IMW (total)	176	344	112	-	-	-	20,9	-	-	-
Y-KK_EW_NORTH	24	40	26	11,42	2,04	1,22	23,3	559	932	606
Y-KK_EW_EAST	24	60	14	16,46	2,04	1,29	33,6	806	2 015	470
Y-KK_EW_SOUTH	17	58	27	11,39	2,04	1,22	23,2	395	1 348	627
Y-KK_EW_WEST	29	45	13	16,43	2,04	1,22	33,5	972	1 508	436
AVERAGE	40	87	21							

222 | Data; Brick Count and Measurements

Given that this is an organic construction, variations in wall thicknesses and heights are present. To still provide accurate results, average values for dimensions such as heights, depths and widths were determined to establish a reliable basis for further calculations.

For the interior wall depths, the minimum and maximum values were measured to calculate an average, a method similarly applied to the exterior walls. All intermediate walls were individually measured, resulting in an average dimension for length, depth, and height. These averages were then used as the foundation for subsequent calculations.

Since the mudbrick edging consists of two rows and two layers, it was calculated separately due to its differing depth. For each structural component, the top surface was measured and multiplied by the height to determine its volume. The resulting data was then added to the calculations for the exterior walls.

VOLUME WALL, BRICKS, MORTAR	Number of mud bricks (per wall in depth)			Total number of bricks	Average volume of mudbrick	Volume Wall		Total mudbrick volume		Mortar volume		Mud Coating Volume	
Wall	stretcher	header	rowlock		cm^3	m^3	cm^3	m^3	in %	m^3	in %	m^3	in %
Y-KK_IW_NORTH	5 383	6 190	0	11 573	1680,83	23,0	22 966 016	19,47	84,8%	2,54	11,1%	0,95	4,1%
Y-KK_IW_EAST	9 287	11 049	0	20 336	1680,83	43,6	43 554 816	34,22	78,6%	8,18	18,8%	1,16	2,7%
Y-KK_IW_SOUTH	4 282	6 781	0	11 063	1680,83	22,5	22 482 810	18,62	82,8%	2,91	13,0%	0,95	4,2%
Y-KK_IW_WEST	9 088	11 360	0	20 449	1680,83	40,9	40 897 332	34,41	84,1%	5,35	13,1%	1,14	2,8%
Y-KK1-8_IMW	*574*	*561*	*183*	*1 319*	*1680,83*	*2,7*	*2 692 800*	*2,22*	*82,4%*	*0,47*	*17,6%*		
Y-KK_IMW (total)	4 596	4 491	1 462	10 549	1680,83	21,5	21 542 400	17,75	82,4%	2,74	12,7%	1,05	4,9%
Y-KK_EW_NORTH	5 591	4 659	3 029	13 863	1680,83	29,3	29 287 362	23,33	79,7%	5,25	17,9%	0,70	2,4%
Y-KK_EW_EAST	8 059	10 074	2 350	21 219	1680,83	44,4	44 387 559	35,71	80,4%	7,92	17,8%	0,76	1,7%
Y-KK_EW_SOUTH	3 950	6 738	3 137	14 427	1680,83	29,4	29 359 542	24,28	82,7%	4,37	14,9%	0,71	2,4%
Y-KK_EW_WEST	9 720	7 541	2 179	20 180	1680,83	42,0	41 967 993	33,96	80,9%	7,27	17,3%	0,74	1,8%
AVERAGE				143 658									

223 | Data; Number of Bricks and Volumes

A total of approximately 143 600 bricks were calculated, with 69 700 attributed to the exterior walls, 63 400 to the interior walls, and 10 500 to the intermediate walls. *(Figure 229, p.157).* The difference of 6 300 bricks between the exterior and interior walls is not very significant. While the exterior walls are longer, they are not as tall as the interior walls, which, though shorter, are considerably higher.

These bricks belong to various courses within the wall. While the entire wall is composed of different courses, the extrapolation of the masonry square meters represents only a selected area.

Nevertheless, by examining the proportional relationships between the courses, valuable insights can be drawn.

MUD COATING

Wall	WALL SURFACES length (m)	WALL SURFACES height (m)	WALL SURFACES Surface Area (m^2)	WALL SURFACE Surface Area (m^2)	TOP SURFACES length (m)	TOP SURFACES depth (m)	TOP SURFACES Surface Area (m^2)	MUD COATING TOTAL Surface Areas (m^2)	MUD COATING Mud coating thickness (m)	MUD COATING Mud coating of component (m^3)
Y-KK_IW_NORTH	6,34	2,83	17,9	21,4	6,34	1,28	8,1	47,4	0,02	0,95
Y-KK_IW_EAST	9,02	2,78	25,1	17,1	11,52	1,36	15,7	57,8	0,02	1,16
Y-KK_IW_SOUTH	6,35	2,81	17,8	21,8	6,35	1,26	8,0	47,7	0,02	0,95
Y-KK_IW_WEST	9,00	2,82	25,4	17,1	11,51	1,26	14,5	57,0	0,02	1,14
Y-KK1-8_IMW	*1,28*	*2,04*	*2,6*	-	*1,28*	*1,03*	1,3	52,3	0,02	1,05
Y-KK_IMW (total)	-	-	20,9	-	-	-	10,6	-	-	-
Y-KK_EW_NORTH	-	-	-	21,4	11,42	1,22	13,9	35,2	0,02	0,70
Y-KK_EW_EAST	-	-	-	17,1	16,46	1,29	21,2	38,2	0,02	0,76
Y-KK_EW_SOUTH	-	-	-	21,8	11,39	1,22	13,9	35,7	0,02	0,71
Y-KK_EW_WEST	-	-	-	17,1	16,43	1,22	20,0	37,1	0,02	0,74
AVERAGE										8,17

224 | Data; Surfaces

CALCULATION AVERAGE DIMENSIONS WALLS

	AVERAGE depth WALL maximum (m)	AVERAGE depth WALL minimum (m)	AVERAGE depth WALL depth (m)	length IMW (m)	height IMW (m)	depth IW (m)
Y-KK_IW_NORTH	1,34	1,22	-	-	-	1,28
Y-KK_IW_EAST	1,31	1,41	-	-	-	1,36
Y-KK_IW_SOUTH	1,30	1,23	-	-	-	1,27
Y-KK_IW_WEST	1,30	1,22	-	-	-	1,26
Y-KK1-8_IMW	-	-	1,09	1,38	2,10	-
Y-KK1-2_IMW	-	-	0,99	1,29	2,22	-
Y-KK2-3_IMW	-	-	0,99	1,16	2,07	-
Y-KK3-4_IMW	-	-	1,04	1,16	2,01	-
Y-KK4-5_IMW	-	-	1,08	1,27	2,02	-
Y-KK5-6_IMW	-	-	0,98	1,28	1,75	-
Y-KK6-7_IMW	-	-	1,02	1,35	2,07	-
Y-KK7-8_IMW	-	-	1,06	1,35	2,07	-
Y-KK_EW_NORTH	1,26	1,17	-	-	-	1,22
Y-KK_EW_EAST	1,35	1,22	-	-	-	1,29
Y-KK_EW_SOUTH	1,24	1,20	-	-	-	1,22
Y-KK_EW_WEST	1,23	1,20	-	-	-	1,22
			1,03	1,28	2,04	1,26

225 | Data; Average Dimensions

SURFACE MAGAZINES

Magazine	MAGAZINES length (m)	MAGAZINES height (m)	MAGAZINES Surface Area (m^2)
Y-KK 1	5,38	2,04	11,0
Y-KK 2	5,09	2,04	10,4
Y-KK 3	4,03	2,04	8,2
Y-KK 4	4,34	2,04	8,9
Y-KK 5	5,45	2,04	11,1
Y-KK 6	5,26	2,04	10,7
Y-KK 7	4,26	2,04	8,7
Y-KK 8	4,13	2,04	8,4
			77,40

226 | Data; Surface Magazines

MUD BRICK EDGING

	MUD BRICK EDGING (EXTERIOR WALLS) surface (top m^2)	height (m)	volume total (m^3)	average mud brick (m^3)	number of mud bricks total
Y-KK_EW_NORTH	5,95	0,165	0,98	0,0017	583
Y-KK_EW_EAST	7,511	0,165	1,24	0,0017	736
Y-KK_EW_SOUTH	6,134	0,165	1,01	0,0017	601
Y-KK_EW_WEST	7,543	0,165	1,24	0,0017	740
					2661

227 | Data; Mudbrick Edging (EW)

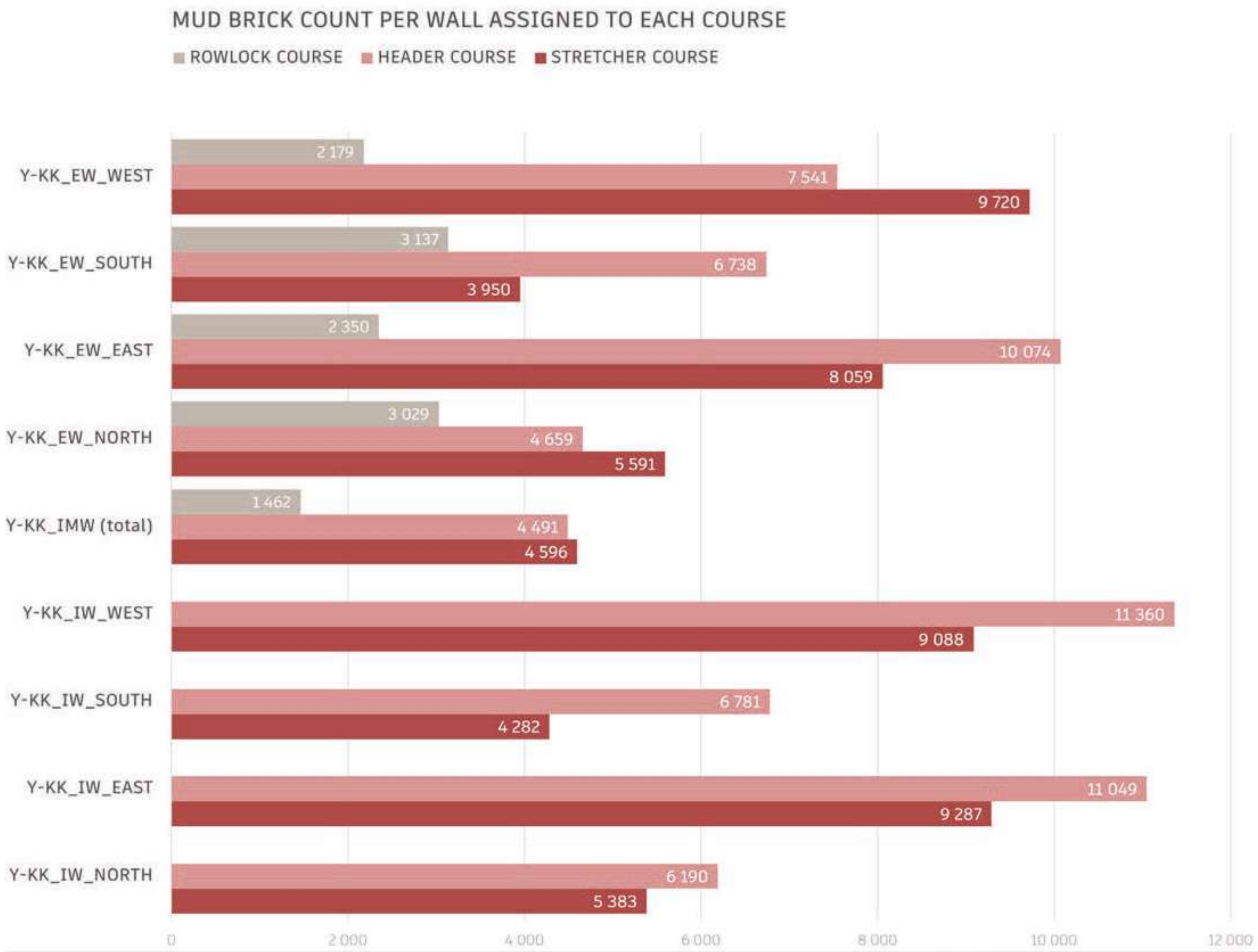
For the mud coating, calculations were performed by assigning wall surfaces to the respective structural components as accurately as possible. The wall surfaces of the magazines were redistributed and attributed to their corresponding structural elements, such as the interior walls (IW), intermediate walls (IMW), or exterior walls (EW). It is important to note that the exterior surface of the exterior walls was never plastered, a detail critical to the accuracy of these calculations.

Finally, results were determined for each structural component in cubic meters and as percentages. These calculations provide estimates for the total volume of the building elements, the volume of bricks, the volume of mortar, and the volume of the mud coating.

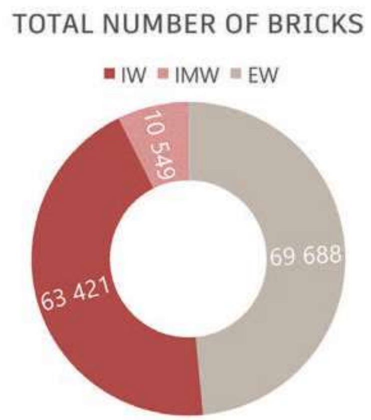
These results can serve as a reference for estimating the material quantities used in the main chamber. It is important to note that this is an unbaked mudbrick structure, which inherently involves variations in brick dimensions, mortar joints, and mud coating thickness. Excavation gaps and the missing mass of the roof construction, which was likely anchored and covered with mudbricks, were not accounted for in the calculations.

For the calculation of the mud coating, the wall surfaces and the top surface were determined. The result was then multiplied by the thickness of the mud coating to calculate the volume in cubic meters of the coating material. Subsequently, the results were consolidated and assigned to their respective structural components.

In conclusion, the total volume of mud coating used for the main tomb is estimated to be approximately 8 m^3. This calculation does not account for areas where the coating has flaked off. It is assumed that all surfaces were coated, except for the exterior sides of the exterior walls.



Diagramm; Number of Mudbrick per Wall and Course Type;



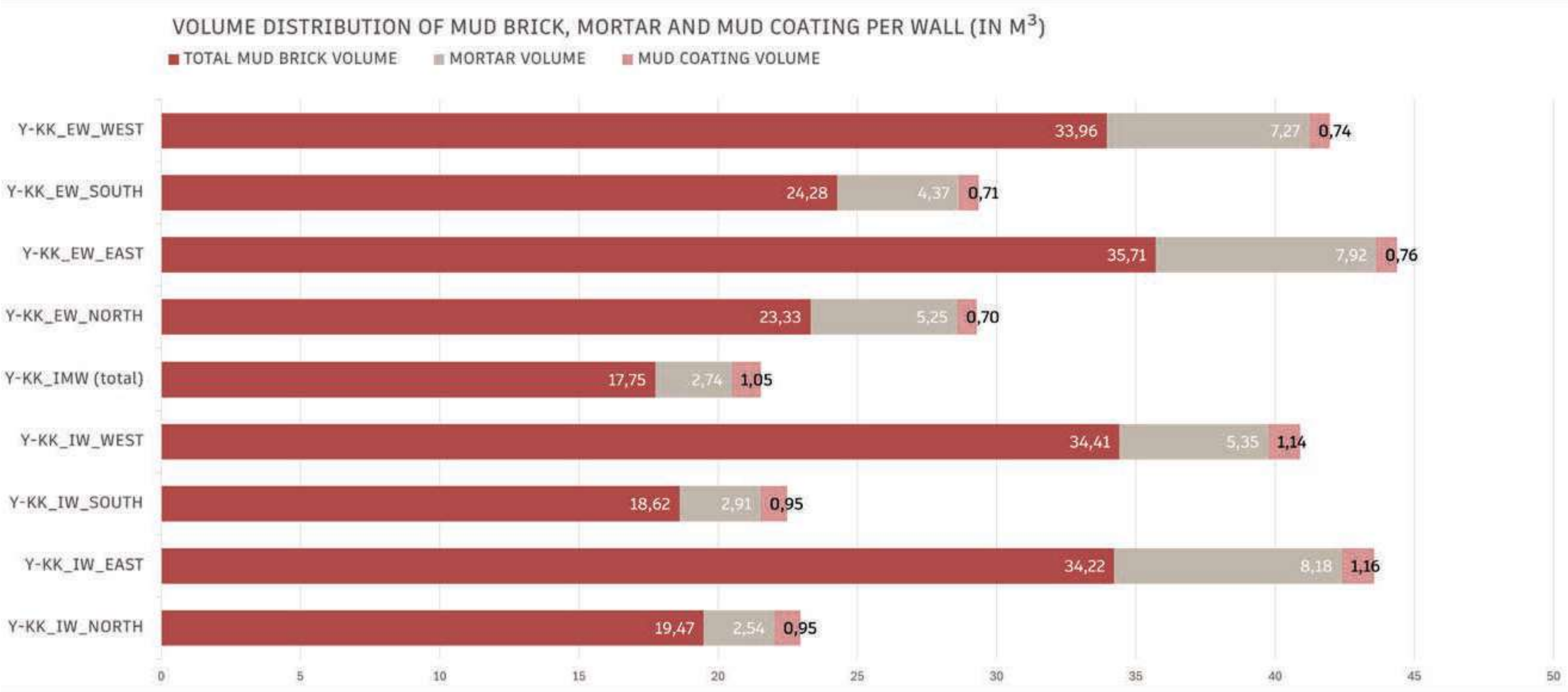
229 | Diagramm; Total Number of Bricks

In the diagram *Figure 228*, the bricks are categorized by course type for each wall. It becomes evident that most bricks were used in header courses, followed by stretchers.

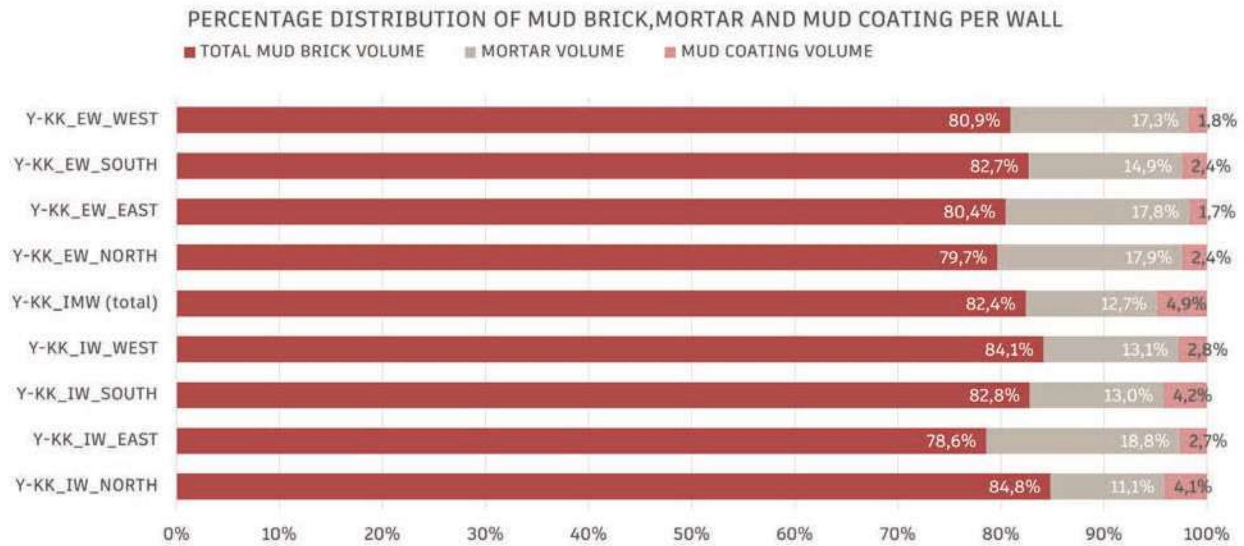
As shown in the analysis, header courses consist of 5 bricks aligned in depth. This means that two header arrangements placed side by side account for a total of ten bricks. For stretcher courses, the outer wall surfaces feature stretcher bricks, while the interior contains two rows of four headers each. Whether two headers are visible side by side in the view or a single stretcher, both configurations represent the use of ten bricks in depth.

Despite this understanding, differences between the header and stretcher courses are still apparent in the results, showing that header courses were used more frequently.

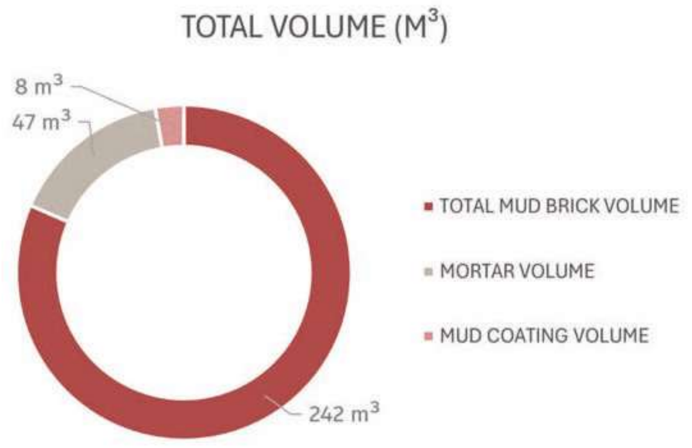
Rowlock courses were observed in this case in the exterior walls and intermediate walls. When comparing the results of the exterior walls, the number of bricks in rowlock courses consistently ranges between 2000 and 3000 bricks.



230 | Diagramm; Volume Distribution per Wall in m³



231 | Diagramm; Volume Distribution per Wall in Percent



232 | Diagramm; Total Volume in M³

In *Figure 230* and *Figure 231*, the proportions of bricks, mortar, and mud coating are illustrated in relation to one another.

Figure 230 highlights the cubic meters of bricks, mortar, and mud coating used for each structural component. It becomes apparent that the structure consists of approximately three-quarters mudbricks, with the remainder comprising mortar and only a minimal amount of mud coating.

Figure 231 displays the percentages of these proportions. It reveals that on average 82% of the material is bricks, 15% is mortar, and 3% is mud coating.

In conclusion, the total mass comprises 242 m³ of mudbricks, corresponding to approximately 144 000 bricks. Between these bricks, 47 m³ of mortar is present, and finally 8 m³ of mud coating, which almost entirely covers and encases the structure. *(Figure 232)*

The extrapolation of the masonry square meters provides a solid foundation for estimating the total mass of materials used in the construction. However, it is important to note that only portions of the masonry bonds are recorded within each square meter and systematically scaled up.

IW_NORTH	IW_EAST	IW_ SOUTH	IW_WEST	EW_NORTH	EW_EAST	EW_SOUTH	EW_WEST
6,34x2,83	9,03x2,78	6,35x2,81	9,02x2,82	13,84x2,04	16,46x2,04	14,27x2,04	16,43x2,04
Header	Header	Header	Header	Header	Header	Rowlock	Rowlock
Rowlock	Rowlock	Stretcher	Rowlock	Stretcher	Stretcher	Stretcher	Stretcher
Header	Stretcher	Stretcher	Stretcher	Rowlock	Rowlock	Header	Header
Stretcher	Header	Header	Header	Stretcher	Stretcher	Stretcher	Stretcher
Header	Stretcher	Header	Stretcher	Header	Header	Header	Header
Stretcher	Header	Rowlock	Header	Header	Header	Rowlock	Rowlock
Header	Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	Header	Stretcher
Stretcher	Header	Header	Header	Header	Header	Stretcher	Header
Header	Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	Header	Stretcher
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Header	Header	Stretcher	Stretcher	Header	Rowlock		Header
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Header	Stretcher	Stretcher	Stretcher				
Stretcher	Header	Header	Header				
Header	Stretcher	Stretcher	Stretcher				
Stretcher	Header	Header	Header				
Header	Header	Stretcher	Stretcher				
Stretcher	Stretcher	Header	Header				
Header	Header	Stretcher	Stretcher				

COUNT	IW_NORTH	IW_EAST	IW_ SOUTH	IW_WEST	EW_NORTH	EW_EAST	EW_SOUTH	EW_WEST
stretcher	17	17	18	18	9	13	5	10
header	22	22	21	21	12	13	7	11
rowlock	1	1	1	1	1	2	2	2

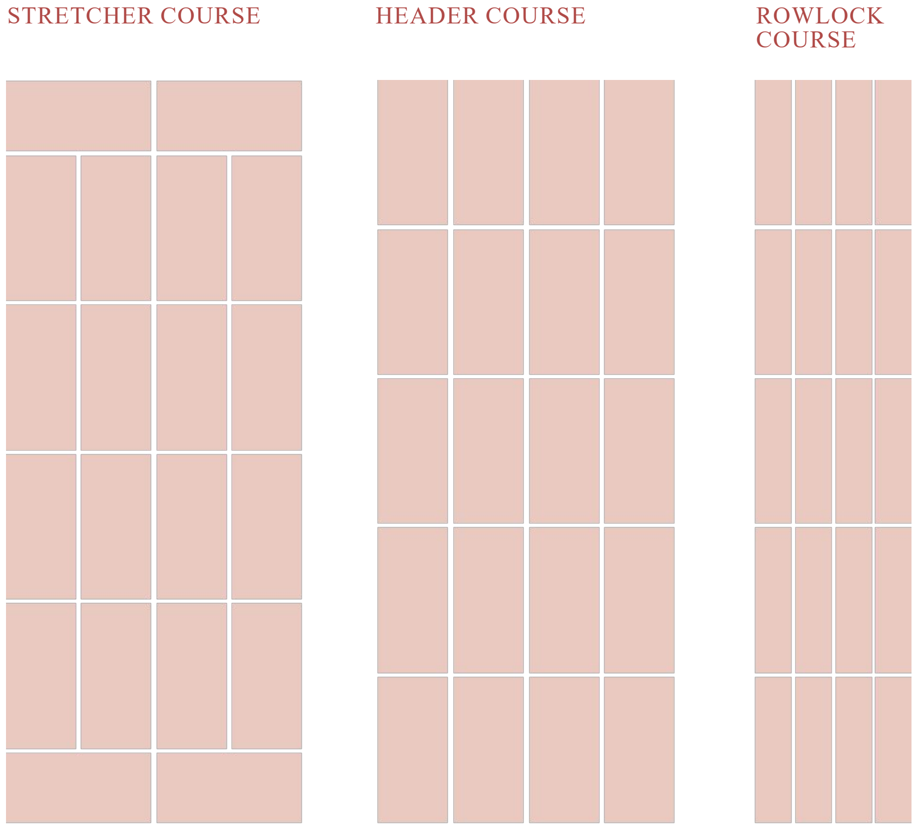
EW=IMW
- Header Course
- Strecher Course
- Rowlock Course

Graphic; Course Type per Layer and Wall

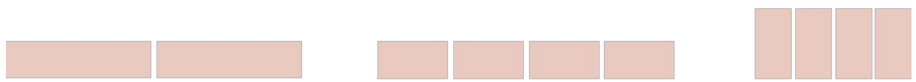
To complement this approach, additional data was collected by documenting and analyzing the course types for each structural component. For the interior walls, much of the lower sections remain coated with mud, so the visible portions were extrapolated to represent the entire length. Courses within a single row rarely change; in such cases, the longest segment was recorded in the database.

The intermediate walls are exceptionally well-preserved and still entirely coated, suggesting that their construction was likely similar to that of the exterior walls. In some cases, the exterior walls were not excavated down to their full depth, and these missing data points were supplemented with assumptions based on comparable walls. The rhythm and arrangement of the courses are remarkably consistent across the walls.

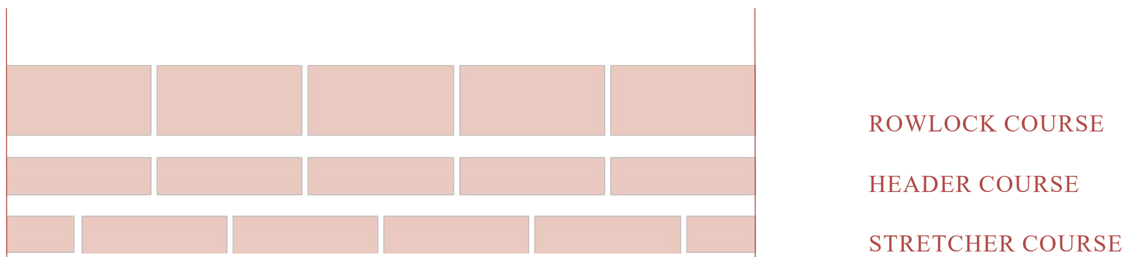
After all, the masonry reveals a recurring pattern of double-layered header courses at regular intervals, while the remaining courses alternate between stretcher and header courses. For the interior walls, the upper sections predominantly feature a single rowlock course, whereas the exterior walls generally exhibit two rowlock courses. The total number of layers for the interior walls amounts to 40 courses, while the intermediate and exterior walls contain 28 courses each.



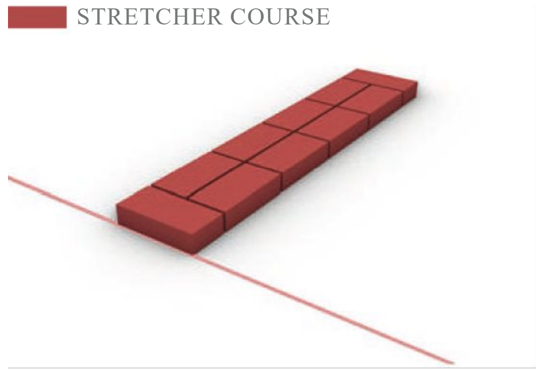
234 | Illustration Top View; Course Concept



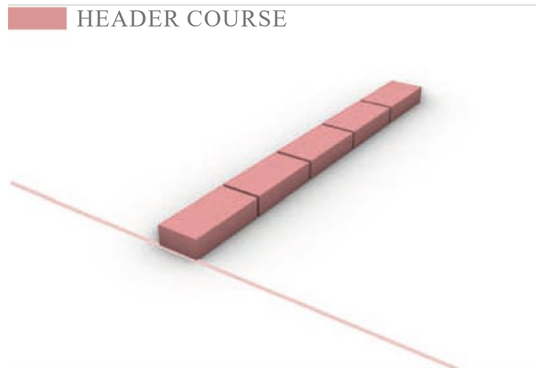
235 | Illustration Front View; Course Concept



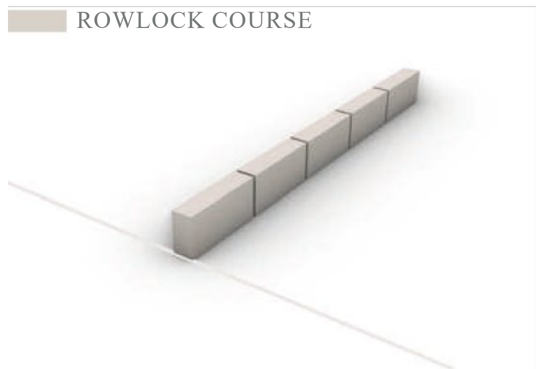
236 | Illustration Section; Course Concept



239 | Unit in Depth of the Stretcher Course

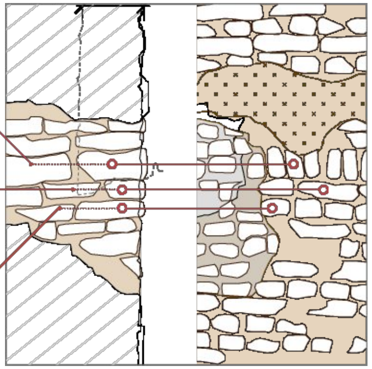


238 | Unit in Depth of the Header Course



237 | Unit in Depth of the Rowlock Course

240 | Elevation View; Y-KK_IW_SOUTH



241 | Folded Section; Y-KK_IW_SOUTH

6.8 Consistencies

In summary, the analysis has revealed several regularities and constants. Data and patterns that consistently emerged can now be used to formulate a hypothesis or a proposal for reconstructing the structure. The facts and results of the analysis serve as the foundation for establishing parameters, which will subsequently provide a basis for simulations of the tomb. What follows is a summary of the analysis results, highlighting the most significant findings.

The analysis identifies three distinct types of courses within the masonry: header courses, stretcher courses (comprising both header and stretcher bricks), and rowlock courses. Through detailed examination of sectional views, floor plans, and elevations, the various brick-laying techniques were systematically analyzed. *Figure 236* provides a simplified representation of the structural characteristics of these courses in plan, section, and elevation.

Variations were observed in stepped configurations (mudbrick edging; embedding for roof construction), particularly in the interior and exterior walls. In these cases, deviations were identified in stretcher courses, where the number of interior header bricks differed.

Header courses were the most frequently documented, followed by stretcher courses. Header courses were occasionally arranged in double layers, typically appearing at rhythmic intervals of 7–8 rows. In general, header and stretcher courses were alternated, with a deliberate alignment of joints to maintain structural integrity.
Rowlock courses were less common, often appearing only twice per wall. Notably, these courses were predominantly utilized as termination layers and were frequently positioned in the first and sixth rows of the exterior walls, emphasizing their functional and structural significance.

IW_NORTH	IW_EAST	IW_ SOUTH	IW_WEST	AVERAGE	
6,34x2,83	9,03x2,78	6,35x2,81	9,02x2,82		COUNT
Header	Header	Header	Header	Header	39
Rowlock	Rowlock	Stretcher	Rowlock	Rowlock	38
Header	Stretcher	Stretcher	Stretcher	Stretcher	37
Stretcher	Header	Header	Header	Header	36
Header	Stretcher	Header	Stretcher	Stretcher	35
Stretcher	Header	Rowlock	Header	Header	34
Header	Stretcher	Stretcher	Stretcher	Stretcher	33
Stretcher	Header	Header	Header	Header	32
Header	Stretcher	Stretcher	Stretcher	Stretcher	31
Stretcher	Header	Header	Header	Header	30
Header	Stretcher	Stretcher	Stretcher	Stretcher	29
Stretcher	Header	Header	Header	Header	28
Header	Header	Stretcher	Stretcher	Stretcher	27
Header	Stretcher	Header	Header	Header	26
Stretcher	Header	Header	Header	Header	25
Header	Stretcher	Stretcher	Stretcher	Stretcher	24
Stretcher	Header	Header	Header	Header	23
Header	Stretcher	Stretcher	Stretcher	Stretcher	22
Stretcher	Header	Header	Header	Header	21
Header	Stretcher	Stretcher	Stretcher	Stretcher	20
Stretcher	Header	Header	Header	Header	19
Header	Header	Stretcher	Stretcher	Stretcher	18
Header	Stretcher	Header	Header	Header	17
Stretcher	Header	Header	Header	Header	16
Header	Stretcher	Stretcher	Stretcher	Stretcher	15
Stretcher	Header	Header	Header	Header	14
Header	Stretcher	Stretcher	Stretcher	Stretcher	13
Stretcher	Header	Header	Header	Header	12
Header	Stretcher	Stretcher	Stretcher	Stretcher	11
Stretcher	Header	Header	Header	Header	10
Header	Header	Stretcher	Stretcher	Stretcher	9
Header	Stretcher	Header	Header	Header	8
Stretcher	Header	Header	Header	Header	7
Header	Stretcher	Stretcher	Stretcher	Stretcher	6
Stretcher	Header	Header	Header	Header	5
Header	Stretcher	Stretcher	Stretcher	Stretcher	4
Stretcher	Header	Header	Header	Header	3
Header	Header	Stretcher	Stretcher	Stretcher	2
Stretcher	Stretcher	Header	Header	Header	1
Header	Header	Stretcher	Stretcher	Stretcher	0

COUNT	IW_NORTH	IW_EAST	IW_ SOUTH	IW_WEST	AVERAGE	COURSES
stretcher	17	17	18	18	s 18	40
header	22	22	21	21	h 21	
rowlock	1	1	1	1	r 1	

EW_NORTH	EW_EAST	EW_SOUTH	EW_WEST	AVERAGE	
13,84x2,04	16,46x2,04	14,27x2,04	16,43x2,04		COUNT
Header	Header	Rowlock	Rowlock	Rowlock	27
Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	26
Rowlock	Rowlock	Header	Header	Header	25
Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	24
Header	Header	Header	Header	Header	23
Header	Header	Rowlock	Rowlock	Rowlock	22
Stretcher	Stretcher	Header	Stretcher	Stretcher	21
Header	Header	Stretcher	Header	Header	20
Stretcher	Stretcher	Header	Stretcher	Stretcher	19
Header	Stretcher	Stretcher	Header	Header	18
Stretcher	Stretcher	Header	Stretcher	Stretcher	17
Header	Header	Header	Header	Header	16
Header	Header	Stretcher	Header	Header	15
Stretcher	Stretcher	Header	Stretcher	Stretcher	14
Header	Header		Header	Header	13
Stretcher	Stretcher		Stretcher	Stretcher	12
Header	Header		Header	Header	11
Stretcher	Stretcher		Stretcher	Stretcher	10
Header	Header		Header	Header	9
Stretcher	Stretcher		Stretcher	Stretcher	8
Header	Header		Header	Header	7
Header	Rowlock		Header	Header	6
	Stretcher		Stretcher	Stretcher	5
	Header			Header	4
	Stretcher			Stretcher	3
	Header			Header	2
	Stretcher			Stretcher	1
	Header			Header	0

COUNT	EW_NORTH	EW_EAST	EW_SOUTH	EW_WEST	AVERAGE	COURSES
stretcher	9	13	5	10	s 12	28
header	12	13	7	11	h 14	
rowlock	1	2	2	2	r 2	

EW=IMW
Header Course
Strecher Course
Rowlock Course

Graphic; Course Type per Layer and Wall with Average Course Type per Layer

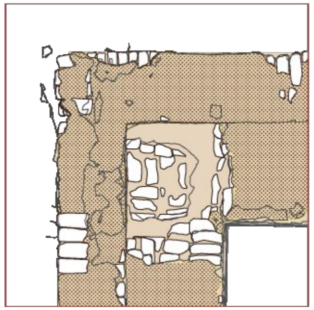
The interior walls consist of 40 courses, while the intermediate and exterior walls are composed of 28 courses. Since portions of the interior walls remained covered with mud coating, the visible brick formations were extrapolated to represent the entire row. For the exterior walls, not all sections were fully excavated; therefore, the height and number of courses from the east wall were applied to the other walls.

From the available data, an average arrangement was established (*Figure 242*) to serve as a foundation for subsequent 3D simulations. Each course was assigned a number, starting from 0, to systematically designate the specific formation corresponding to each level. This numbering system ensures clarity and consistency in the modeling process.

In this average, the interior wall is made up of 40 courses, of which 18 are stretcher courses, 21 are header courses, and one is a rowlock course. For the exterior and intermediate walls, a total of 28 courses were identified, comprising 12 stretcher courses, 14 header courses, and two rowlock courses.

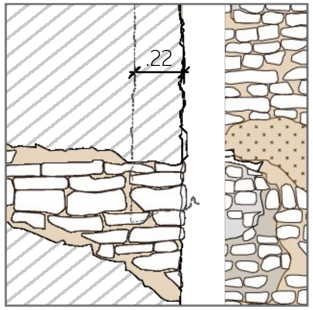
243 | Plan View;

Y-KK_EW_SOUTH-WEST



244 | Folded Section;

Y-KK_IW_SOUTH

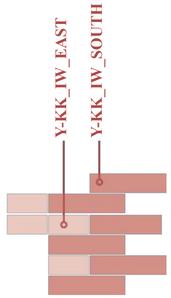


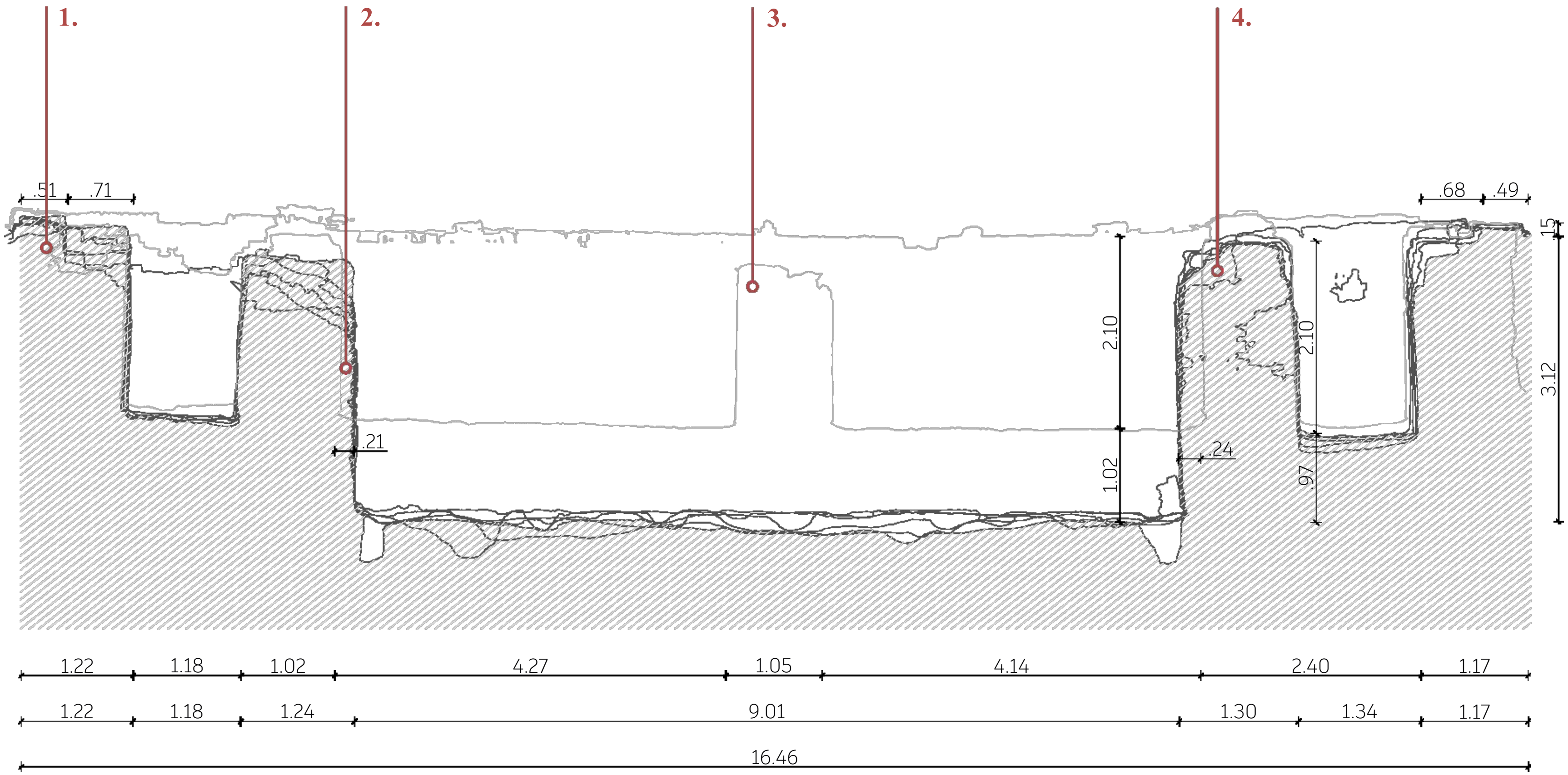
245 | Section;

Y-KK_IW_EAST

246 | Snapshot;

Y-KK5-6_IMW





247 | Longitudinal Sections (one cut per meter)

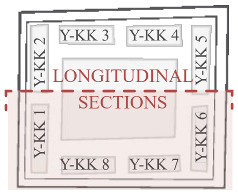
SCALE 1:75

(1.) The stepping in the exterior wall is defined by a mudbrick edging consisting of two layers, each two brick lengths deep. At the corners where exterior walls meet, interlocking occurs, but the methods vary depending on the specific corner. For example, some corners show a staggered alignment of bricks, while others demonstrate a more seamless transition.

(2.) The intermediate walls, while constructed similarly to the interior and exterior walls, differ in their depth. They are consistently one brick length shorter, a detail that impacts their alignment and connection with adjacent walls. This reduced depth highlights their role as secondary structural components within the overall design.

(3.) The interlocking of the intermediate walls with the interior and exterior walls remains a subject of uncertainty. Gaps observed in some areas suggest that no direct interlocking occurs, leaving the intermediate walls as independent components. However, evidence of overlapping courses in other sections indicates a potential connection between these walls. This ambiguity could reflect differing functional or temporal construction phases.

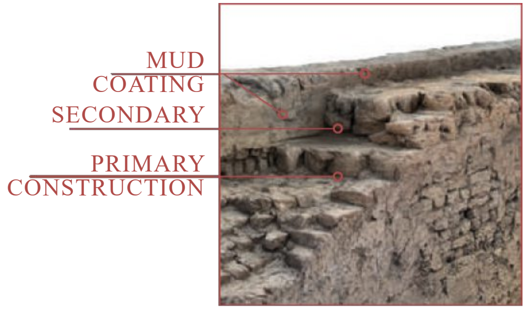
(4.) At the corner where the interior walls east and south intersect, partial visibility of the brick arrangement reveals how the layers interlock. It is evident that the walls alternate their courses at the point of connection, with each wall extending its courses into the other. For instance, the header course of the east wall continues into the south wall, while the south wall reciprocates with its own header course extending into the east wall. In this corner, it is also evident that the two walls merge. The breakout reveals that the walls interlock rather than being constructed separately. While the role of the intermediate wall in this configuration is unclear, it is possible that all three components - interior wall, exterior wall, and intermediate wall - are connected through interlocking construction.



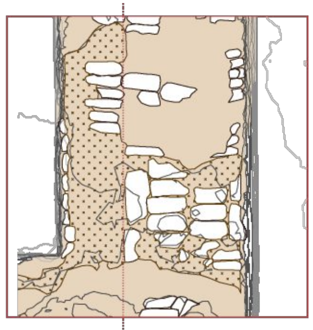
248 | Snapshot; Y-KK_IW_SOUTH-EAST

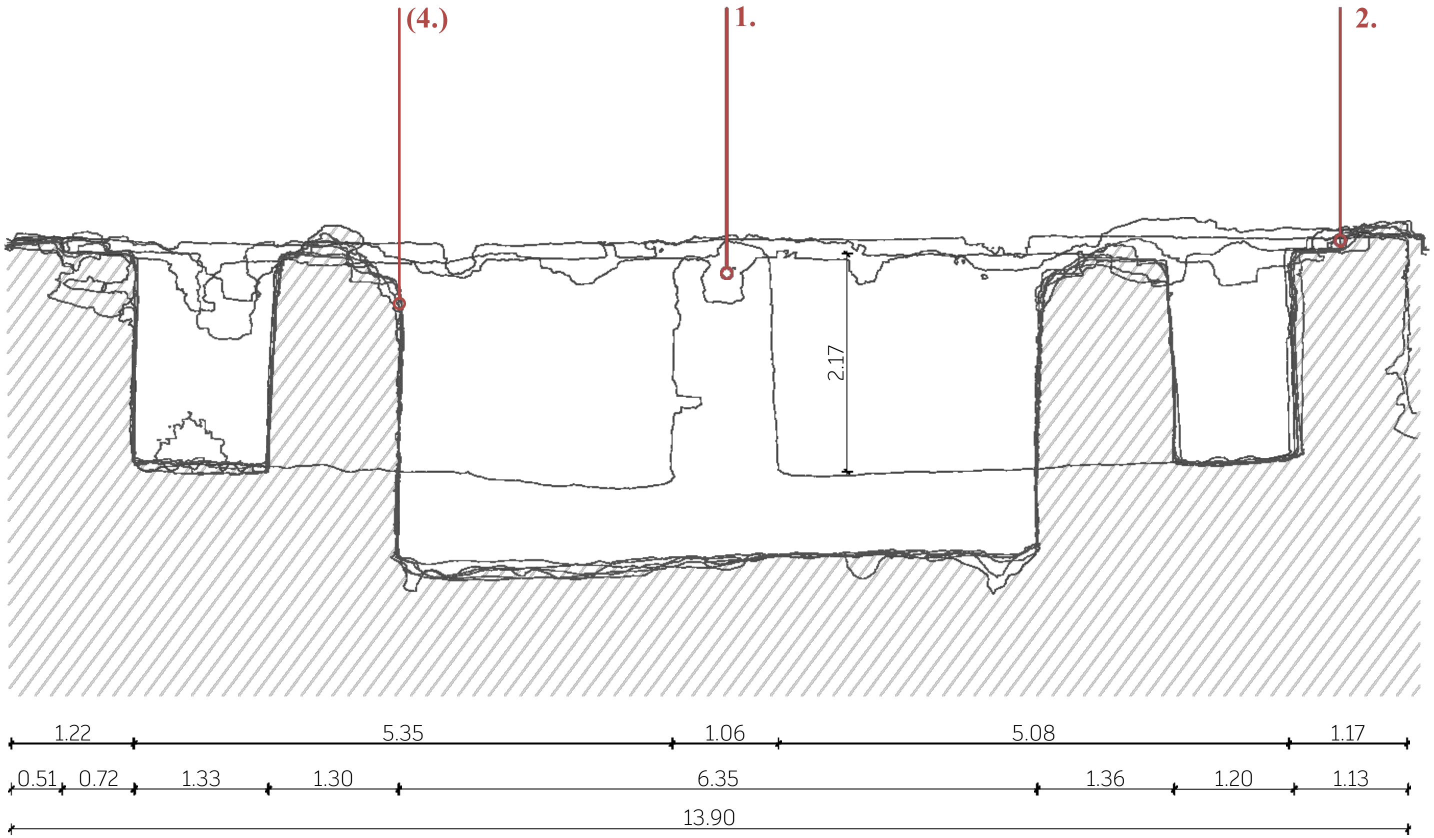
249 | Snapshot; Beam Hole of Y-KK_IW_NORTH

250 | Snapshot; Y-KK_EW_WEST



251 | Planview; Y-KK_IW_NORTH





252 | Cross Sections (one cut per meter)

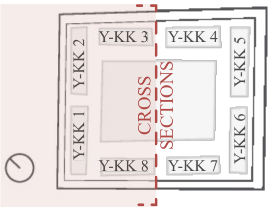
SCALE 1:75

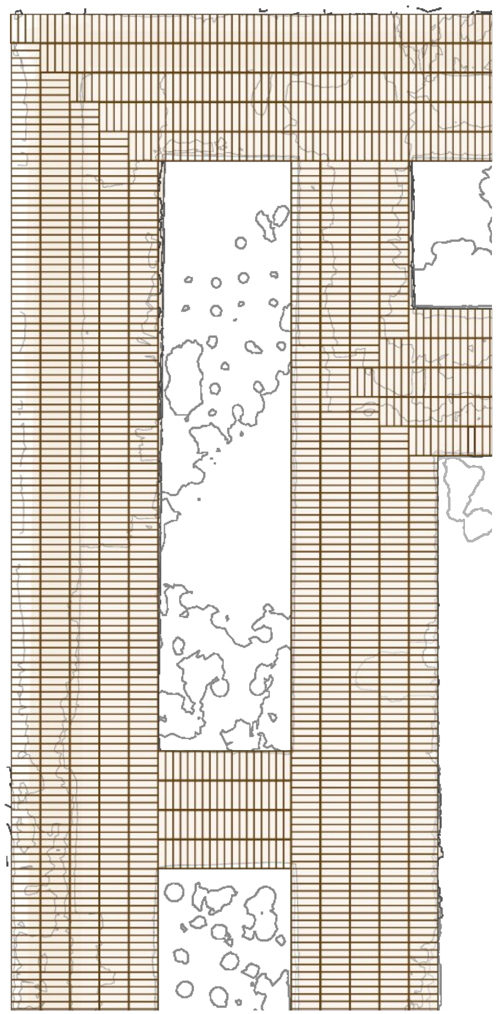
(1.) Several areas reveal the presence of beam sockets. Unfortunately, the roof structure, which most likely consisted of beams, mats, and an additional layer of bricks, has not been preserved. However, there are indications of how the construction was integrated into the mudbrick structure. Beam sockets are voids in the masonry found at the upper edges of the walls. Such voids were exclusively identified at the top of the walls; while other parts of the walls exhibit damage, no beam sockets were found elsewhere.

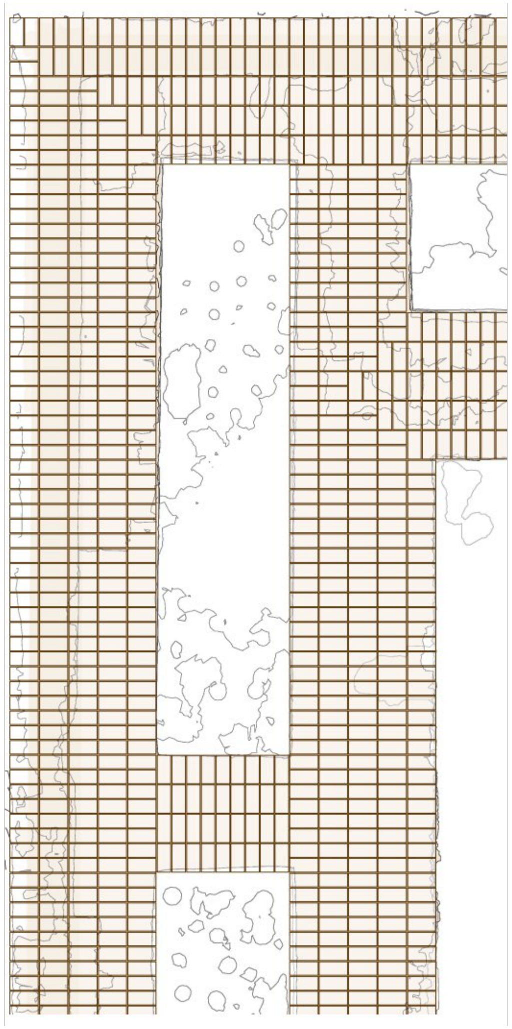
This observation strongly suggests that the subterranean tomb was covered by a roof structure, but no intermediate floors were present. It is highly probable that the previously mentioned stepped configurations of the interior and exterior walls were used to support the roof beams. These beams were then integrated into the structure, likely enclosed and embedded with additional mudbricks and mortar to form a cohesive and stable roof.

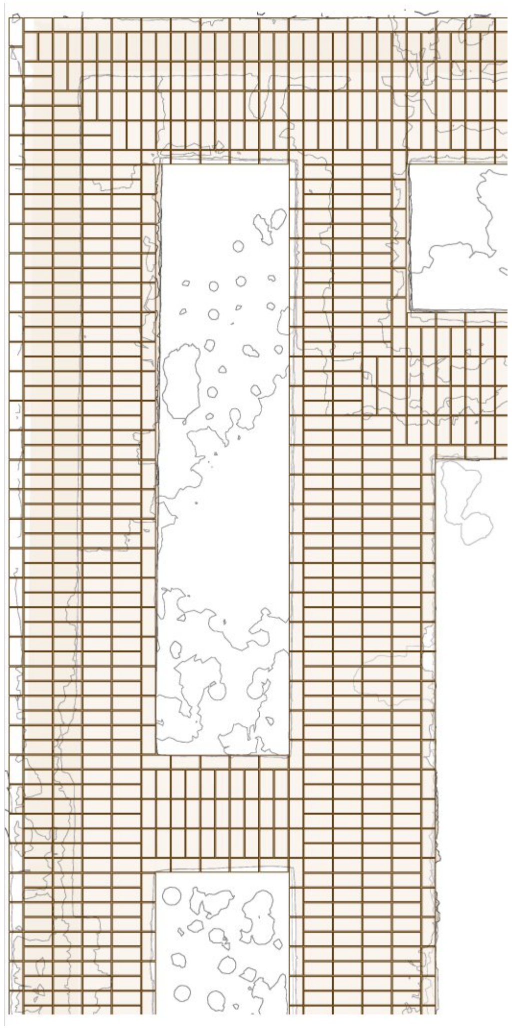
(2.) It is possible that the upper construction partly consists of two distinct parts: the mudbrick edging and an additional layer. Not only in the exterior walls but also in the interior walls, there are indications that the upper wall termination consists of two distinct constructions. Sections through wall openings suggest that these components form a cohesive unit, but the top view at Y-KK_IW_NORTH reveals the uppermost layer as a combination of a rowlock course and a stretcher course with two headers in depth.

This configuration may have been intentionally designed to facilitate the embedding of the roof structure, providing additional stability and integration at the critical juncture between the wall and the roof.









SCALE 1:100

253 | Top View;

Proposal Concept Rowlock Course

254 | Top View;

Proposal Concept Header Course

255 | Top View;

Proposal Concept Stretcher Course

6.9 Proposal of Brick Laying Technique

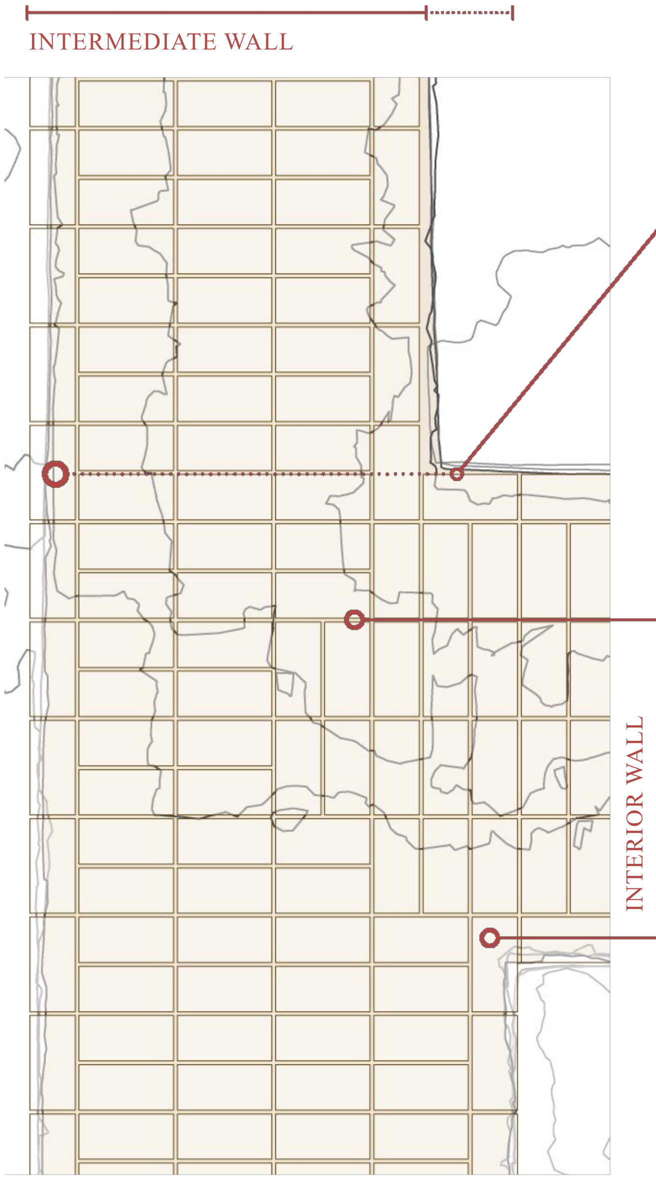
From the observed consistencies, a proposal has been developed to reconstruct the brick-laying techniques used for the various courses. While the analysis clarified several aspects of the construction process, some questions remain unresolved, requiring assumptions to fill these gaps. Despite these uncertainties, the general patterns and systems identified during the study of the structural components were largely confirmed.

As part of this effort, an initial step involved creating a detailed top view of the stretcher, header, and rowlock courses. Additionally, the plan includes formations designed to represent the construction and arrangement of the mudbrick edging. This approach was conducted in a systematic and schematic manner, focusing on structural consistency rather than accounting for minor variations in brick dimensions or alignment.

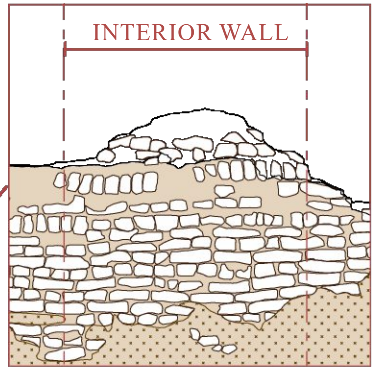
It is important to highlight that the structure was constructed using unbaked mudbricks, which are naturally prone to irregularities and deviations. These inherent variances were deliberately excluded from this analysis to ensure a streamlined and methodical approach. Instead, the hypotheses were used as a foundation to propose a coherent and functional reconstruction of the masonry.

Given the symmetrical design of the tomb, the analysis concentrated on one-quarter of the structure, which served as a representative area. The system developed for this segment can be applied to other similarly categorized structural components throughout the tomb. This formation not only establishes a basis for the reconstruction process but also provides a foundation for advanced simulation efforts.

STRETCHER COURSE



256 | Top View; Proposal Stretcher Course



257 | Detail; Y-KK_IMW_Y-KK8

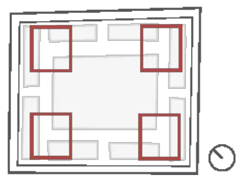
258 | Detail; Y-KK_IW_EAST

259 | Detail; Y-KK_IW_SOUTH-EAST

In the stretcher course, there is evidence suggesting that the intermediate wall and the interior wall, which align seamlessly, were constructed as a continuous masonry element.

Additionally, it was observed that the brick-laying technique remains consistent along the length of the wall. For this reason, the initial rows of bricks extending toward the magazine were laid continuously before the intermediate wall was narrowed by one brick length in depth.

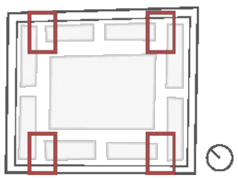
At the point where these two walls overlap, another interior wall intersects at a 90-degree angle. However, the extent to which the inner rows of bricks from the interior wall or the intermediate wall interlock within this complex junction is not clearly visible. Consequently, these connections were based on reasonable assumptions derived from the observed patterns. Breakouts further reveal that the interior walls intersecting at the corners are



interwoven, with courses alternating and interlocking at their junctions. This interlacing ensures stability and demonstrates a deliberate method of creating a cohesive bond between walls. The outermost row of bricks within the stretcher course appears to run continuously along the alignment of the wall edge.

How the intermediate wall integrates with the exterior wall remains unclear. Observations of the upper layers and breakouts do not suggest a strong interlocking connection; instead, the exterior wall appears to maintain its continuity with its brick-laying technique running uninterrupted.

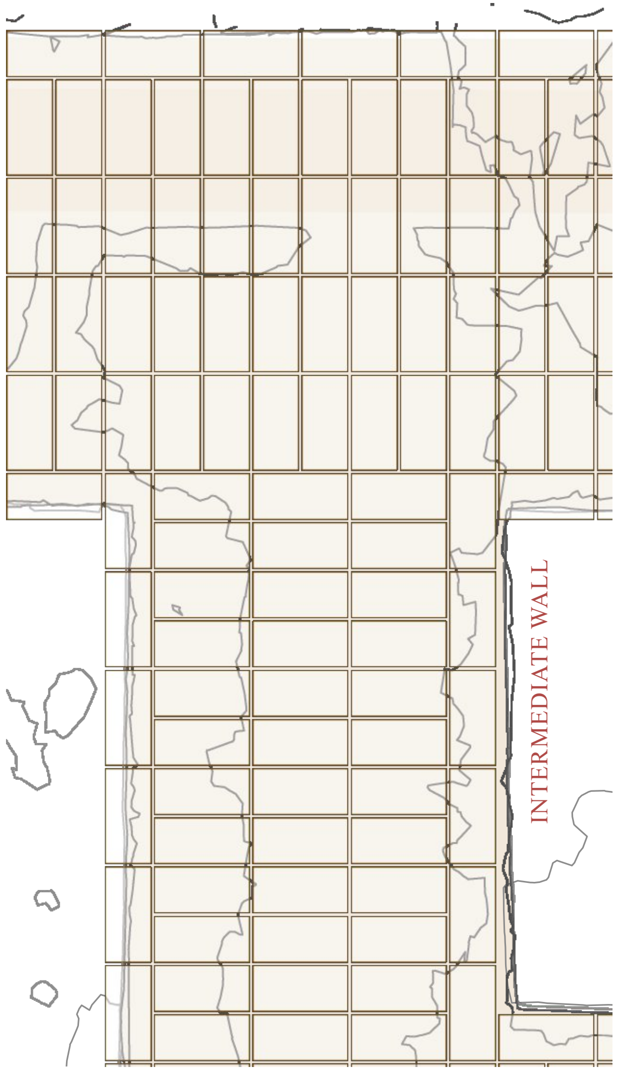
The course of the exterior wall mirrors that of the interior wall. Since voids or openings are found exclusively in the interior walls, the internal structure of the exterior wall has been inferred based on evidence from breakouts at the upper edge, the exterior view, and the established pattern observed in the interior walls.



260 | Intersection; Y-KK5-6_IMW

261 | Plan View; Y-KK1-8_IMW

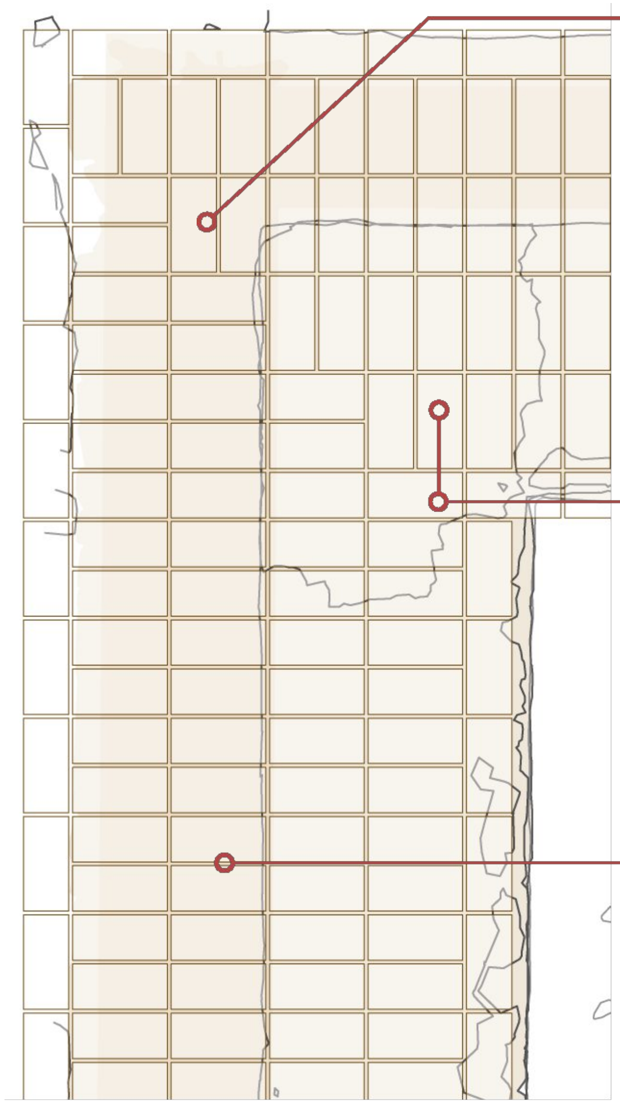
STRETCHER COURSE



262 | Top View; Proposal Stretcher Course

PROPOSAL

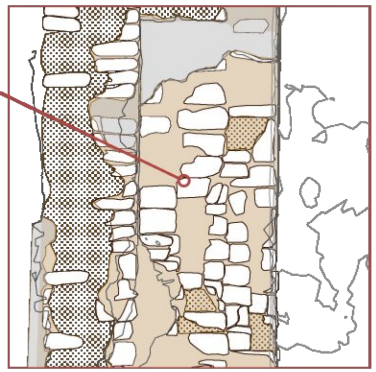
STRETCHER COURSE



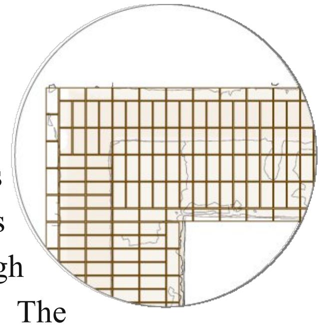
263 | Top View; Proposal Stretcher Course

264 | Detail; Y-KK_EW_SOUTH-WEST

265 | Plan View; Y-KK_EW_SOUTH-EAST



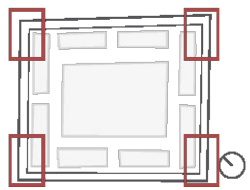
266 | Plan View; Y-KK_EW_SOUTH



267 | Plan View; Proposal Option Exterior Wall

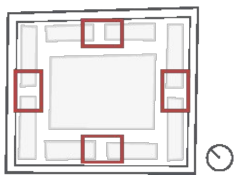
How the exterior walls meet at their intersections is partially visible through breakouts at these points. The continuity of the brick rows varies, and it remains unclear whether a strict stepping pattern is applied for each individual brick row or if some rows are extended in pairs. These variations suggest that different construction approaches may have been employed at specific junctions, potentially reflecting adjustments made during the building process. Overall, the exterior wall is well-preserved, the construction beneath the mudbrick edging remains obscured.

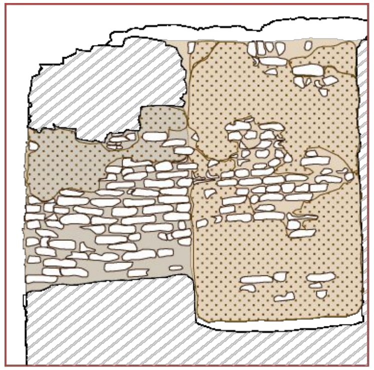
In the representation, a stepping pattern for each brick row was illustrated to reflect one possible approach, while *Figure 267* presents an alternative brick-laying technique, highlighting the variability in potential construction methods.
In some areas, half-bricks protruding



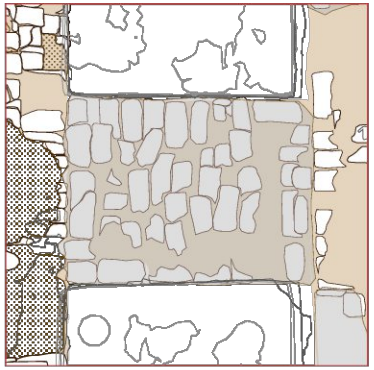
from the exterior wall are visible, revealed through damage to the upper sections of the wall. These features suggest a degree of interlocking, indicating that the walls were not entirely independent constructions. Instead, certain courses may have been intentionally interwoven. In some cases, it appears that only the stretcher bricks along the outer edge connect the interior and exterior walls with the intermediate wall. This suggests a selective integration approach, with connections at specific points, possibly added secondarily. If the length of the wall is considered, aligning the stretcher bricks end-to-end reveals that the width corresponds to four and a half bricks.

This observation further supports the notion of a carefully planned integration method, influenced by both functional demands and the need for alignment within the overall structure.

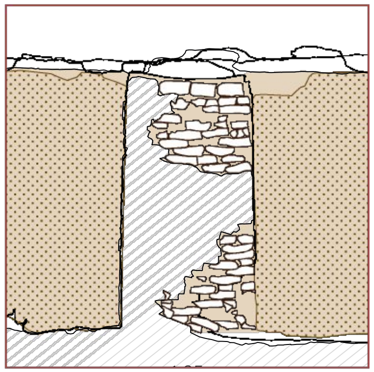




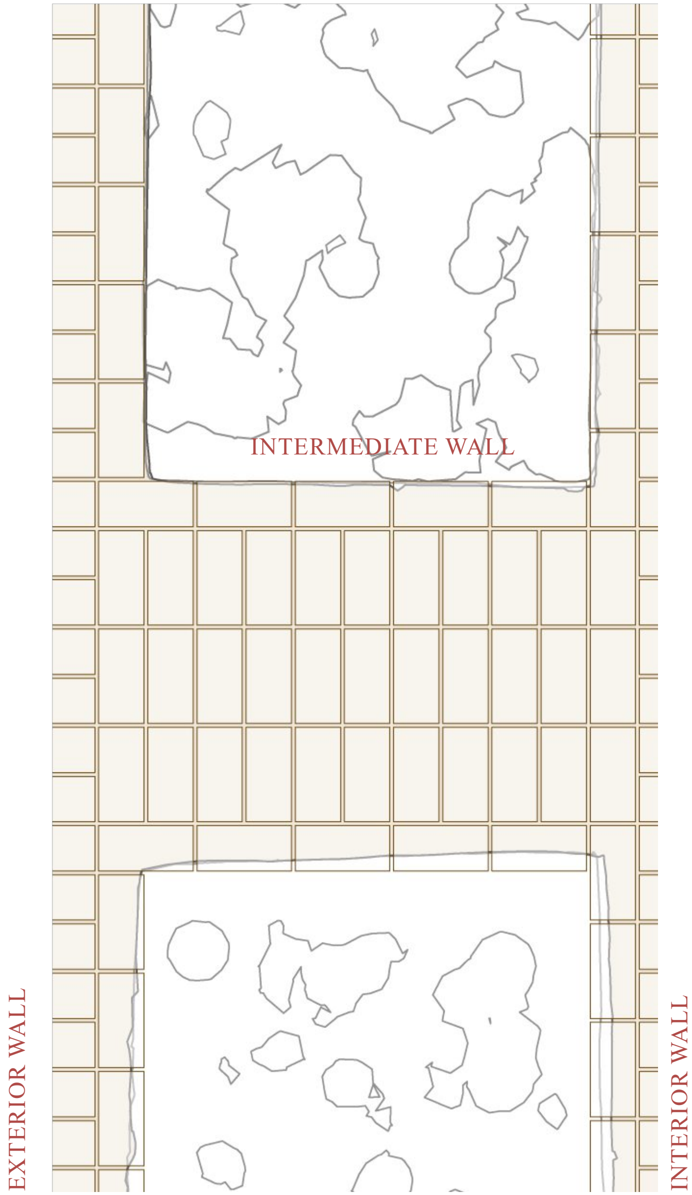
268 | Section; Connection IW to IMW



269 | Plan View; Y-KK5-6_IMW



270 | Section; Y-KK7-8_IMW

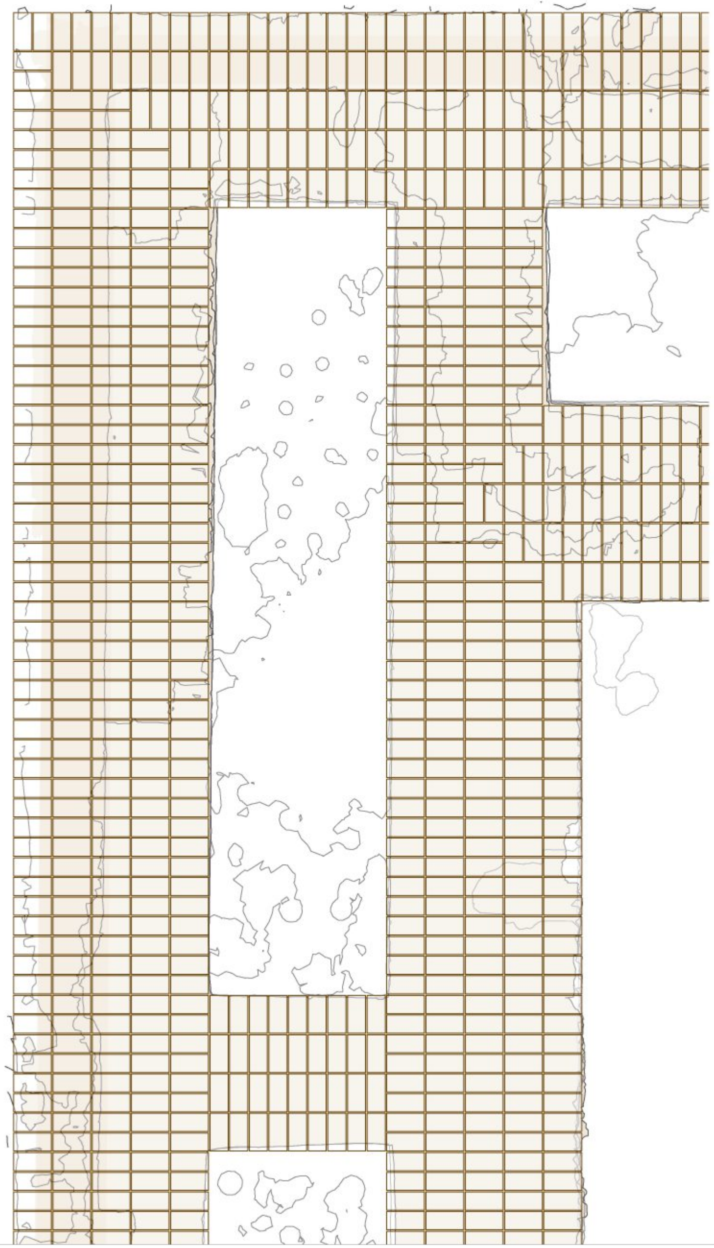


SCALE 1:20

PROPOSAL

271 | Top View; Proposal Stretcher Course

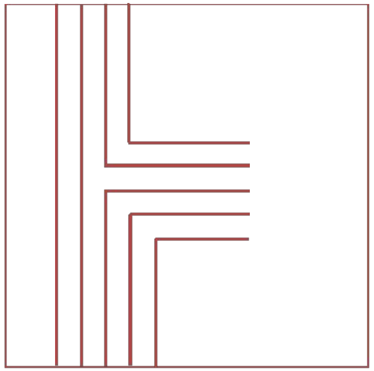
HEADER COURSE



EXTERIOR WALL INTERIOR WALL

SCALE 1:50

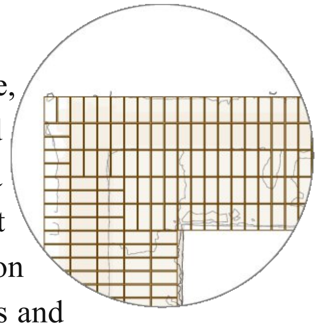
272 | Top View; Proposal Header Course



273 | Illustration; Path of Courses IW-IMW

274 | Snapshot; Y-KK7-8_IMW to EW

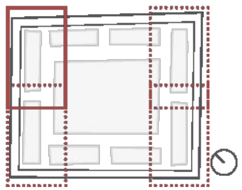
275 | Snapshot; Y-KK_EW_NORTH-

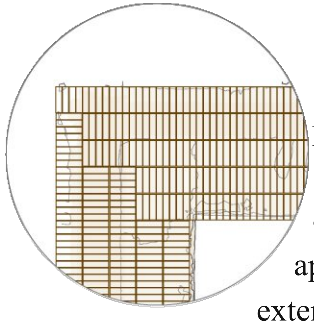


276 | Plan View; Proposal Option Exterior Wall

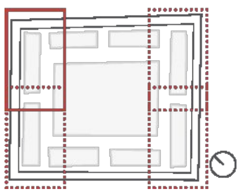
In the stretcher course, five bricks are aligned lengthwise, forming a consistent arrangement in depth. The interaction between the interior walls and the intermediate wall follows the same principle as observed in the stretcher course. The interior wall that aligns with the intermediate wall continues uninterrupted, while the other interior wall intersects at a 90-degree angle at the junction. The interior walls are interlocked, but it remains unclear to what extent the rows intersect into one another.

At the junction, the interior remains ambiguous. It appears that the exterior course continues uninterrupted. This means that, in the exterior view at the corner, (*Figure 275*) only one brick is visible per course in a position that does not belong to the course itself. If multiple rows were extended through, several bricks in alternate positions would be visible in the view. The junction of courses at the exterior wall follows a similar





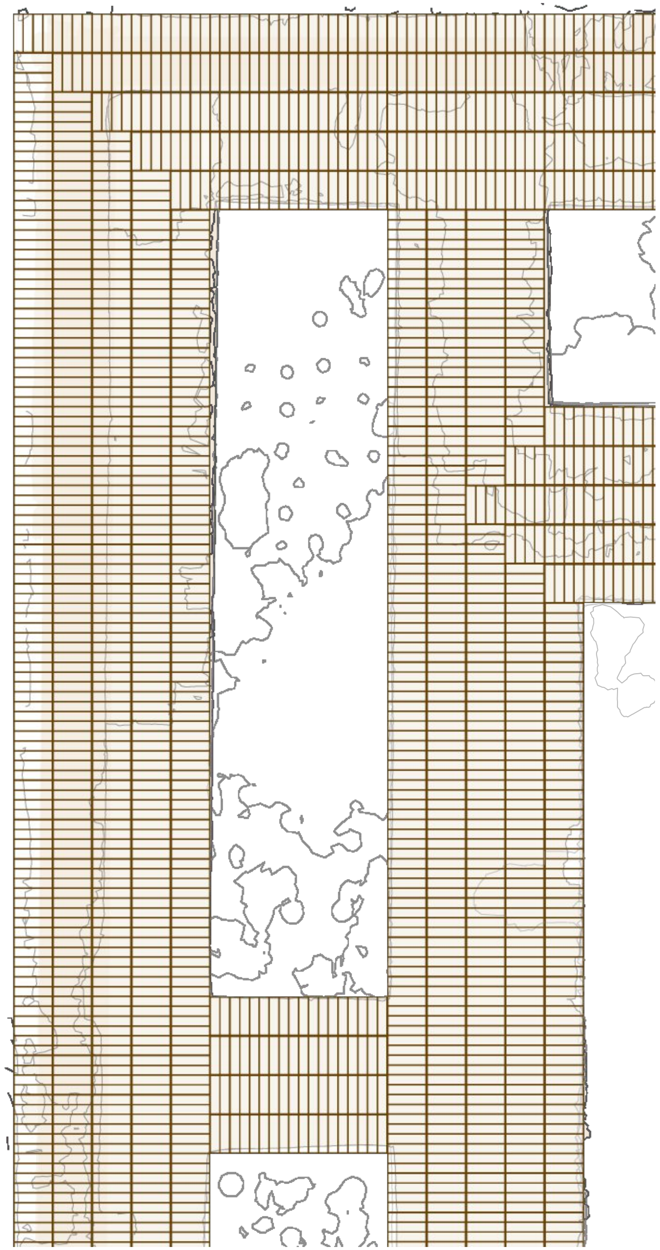
277 | Plan View; Proposal Option Exterior Wall



pattern. Here, the same schematic principle, as described above, was applied. The interior and exterior walls continue as independent entities, indicating that no interlocking occurs at the intermediate walls in this and the rowlock course. This lack of interlocking may explain the significant gaps and separations observed in some intermediate walls (*Figure 274*).

The only potential connection might be provided by the stretcher course itself, combined with the roof structure. The rowlock course behaves similarly to the header course. The interior and exterior walls are interlocked, while the intermediate walls are integrated between these two components without any direct connection. It should be noted that in this course, the bricks are placed upright, increasing the number of bricks required. However, this type of bond was rarely used.

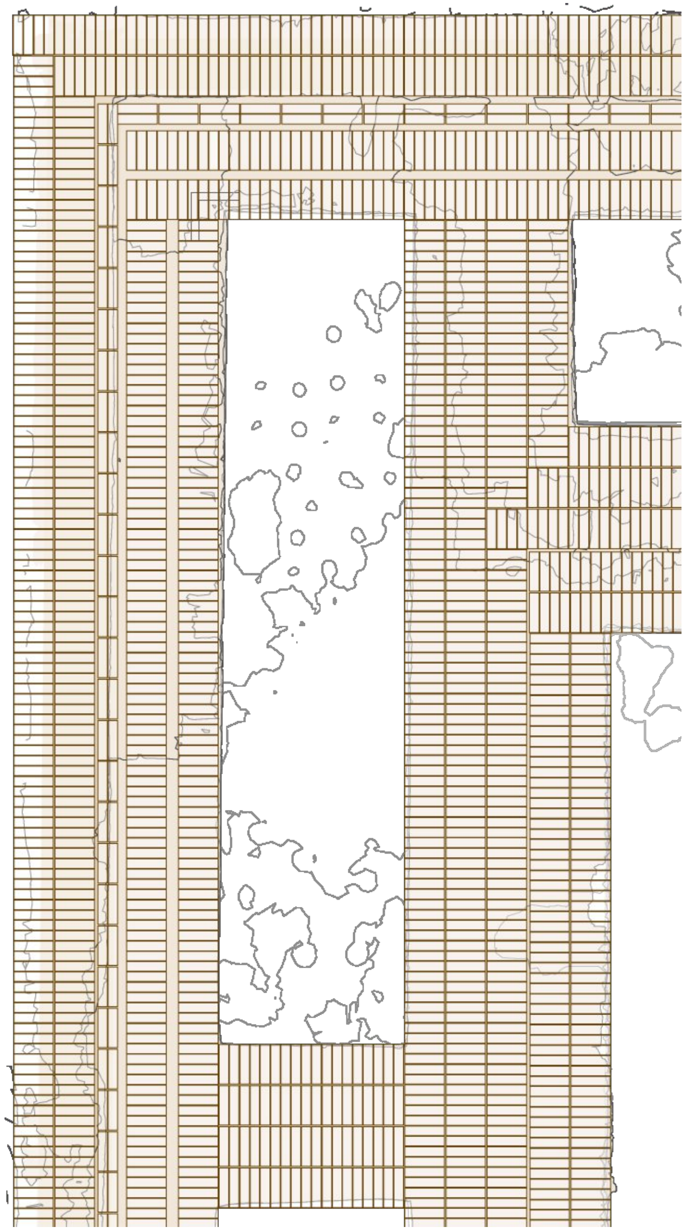
ROWLOCK COURSE



SCALE 1:50

278 | Top View; Proposal Rowlock Course

MUDBRICK EDGING- ROWLOCK COURSE



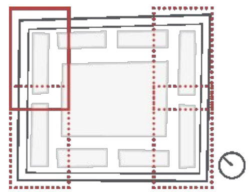
SCALE 1:50

Top View; Proposal Mudbrick Edging Rowlock Course

In the analysis, certain indications suggest that the exterior wall‘s first six rows consist of two components - essentially forming mudbrick edgings. Similarly, the top layer of the interior wall appears to follow this principle.

Considering these indications and expanding the system to encompass the entire structure, a new bonding technique emerges for the rowlock and stretcher courses. For the header course, there are minimal changes; however, in some cases, the first two rows of the mudbrick edging are extended outward. In the view, this alternation becomes apparent.

The rowlock course in the exterior wall comprises the mudbrick edging, which is two brick lengths deep. On the interior side, it features a construction that is generally three brick lengths deep and consists of three layers, while the mudbrick edging has five layers. This interior construction includes two brick-length deep rowlock bricks and two bricks rotated 90 degrees. Additionally, the spacing of the bricks in the inner circle of



the exterior wall is larger than in the standard technique, with the gaps filled and plastered with mortar.

Occasionally, the rotated bricks extend to a depth of three (slim side), but for this analysis, a depth of two was assumed. These rotated bricks are placed along the exterior mudbrick edging, contributing to a cohesive integration between the inner and outer structures.

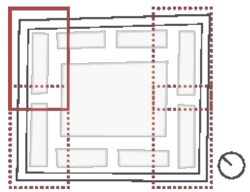
The stretcher course of the mudbrick edging is generally constructed in a similar manner. The higher, or outer ring of the structure from both the interior and exterior walls, consists of a course where stretcher bricks are laid along the outer edges, while a header course is placed on the interior. In the ring of the exterior wall, the depth is exclusively one brick-length of headers, whereas the outer ring of the interior wall has two brick-lengths of headers on the interior side.

The inner ring of the exterior construction comprises two brick-lengths of headers, finished with

MUDBRICK EDGING- HEADER COURSE

SCALE 1:50

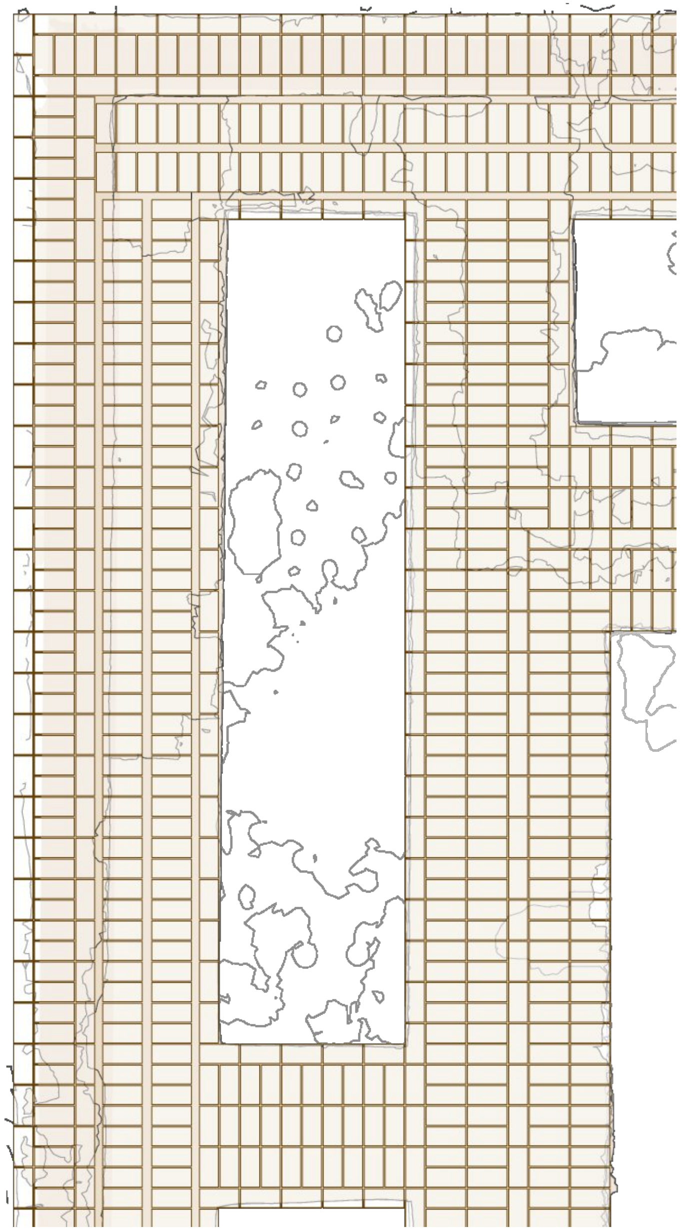
280 | Top View; Proposal Mudbrick Edging Header Course



stretcher bricks along the outer edge. Since a brick-width in depth is missing to complete the inner ring, this gap was not filled with an additional row of bricks but was instead expanded and supplemented with mortar.

The inner component of the interior wall consists of two rows of headers or rowlocks. Only partial indications of the uppermost edge were discovered, as many sections have already collapsed or were plastered over. In this context, the indications that were present were extrapolated to inform the construction analysis.

MUDBRICK EDGING- STRETCHER COURSE

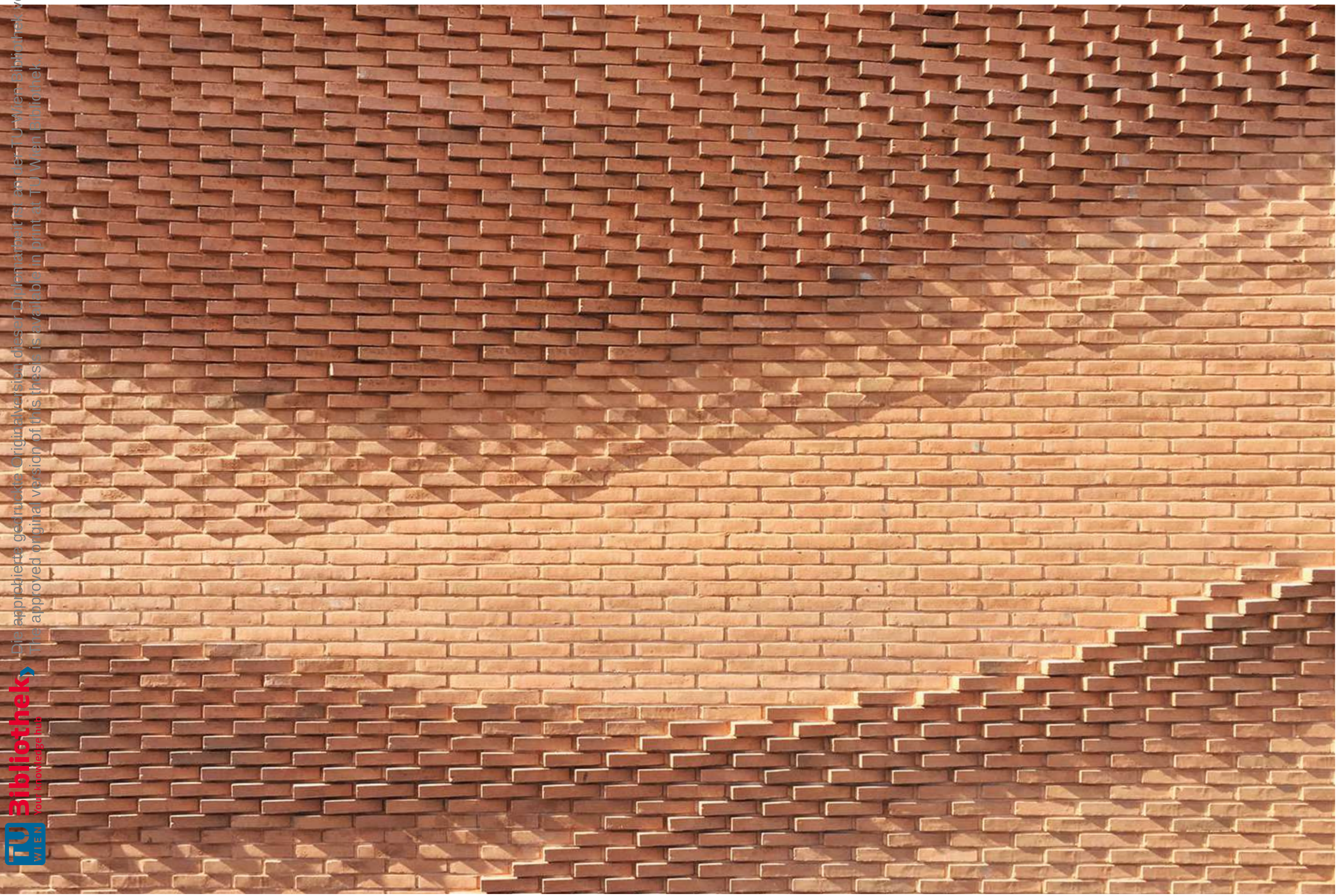


SCALE 1:50

281 | Top View; Proposal Mudbrick edging Stretcher Course

7

DIGITAL SIMULATION OF THE BRICK-LAYING TECHNIQUE



Brick facade with Imitation of a Textile Fabric

7.1 Parametric Modelling

Parametric modeling is an innovative design approach that leverages mathematics and algorithms to create and optimize architectural structures. By defining parameters in a software such as dimensions, material properties, and load conditions, architects and engineers are able to design complex structures that can automatically adapt to changes and respond to specific requirements.

Fundamentally, parametric design operates by feeding parameters and algorithms into design software. These parameters can be continuously adjusted, causing the design to update automatically.
This dynamic process allows for the limitless variation and optimization of structures, facilitating rapid exploration of different design options.

Algorithms play a central role in this process. They define how the parameters interact with one another, determining the relationships between different design elements.
Mathematical calculations and formulas enable the creation of intricate structures that would typically be difficult or even impossible to achieve manually. Through this approach, complex forms and geometries can be generated efficiently, offering flexibility, precision, and the ability to optimize design outcomes.

To provide an example, the design office Behet Bondzio was tasked with creating a facade made of facing bricks that mimics the flowing pleats of a gigantic cloth draped over the building. Using a parametric computer program, the planners were able to model the desired light and shadow conditions on the facade.[77]

7.2 Software for Parametric Modelling

Various software tools and platforms are available for the creation of parametric structures, each designed to cater to specific needs in design and engineering workflows. Many Computer-Aided Design (CAD) and Building Information Modeling (BIM) programs, such as *Autodesk Revit*, incorporate integrated parametric capabilities, with an emphasis on enabling collaboration among multidisciplinary teams. These platforms facilitate a shared workflow, ensuring that various specialists such as architects, engineers,

77 BAUNETZ. *Ziegelfassade mit Faltenwurf: Gelungene Imitation eines textilen Stoffes.*

Brick Facade with Imitation of a Textile Fabric

284 | Guggenheim Museum Bilbao; Frank O. Gehry

and construction professionals can work seamlessly together, often on large-scale projects. Revit's parametric tools are particularly valuable in the context of building design and construction, where real-time collaboration and modifications are critical.

Dynamo, a extension of *Autodesk Revit*, introduces a visual programming environment that enhances the parametric capabilities of *Revit* by allowing users to create dynamic relationships between objects and geometries. This scripting environment enables users to automate repetitive tasks, generate complex forms, and make adjustments to *Revit* models based on specific parameters. With *Dynamo*, changes can be made parametrically, ensuring greater flexibility in design iterations and enabling the user to explore a wide range of design possibilities.[78]

CATIA, a robust design software, is primarily used in the aerospace and automotive industries for the creation of highly precise components and assemblies. While *CATIA's* parametric design capabilities are well-suited for creating complex, engineering-focused geometries, its application is more specialized and focused on the creation of individual parts for large-scale manufacturing processes, rather than the holistic architectural design process.[79]

The Guggenheim Museum in Bilbao by Frank O. Gehry is a well-known example of the use of the modeling software CATIA (Computer-Aided Three-Dimensional Interactive Application). The result of the interplay between analog and digital practices is a curved and angular titanium-clad building.[80]

However, when it comes to highly complex, organic forms, particularly in architecture, the software *Grasshopper* for *Rhino* is often chosen. *Grasshopper* is a visual programming language integrated with *Rhino*, a 3D modeling software, that allows for an unprecedented level of flexibility in parametric design.[81]

78 HAGER. *Parametrisches Design und Algorithmen [...].*

79 KARADOGAN. *10 Parametric CAD Software for Architects in 2024.*

80 MENDELSOHN. *How Analog and Digital Came Together in the 1990s: Creation of the Guggenheim Museum Bilbao.*

81 KARADOGAN.

7.3 Software Rhino and Grasshopper

Rhino is a comprehensive computer-aided design (CAD) software that offers a robust platform for the creation, modification, analysis, documentation, rendering, animation, and translation of NURBS (Non-Uniform Rational B-Splines) curves, surfaces, and solids. In addition to NURBS geometry, Rhino also supports the handling of SubD geometry, point clouds, and polygon meshes. Notably, the software is designed to handle extremely complex and large-scale models, with only the limitations imposed by the hardware capabilities, rather than any inherent restrictions in the software itself.

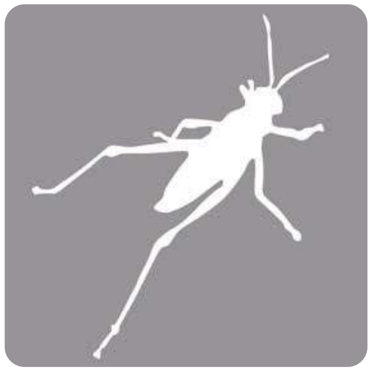
Grasshopper, in turn, is a visual programming environment fully integrated into Rhino, which empowers users to create parametric and generative algorithms for a wide range of applications, such as architectural design, structural planning, and building physics. *Grasshopper* is designed to be accessible to users with no prior programming experience, providing an intuitive interface that allows users to interactively construct algorithms by visually connecting components. This visual approach to programming abstracts away much of the complexity involved in traditional coding, thus making advanced computational design more approachable. [82]

While programming skills are not a prerequisite for its use, there remains the option to integrate custom scripts to extend its functionality. This capability was utilized in one of the tools to develop a Python script that addresses additional requirements for the tool, ensuring it can handle various customized parameters and specific conditions beyond its basic functionality.

Despite the accessibility of *Grasshopper*'s core functionalities, the platform offers the flexibility to integrate custom scripts, which can significantly extend its capabilities.
To introduce algorithms and functionalities that go beyond the predefined operations available within the *Grasshopper* environment.

The core of a design in *Grasshopper* is constructed by combining standard components, which serve as the foundational building blocks of the software's computational language. These components, each representing a distinct function or

82 MCNEEL. *Rhino in Architektur […].*



285 | Icon Grasshopper Software

operation, are interconnected to form a directed acyclic graph. The structure facilitates the systematic processing of data, where each component receives input data, processes it according to predefined algorithms or parameters, and then passes the processed data to the next component in the sequence. This flow of data allows for a highly modular and flexible design process, where the outputs of one component serve as the inputs for subsequent components, ensuring seamless progression through the algorithm.[83]

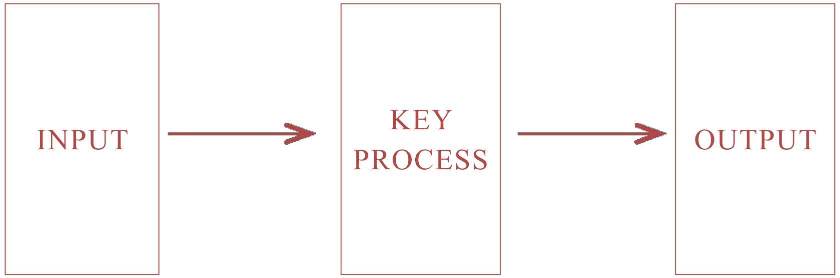
Grasshopper's architectural framework is particularly advantageous for the creation of multiple design variations, as it allows for the recombination and adjustment of input variables while preserving the underlying logical structure of the design process. By modifying the parameters within individual components, users can explore a wide range of configurations and analyze their respective impacts. This capability enhances the adaptability of the design, enabling rapid iteration and optimization. The diverse library of components available within *Grasshopper* further strengthens its capacity as a powerful tool for developing complex, parametric models. These components offer a broad range of functions that allow for intricate and dynamic manipulations of geometry, data, and parameters.

An additional benefit of *Grasshopper* is its ability to generate parametric designs that are not confined to a single project but can be reused and adapted across different design contexts. This stands in contrast to traditional 3D modeling tools, which often result in project-specific outputs that are difficult to transfer or modify for use in new scenarios. In contrast, the parametric models created in *Grasshopper* are inherently flexible and can be iterated upon, modified, and applied to a wide variety of projects, regardless of their specific requirements.

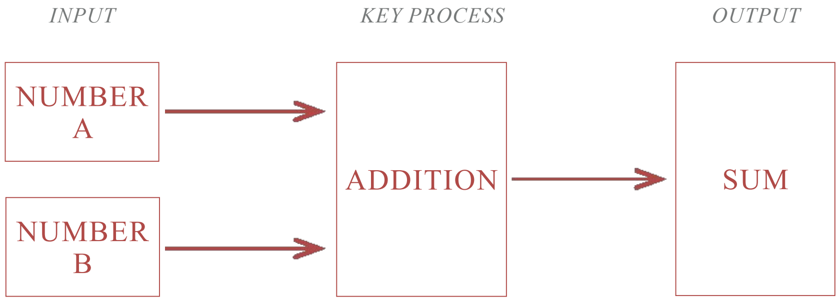
This flexibility allows for the creation of adaptable, reusable design solutions, making *Grasshopper* an invaluable tool for architects, engineers, and designers working across diverse and evolving project contexts.

83 STANCATO. *Enhancing Parametric Design Education Through Rhinoceros/Grasshopper [...]*, p. 813ff.

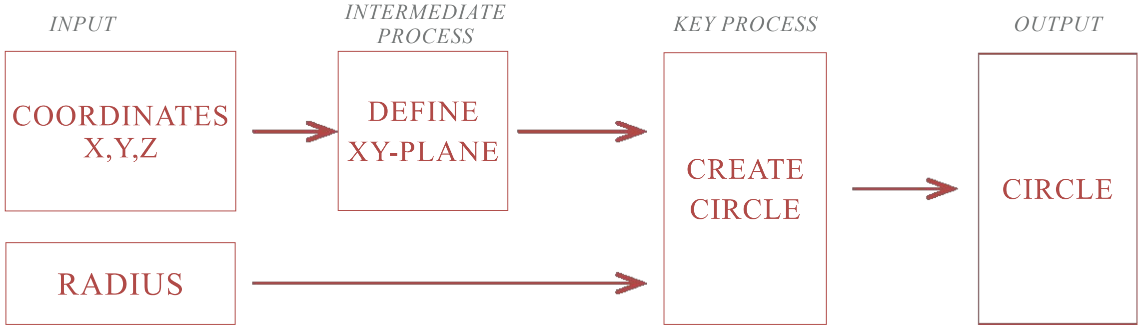
Icon Rhino Software



287 | Algorithmic Solution - Three Phases



288 | Components of Addition Algorithm



289 | Components of Algorithm for Constructing Circle

7.3.1 Techniques for Implementing 3D Modeling Algorithms in Grasshopper for Rhino

The integration of algorithms for 3D modeling within the *Grasshopper* framework is a fundamental aspect of parametric design, enabling the systematic generation and manipulation of geometric forms based on defined parameters. Algorithms, which serve as the core of parametric design, facilitate the establishment of relationships between data inputs and outputs, thereby allowing for the creation of complex, adaptable structures. The development of such algorithms requires a deep understanding of computational processes and their application to design data, as well as expertise in the logic and mathematical operations that underpin them. Algorithms generate outputs through a structured sequence of clearly defined steps, automating tasks that are traditionally carried out manually, which in turn enhances design efficiency and flexibility.

Despite their complexity, all algorithmic solutions follow three phases:

INPUT → KEY PROCESS → OUTPUT.

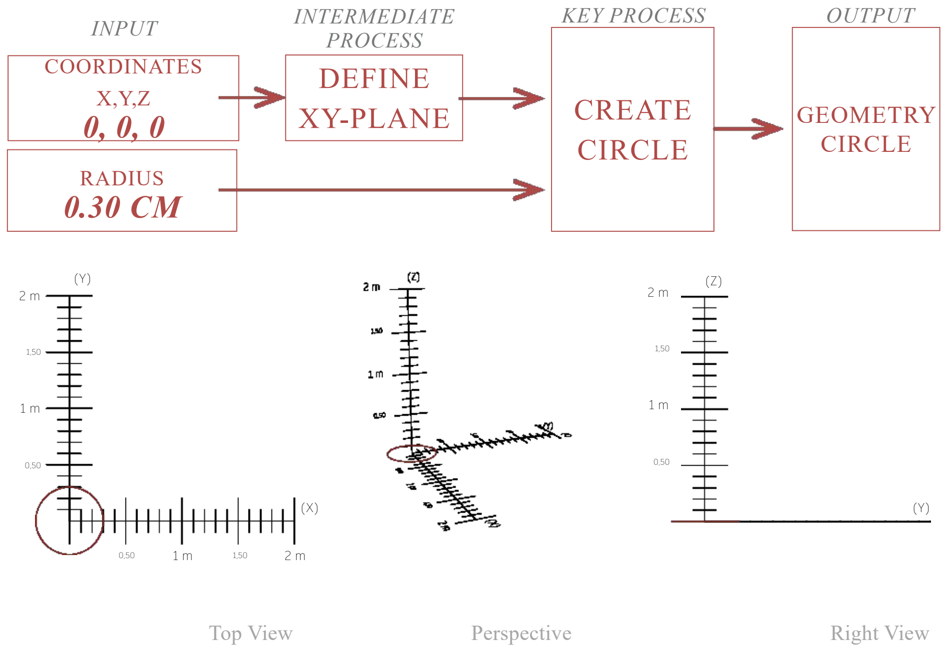
(In some cases, the key process requires additional inputs and steps.)

For instance, when considering the production of a mudbrick, the *materials* (sand, mud and water) and the *manufacturing process* (with precisely defined steps) result in a finished *brick* (output). Any deviation in the materials or manufacturing process will result in a different brick.

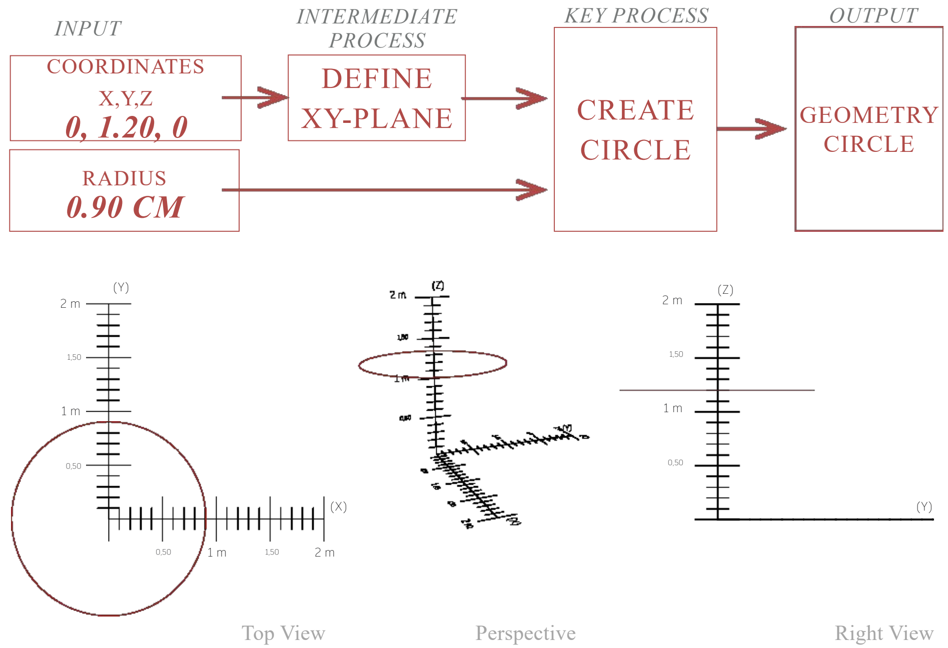
7.3.2 Algortithmic Creation Process

Grasshopper's interface operates as a visual representation of the algorithmic process. The flow of data in *Grasshopper* typically follows a left-to-right trajectory, with input data on the left, followed by key processes, and the output displayed on the right. This design workflow allows users to trace how data flows through the system and interact with various components to fine-tune the output. The generated output in *Grasshopper* is displayed in Rhino, where the geometric result is visualized and further refined.

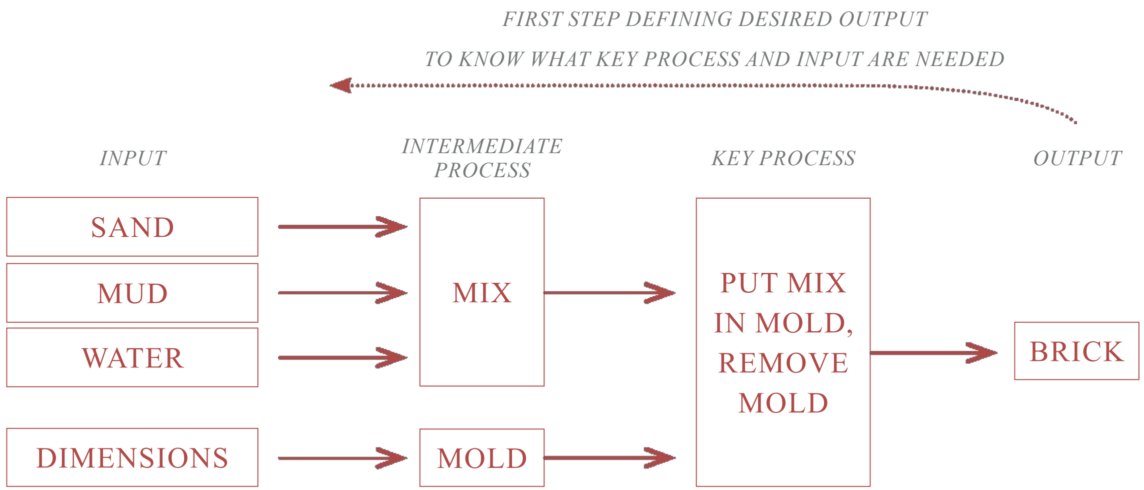
The diversity of components within *Grasshopper* enables the creation of intricate parametric models by offering a wide range of options for processing input data. Each component in *Grasshopper* represents a distinct function or operation, such as geometric transformations, mathematical calculations, or logical conditionals. Once the input data is defined, the algorithm is



290 | Example Circle with Radius 30cm



291 | Example Circle with Radius 90 cm

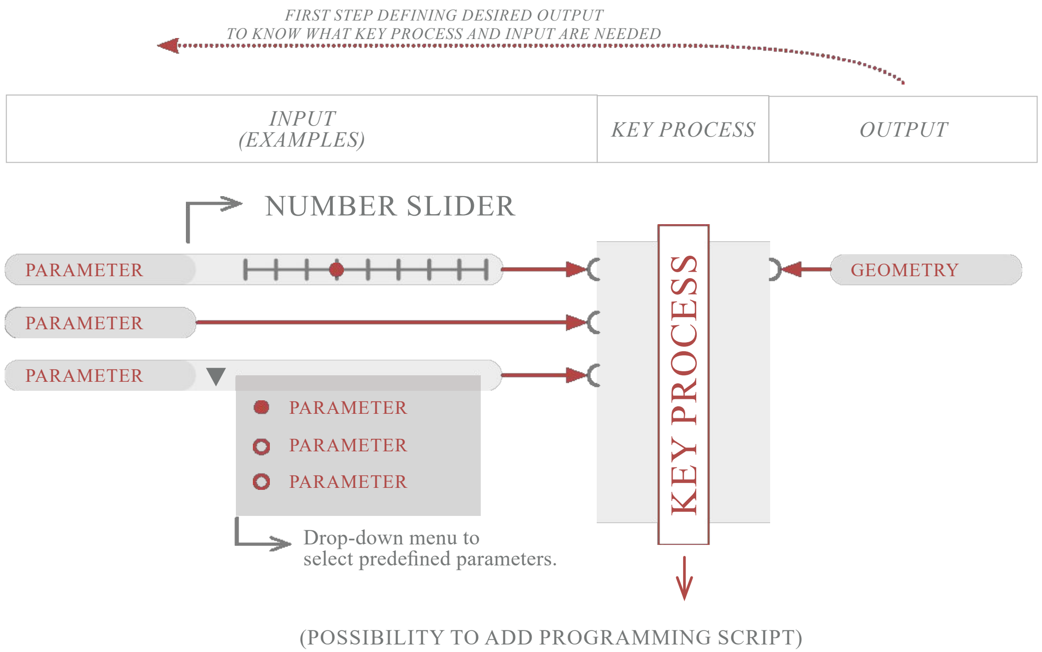


292 | Components Algorithm for Producing Mudbrick

executed through the sequential application of these components, resulting in the generation of complex 3D forms.
To further show the algorithmic process, consider the example of an addition algorithm, the input consists of two numbers, the output is the sum, and the key process is the addition operation. Expanding this idea further, for creating a circle with a specific radius, an intermediate process is required: the plane where the circle should be created. The input includes the X, Y, Z coordinates and the radius, the intermediate process defines the plane, the key process computes the circle, and the output is the circle positioned at the desired location.The creation of an algorithm begins by recognizing the necessary processes.

Figure 290 and *Figure 291* are two examples of this algorithm. In *Figure 290*, parameters were created with the position set to x, y, z coordinates all set to zero, and the radius set to 30 cm. This results in the geometry in Rhino being created exactly with these dimensions at the set position. The parameters can now be modified as needed. In *Figure 291*, the position and radius were changed to a height of 1.20 m (z-axis at 1.20 m) and the radius set to 90 cm. The circle was then recalculated and adjusted to the desired position and size. For the mudbrick example, there is a list of material compositions, which are then gathered and processed by being assembled in the correct proportions, mixed, pressed into a mold, sun-dried, and result in the finished brick. Modifying any of these processes can influence the physical properties of the brick. For instance, changing the material composition affects the thermal and mechanical properties of the brick, while altering the manufacturing process, such as shaping the brick by hand, using the mold with different dimensions or creating the brick by cutting it, can produce different bricks. By identifying the appropriate steps and allowing for modifications, algorithms in design enable the exploration of multiple variants and iterations of a given output, providing flexibility and adaptability in the design process.

Typically, the desired output product (for example the brick) is conceptualized first, and the processes needed to achieve that output are selected and arranged accordingly. This means that 3D modeling inherently involves a level of algorithmic thinking.



The graphic is intended to reflect the representation of the components in Grasshopper. Each process or parameter is visually represented, and the user can connect these components to enable the process.

 | Grasshopper Component Options with different Parameter as Input

1. **Output:**
   The final result of the computation, derived from the processed input. The output may be a geometric form, a dataset, or other design-related information that meets the requirements defined at the input stage.(e.g., defined box representing the brick).

2. **Key Process:**
   This phase involves the manipulation and processing of the input data according to specific algorithms, operations, or rules. It is the core of the algorithm, where the relationships between input and output are defined and executed. (e.g., moving a box multiple times to generate a row of bricks), with data such as the base point, dimensions, and direction of movement being associated with and required for the commands.

3. **Intermediate Inputs and Processes:**
   Definition of the intermediate steps to generate the output. By consistently keeping track of these steps, algorithmic design can be created and refined.

4. **Input:**
   The foundational data or parameters that serve as the basis for algorithmic computation. These inputs may derive from geometric specifications, user-defined variables, or external data sources.

Data is information stored and processed by the computer. It can be obtained from different sources: internal, referenced, and external. Internal data is created within a parameter instance and remains constant until manually altered (e.g., a point with defined XYZ coordinates in Grasshopper). Referenced data comes from Rhino or external documents (e.g., a point created in Rhino that is referenced by a Grasshopper component).

External data originates from previous processes and is useful for dynamically or parametrically controlled data. Algorithmic designs in *Grasshopper* typically involve a variety of data operations, which can be categorized into five primary areas: numerical and logical operations, analysis, sorting, and selection. Numerical operations support basic arithmetic functions, such as addition, multiplication, and geometric transformations, while logical operations enable the creation of conditional statements that dictate the flow of data based on specific criteria. The analysis phase includes tools for data verification and refinement, ensuring the integrity of the data being processed. Sorting operations help organize numerical and geometric data according to predefined rules, and selection allows for the interactive selection of specific objects or groups of objects within the design.

All algorithmic designs involve processing input data to generate a new dataset, which is then visualized as output.[84]

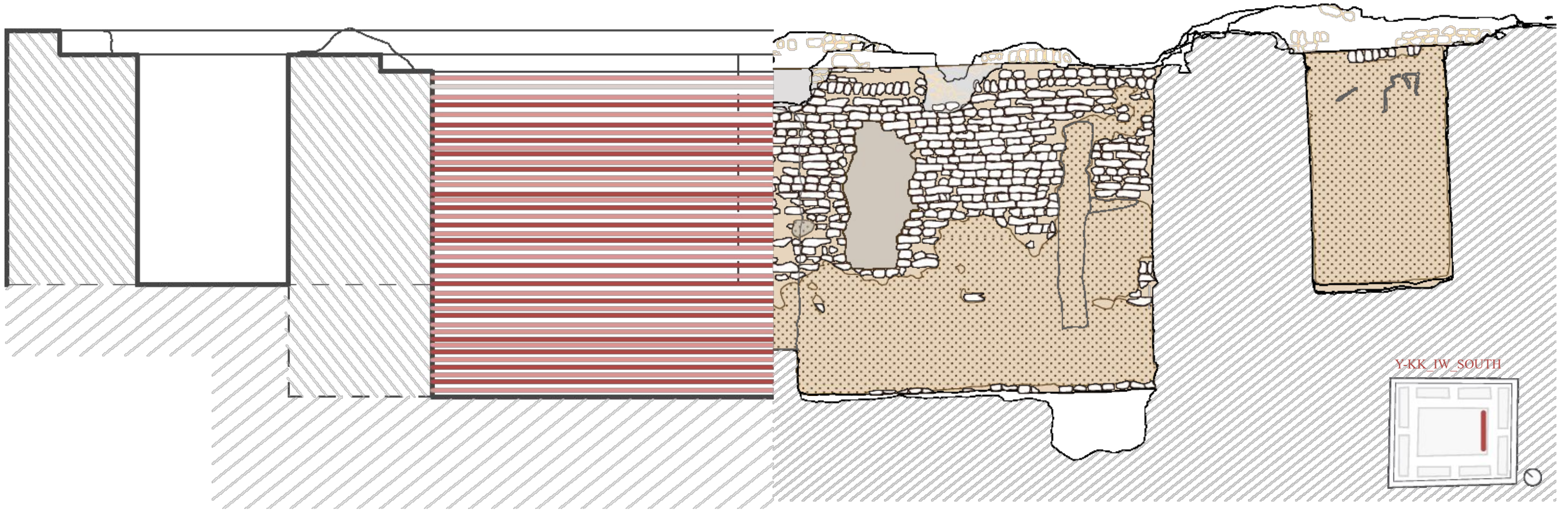
The basic tools and explanations of how the functions in *Grasshopper* work have now been outlined; however, there are numerous possibilities for creating complex structures using components in *Grasshopper*.

84 ISSA. *Essential Algorithms and Data Structures for Computational Design in Grasshopper.* p. 1-36.

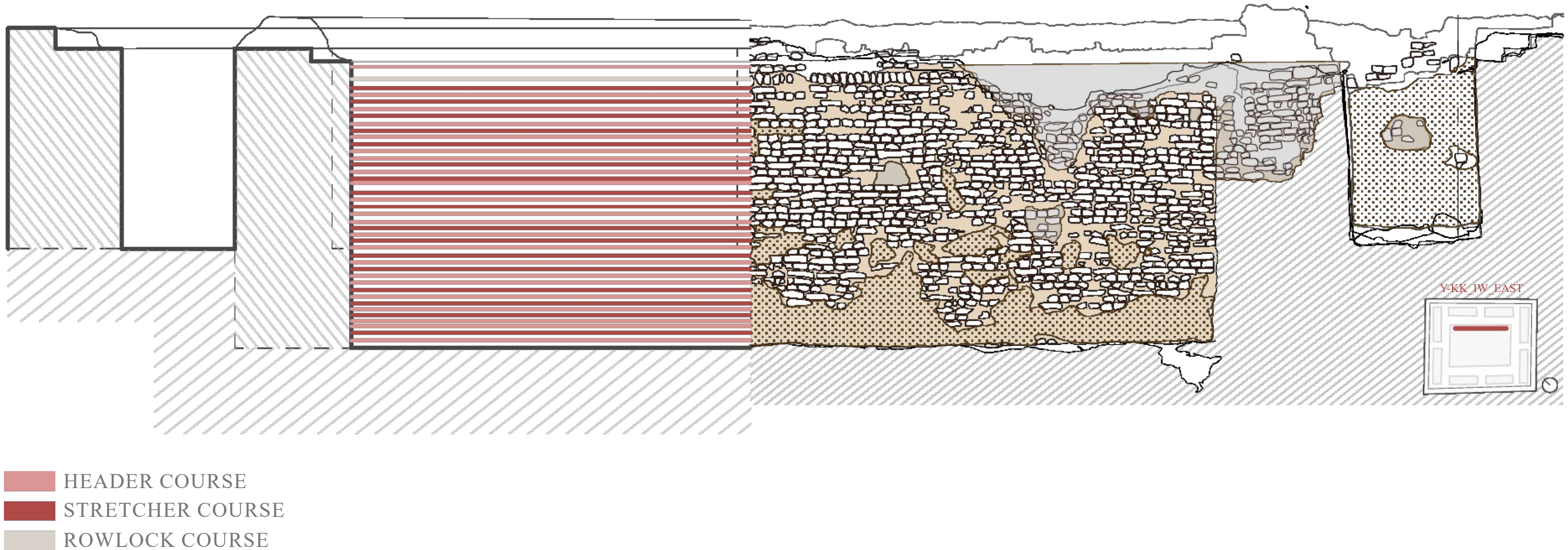
The figures display the different bricklaying techniques for each course, represented in simplified elevation views of the tomb Y.

Each laying technique is assigned a color code for easy identification.

This was done for all wall

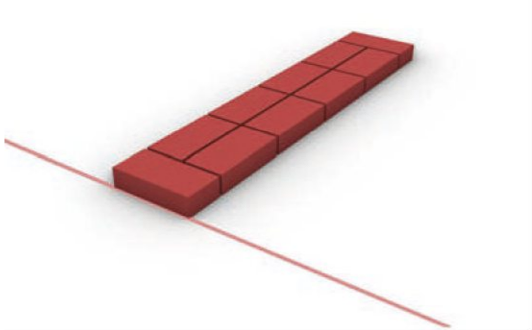


294 | Combination of Simplified Section with Grouped Curves and Elevation View; Y-KK_IW_NORTH



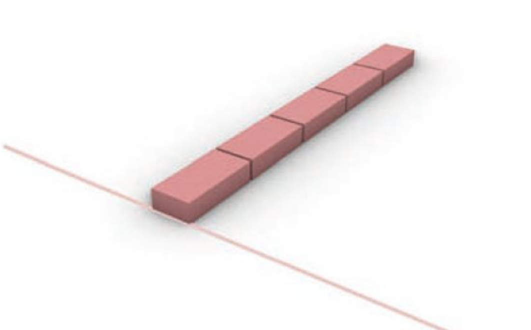
295 | Combination of Simplified Section with Grouped Curves and Elevation View; Y-KK_IW_EAST

STRETCHER COURSE



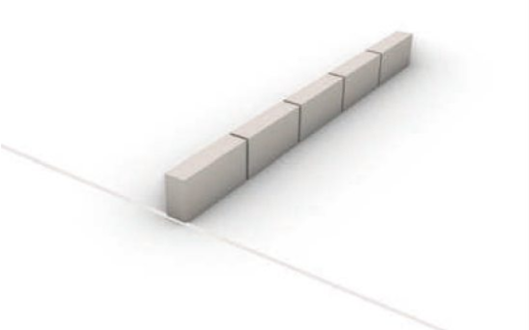
296 | Unit in Depth of the Stretcher Course

HEADER COURSE



297 | Unit in Depth of the Header Course

ROWLOCK COURSE



298 | Unit in Depth of the Rowlock Course

7.4 Simulating Tomb Y: Defining Parameters and Developing Digital Tools

7.4.1 Defining Parameters from created Indicators of Tomb Y

The objective of this study is to use software tools to develop a process that enables the generation of different brick formations and allows for inferences to be drawn about the construction techniques used. The methodology leverages digital tools to simulate and test various construction methods and brick-laying techniques.

These simulations facilitate comparative analyses, enabling the evaluation of the strengths and weaknesses of each approach, while providing a more comprehensive understanding of the architectural principles and design choices involved in constructing the tomb.

Following the creation of a proposal based on the initial analysis, the collected data is employed to model the hypothesis and other potential scenarios in 3D. This process not only adds clarity but also serves as a tool for replicating the tomb's construction, exploring multiple design possibilities.

Additionally, data related to the masonry square meters (SM) is included, which is utilized to calculate the average dimensions of a single brick.

The courses, which were counted and documented from the elevation views, are integrated into the database (*Figure 294, 295*). Following this, a continuous course for each layer is defined, providing a structured foundation for the simulation. This approach facilitates a more detailed and accurate analysis, where variations in design can be tested, and outcomes can be compared.

The aim of this work is to employ this software to create a process that can generate various wall formations, bond types, and brick layers. Thus, the generation of wall formations is considered the desired output of the process.

To achieve this output, it is necessary to define the key processes. These processes must outline the steps required to create the brick bonds: the bricks must be designed, placed in the correct positions, and their dimensions calculated in relation to the desired wall. A key aspect of this step is determining the necessary size of the bricks and the specific dimensions of the wall to be constructed.

	IW_NORTH	IW_EAST	IW_SOUTH	IW_WEST	AVERAGE	
	6,34x2,83	9,03x2,78	6,35x2,81	9,02x2,82		COUNT
	Header	Header	Header	Header	Header	39
	Rowlock	Rowlock	Stretcher	Rowlock	Rowlock	38
	Header	Stretcher	Stretcher	Stretcher	Stretcher	37
	Stretcher	Header	Header	Header	Header	36
	Header	Stretcher	Header	Stretcher	Stretcher	35
	Stretcher	Header	Rowlock	Header	Header	34
	Header	Stretcher	Stretcher	Stretcher	Stretcher	33
	Stretcher	Header	Header	Header	Header	32
	Header	Stretcher	Stretcher	Stretcher	Stretcher	31
	Stretcher	Header	Header	Header	Header	30
	Header	Stretcher	Stretcher	Stretcher	Stretcher	29
	Stretcher	Header	Header	Header	Header	28
	Header	Header	Stretcher	Stretcher	Stretcher	27
	Header	Stretcher	Header	Header	Header	26
	Stretcher	Header	Header	Header	Header	25
	Header	Stretcher	Stretcher	Stretcher	Stretcher	24
	Stretcher	Header	Header	Header	Header	23
	Header	Stretcher	Stretcher	Stretcher	Stretcher	22
	Stretcher	Header	Header	Header	Header	21
	Header	Stretcher	Stretcher	Stretcher	Stretcher	20
	Stretcher	Header	Header	Header	Header	19
	Header	Header	Stretcher	Stretcher	Stretcher	18
	Header	Stretcher	Header	Header	Header	17
	Stretcher	Header	Header	Header	Header	16
	Header	Stretcher	Stretcher	Stretcher	Stretcher	15
	Stretcher	Header	Header	Header	Header	14
	Header	Stretcher	Stretcher	Stretcher	Stretcher	13
	Stretcher	Header	Header	Header	Header	12
	Header	Stretcher	Stretcher	Stretcher	Stretcher	11
	Stretcher	Header	Header	Header	Header	10
	Header	Header	Stretcher	Stretcher	Stretcher	9
	Header	Stretcher	Header	Header	Header	8
	Stretcher	Header	Header	Header	Header	7
	Header	Stretcher	Stretcher	Stretcher	Stretcher	6
	Stretcher	Header	Header	Header	Header	5
	Header	Stretcher	Stretcher	Stretcher	Stretcher	4
	Stretcher	Header	Header	Header	Header	3
	Header	Header	Stretcher	Stretcher	Stretcher	2
	Stretcher	Stretcher	Header	Header	Header	1
	Header	Header	Stretcher	Stretcher	Stretcher	0
COUNT						
stretcher	17	17	18	18	s 18	COURSES
header	22	22	21	21	h 21	40
rowlock	1	1	1	1	r 1	

	EW_NORTH	EW_EAST	EW_SOUTH	EW_WEST	AVERAGE	
	13,84x2,04	16,46x2,04	14,27x2,04	16,43x2,04		COUNT
	Header	Header	Rowlock	Rowlock	Rowlock	27
	Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	26
	Rowlock	Rowlock	Header	Header	Header	25
	Stretcher	Stretcher	Stretcher	Stretcher	Stretcher	24
	Header	Header	Header	Header	Header	23
	Header	Header	Rowlock	Rowlock	Rowlock	22
	Stretcher	Stretcher	Header	Stretcher	Stretcher	21
	Header	Header	Stretcher	Header	Header	20
	Stretcher	Stretcher	Header	Stretcher	Stretcher	19
	Header	Stretcher	Stretcher	Header	Header	18
	Stretcher	Stretcher	Header	Stretcher	Stretcher	17
	Header	Header	Header	Header	Header	16
	Header	Header	Stretcher	Header	Header	15
	Stretcher	Stretcher	Header	Stretcher	Stretcher	14
	Header	Header		Header	Header	13
	Stretcher	Stretcher		Stretcher	Stretcher	12
	Header	Header		Header	Header	11
	Stretcher	Stretcher		Stretcher	Stretcher	10
	Header	Header		Header	Header	9
	Stretcher	Stretcher		Stretcher	Stretcher	8
	Header	Header		Header	Header	7
	Header	Rowlock		Header	Header	6
		Stretcher		Stretcher	Stretcher	5
		Header			Header	4
		Stretcher			Stretcher	3
		Header			Header	2
		Stretcher			Stretcher	1
		Header			Header	0
stretcher	9	13	5	10	s 12	COURSES
header	12	13	7	11	h 14	28
rowlock	1	2	2	2	r 2	

The table illustrates the bricklaying technique for each course and wall. An average wall bond for both the interior and exterior walls was generated to enable parametric modeling.

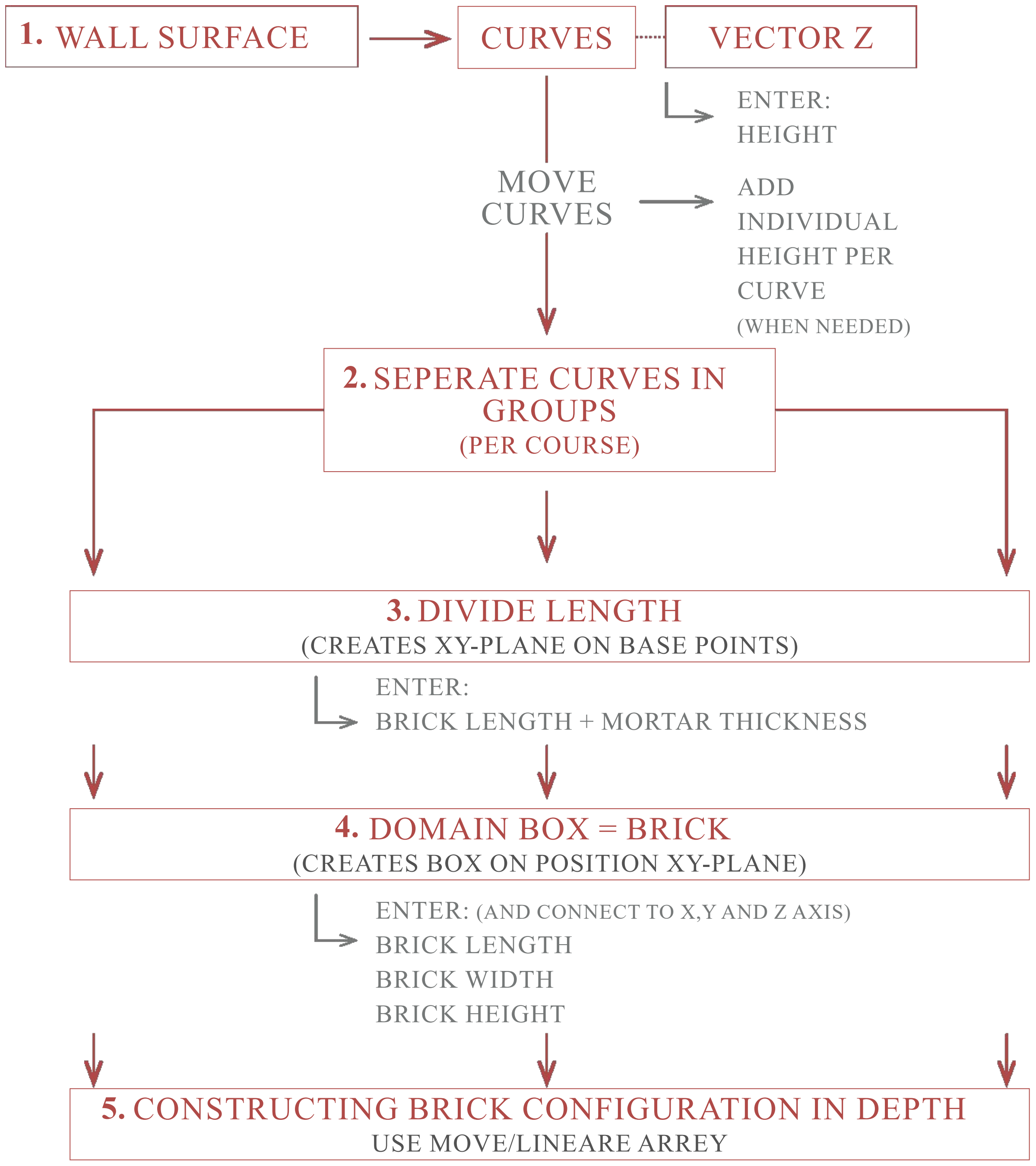
All these steps - defining the brick dimensions, positioning, and wall design - must be carefully articulated to ensure the successful creation of the desired result.
The input data is equally important to the success of the process. The analysis conducted during the project has provided specific parameters that serve as input for the software tool. First, the average dimensions of a brick from the tomb of Meret Neith were calculated. Second, the types of brick layers for each wall were recorded and compared, leading to the calculation of an average (see *Figure 299*). These parameters form the input for the simulation process, ensuring that the final model accurately represents the construction techniques and design principles used in the tomb's building process.

Two distinct tools have now been developed to enable such simulations. Both rely on the program *Rhino* 8 in combination with Grasshopper. The digital tools developed are *Digital Brick Tool - Block* and *Digital Brick Tool - Line*. Each of these tools is equipped with specialized features tailored to different aspects of the brick-laying process.

The *Digital Brick Tool - Block* is designed to handle the placement of bricks in more rigid, block-like arrangements. This tool is ideal for constructing walls or structures that follow a more uniform and linear pattern, where precise alignment and consistent spacing are essential. The tool incorporates algorithms that ensure the accurate stacking of bricks, taking into account their size and alignment with respect to the base structure.

The *Digital Brick Tool - Line,* on the other hand, focuses on placing bricks along curves and non-linear forms. It allows for more dynamic control of brick placement, accommodating the more fluid and organic shapes that might be required in complex architectural designs. The tool's flexibility is enhanced by the integration of the Python script, which enables it to adjust the placement process based on continuous updates to the design parameters.

Together, these two tools offer complementary functionalities that enable users to efficiently model and simulate the laying of bricks in both rigid and curved geometries.

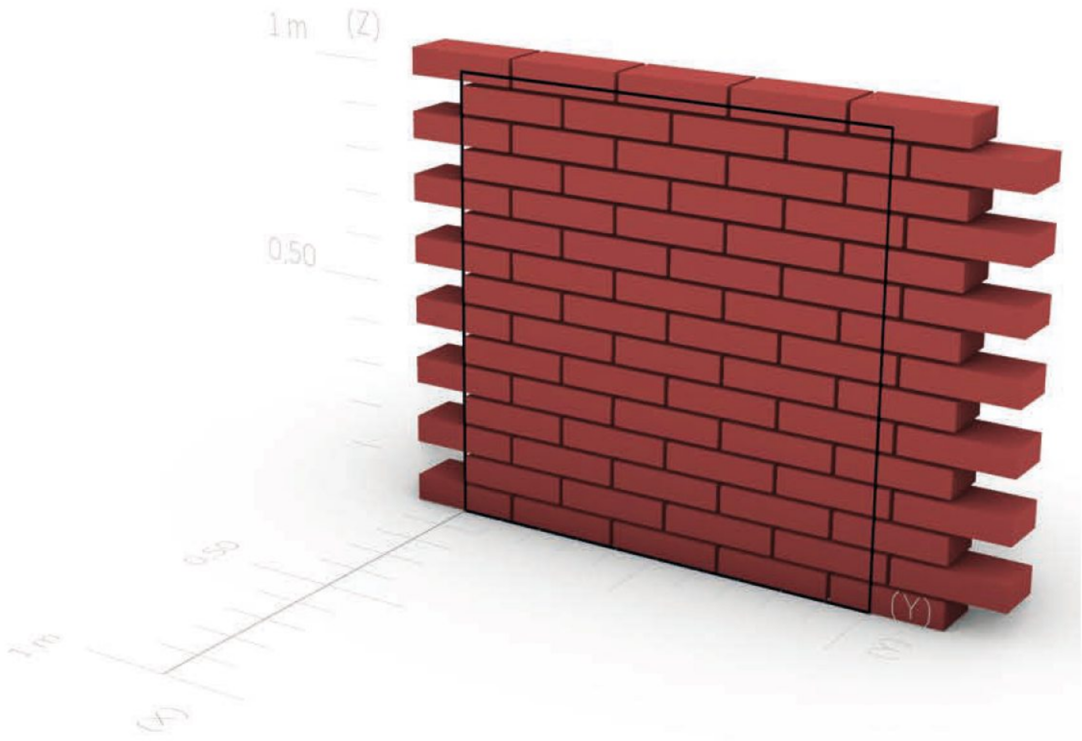

1. WALL SURFACE
CURVES
VECTOR Z
ENTER:
HEIGHT
MOVE CURVES
ADD INDIVIDUAL HEIGHT PER CURVE (WHEN NEEDED)
2. SEPERATE CURVES IN GROUPS
(PER COURSE)
3. DIVIDE LENGTH
(CREATES XY-PLANE ON BASE POINTS)
ENTER:
BRICK LENGTH + MORTAR THICKNESS
4. DOMAIN BOX = BRICK
(CREATES BOX ON POSITION XY-PLANE)
ENTER: (AND CONNECT TO X,Y AND Z AXIS)
BRICK LENGTH
BRICK WIDTH
BRICK HEIGHT
5. CONSTRUCTING BRICK CONFIGURATION IN DEPTH
USE MOVE/LINEARE ARREY

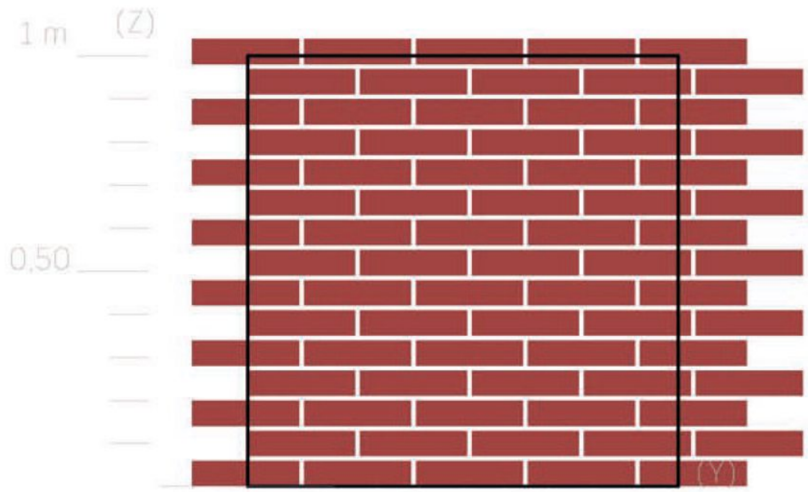
7.4.2 Digital Brick Tool - Block

This tool enables the creation of an entire wall in a single process. The system is fundamentally based on the coordinates x, y, and z, and incorporates parameters such as the structure's dimensions, brick dimensions, and the chosen laying technique. These parameters allow for the construction of walls with any desired width, height, and length, while maintaining precise control over the geometry and placement of individual bricks. Fundamentally, the base structure, i.e., the surface, is first created in *Rhino* and subsequently connected to the input components in *Grasshopper*. The remaining processes are defined through sequences in *Grasshopper*, where the final output can be baked - meaning the model is converted into solid bodies of the final product within *Rhino*. This digital workflow ensures that each step is optimized for flexibility and precision, making it possible to rapidly adjust the design as needed.

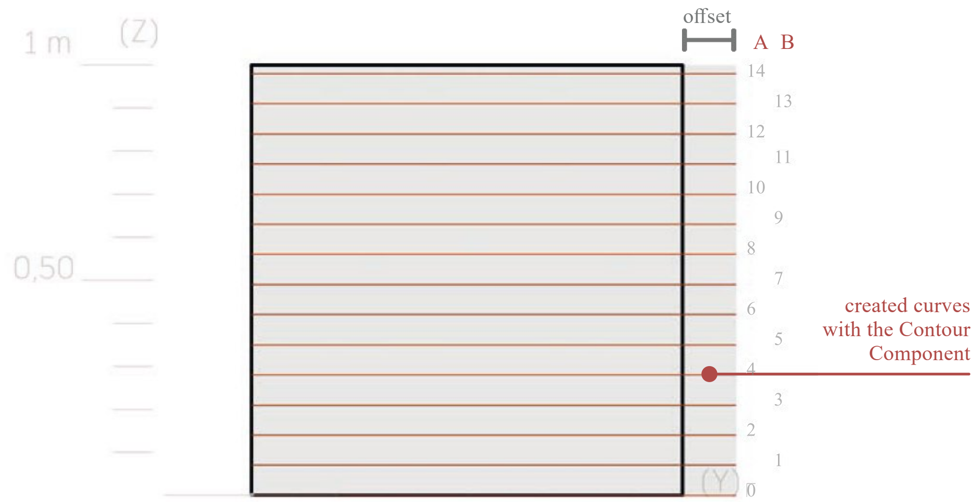
To provide an overview of the process, the tool works by first generating an input (the surface), which is then subdivided into various curves. These curves serve as the base for further operations. A key input allows for the definition of the height of the structure, while the curves are grouped according to the selected laying technique. Following this, the curves are subdivided again in the horizontal plane, taking into account the specific laying technique, the size of the bricks, and the mortar gap. At the base points of these curves, XY-planes are created to serve as the foundation for positioning the bricks. These planes provide the necessary starting platform from which the bricks are modeled and placed with the correct dimensions. Once the bricks are positioned according to the design, their depth within the wall can be modeled by adjusting their placement using processes such as translation or linear array, ensuring they are positioned according to the specified design criteria.

In order to better follow the upcoming detailed workflow, a simple example is now presented which explains the steps for creating a bond using the *Digital Brick Tool - Block*. The exact same example will also be created using the *Digital Brick Tool - Line* to enable a direct comparison. In both examples, a square meter of a wall was laid with the same bond, using the same parameters for brick dimensions.





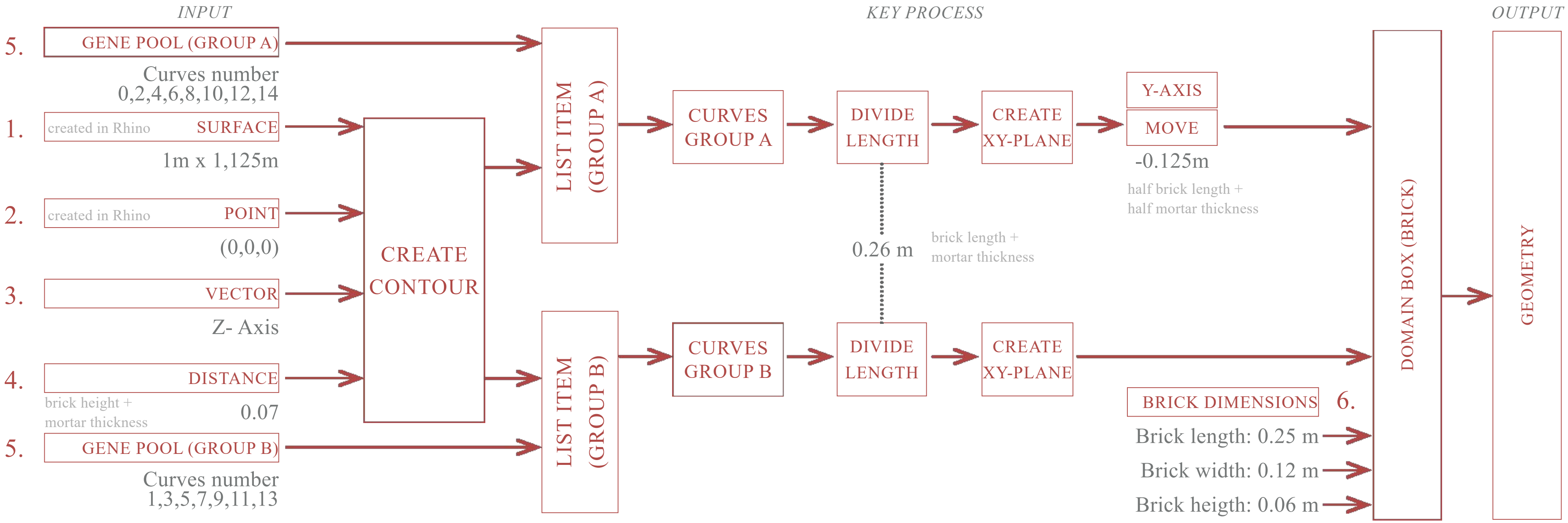
Front View



Front View

Perspective

Wall Formation created with the *Digital Brick Tool - Line*



302 | Illustration Interface Grasshopper; Workflow of Sqaure Meter Brick Bond

First, the data for the input is created, consisting of different parameters.

Parameter 1: First, a surface is created in Rhino. This surface represents the wall surface, i.e., one square meter. The bricks are placed step by step along a curve. As the curve approaches its end, the last brick is only placed if more than half of its brick length is available. Therefore, the surface was made one meter high and 1.125 meters wide.

Parameter 2: A point is also set in Rhino. This point symbolizes the starting point from which curves are formed, in the direction of the chosen axis.

Parameter 3: The vector defines the axis direction along which the curves are drawn. In this case, since the base is the wall surface, it is the z-axis.

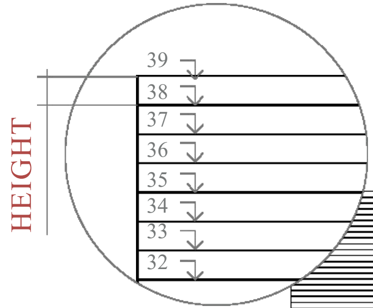
Parameter 4: The distance between the curves is the brick height plus the mortar thickness.

Parameter 5: The Gene Pool is a tool that allows for manually sorting the curves into two groups.

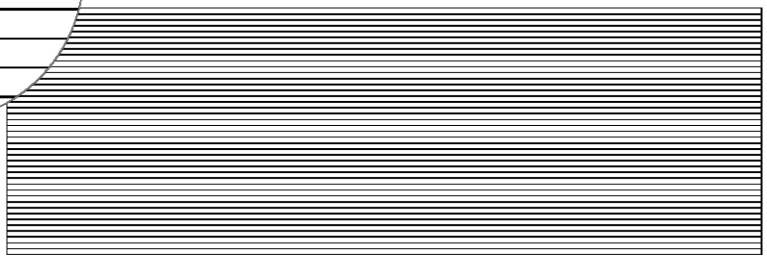
Parameters 1-4 form the basis for creating the curves. These curves are then divided into groups using the Gene Pool. The process that handles this division is the List Item component. This yields the curves that belong exclusively to one group. This group of curves is then divided into steps. These steps consist of the brick length and the mortar thickness. At the desired position, an xy-plane is created. This serves as the basis for each brick that is created. Since there is an offset in this example, the xy-planes of the group are shifted by the offset (half the brick length + half the mortar thickness). Now, at the base points with the xy-planes, a brick is created with dimensions 0.25x0.12x0.06 meters. Finally, the bond is generated as geometry.

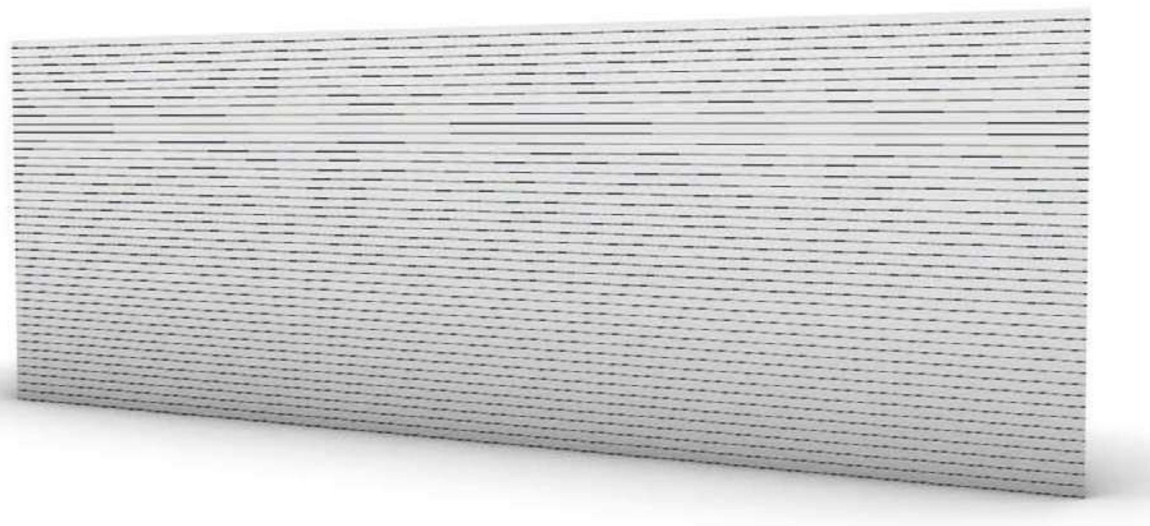
The precise steps for constructing a wall with different brick layers and varying brick formations in depth will now be outlined.

1.

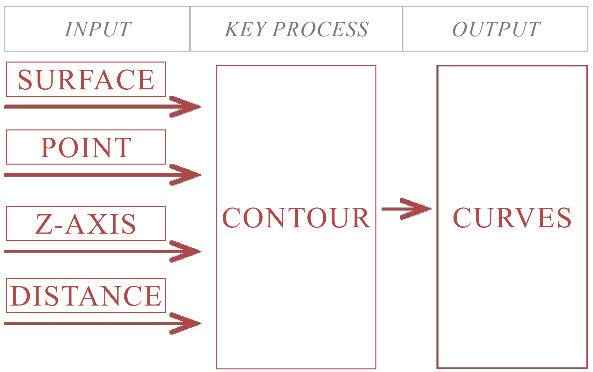


The surface representing the wall is now subdivided with curves, each curve assigned a number, starting from 0 at the bottom and continuing along the Z-axis.





SUBDIVISION SURFACE



304 | Illustration Process creating Curves

The following sections provide a more detailed explanation of the individual steps involved in creating a wall formation, from surface generation to brick placement and alignment, highlighting how the integration of parametric design principles can facilitate the development of complex, adaptable architectural structures.

(1.) The process begins with defining the wall surface in *Rhino*.
Next, the surface is connected to the component in Grasshopper. Once this input is provided, it is linked to the process for creating curves. Not only is the surface defined, but also the direction in which the curves will be created. Since a wall is being created and the surface represents the outer shell, the Z-vector is chosen. It is important to also define the starting point of the curves along the surface. This means that in *Rhino*, not only is the surface created, but a point is set at the base that is connected to the input in *Grasshopper*.

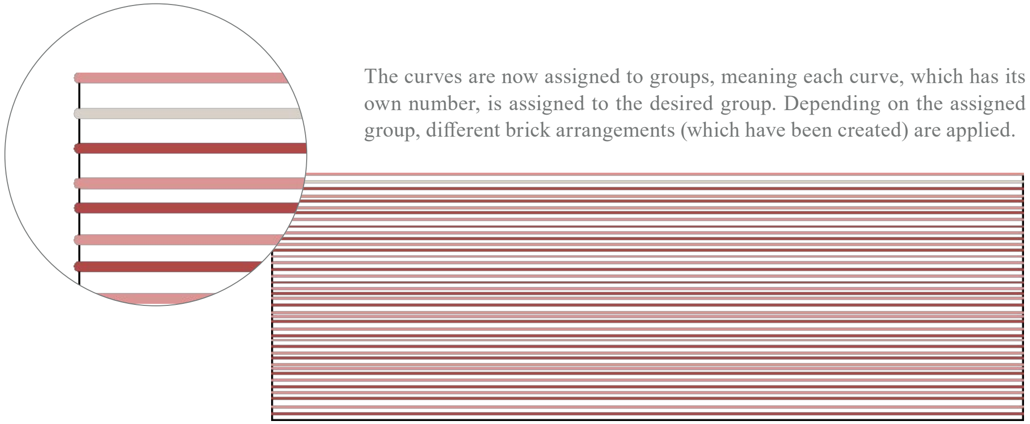
From this point, the curves begin to be created along the Z-axis at a certain distance. This distance is provided as an input number and can always be adjusted.

This height typically corresponds to the brick height plus the mortar thickness.
Each layer is assigned a number, starting from zero at the base, and continuing incrementally upwards. Adjustments can then be made for individual layers. For example, if some brick layers have wider mortar joints or if a brick row is tilted and thus taller, modifications can be applied to the corresponding layer. The first curve (0) does not start directly at the floor level but at 0 plus the specified height.

As a result, each curve represents the upper edge of a course. When aligning the bricks to the base point, it is essential to ensure that the Z-input includes a negative sign to correctly position the bricks relative to the base point.

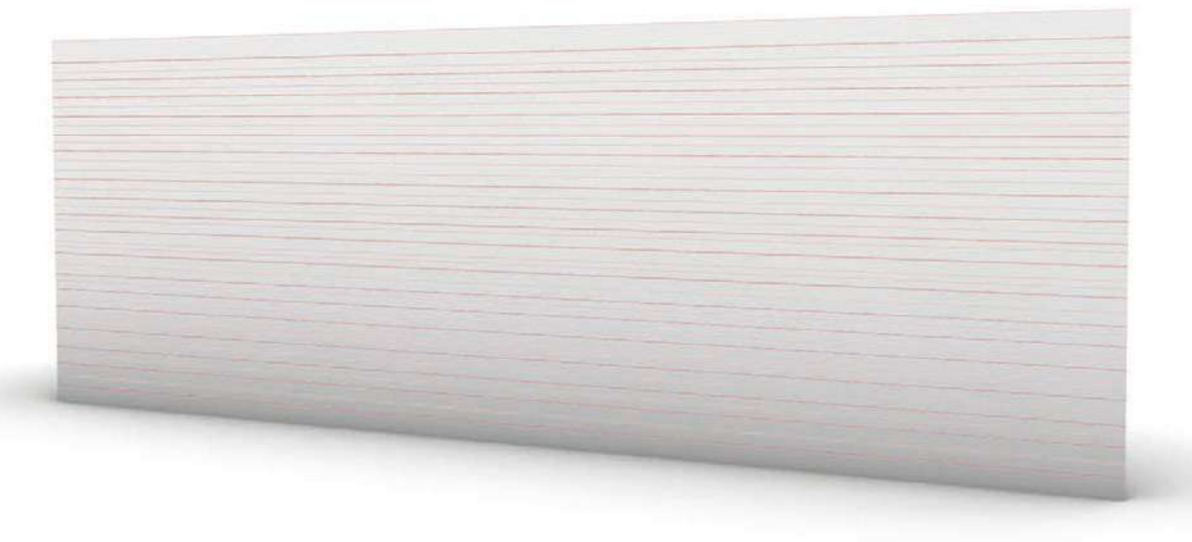
At this point, the inputs (surface, starting point, Z-vector, distance/height) and the process of creating the curves lead to an output, which can then be further processed. Now, each curve that is created indirectly has a number.

The curves are now assigned to groups, meaning each curve, which has its own number, is assigned to the desired group. Depending on the assigned group, different brick arrangements (which have been created) are applied.



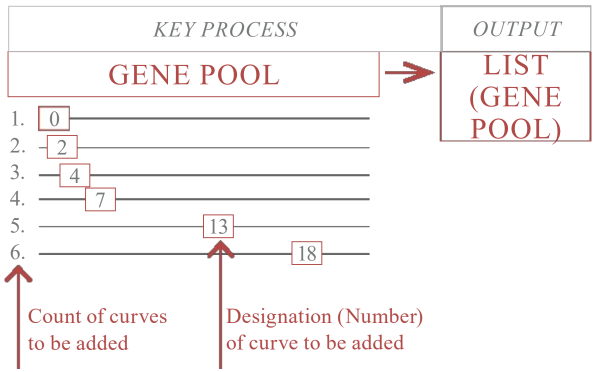
2.

SEPERATE CURVES

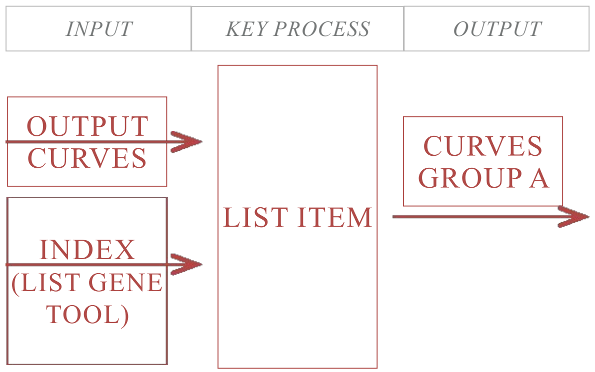


GROUP 1 | HEADER COURSE
GROUP 2 | STRETCHER COURSE
GROUP 3 | ROWLOCK COURSE

Curves assigned to Groups based on the Course Type



306 | Illustration of Gene Pool; Manual Grouping of Curves



307 | Illustration Process Seperation Curves

(2.) Once the curves are defined, they are assigned to different groups. This involves associating the assigned layer numbers with the corresponding groups. In the main chamber of Meret Neith, three distinct laying techniques were identified. Each technique constitutes a group, and the curves are allocated to these groups accordingly.

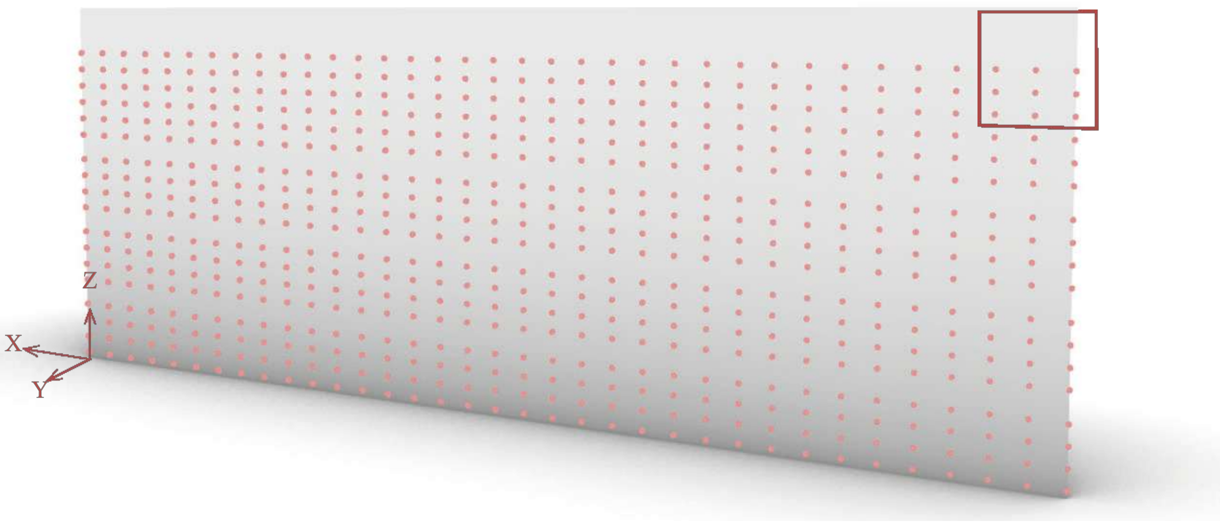
Each curve that is now generated has a designation, essentially a number. Depending on the number of different types of brick layers, the layers corresponding to a particular type must now be grouped together. The Gene Pool component is a tool that facilitates this grouping manually. This means that it is now possible to manually input the curve numbers that belong to a specific group. The total number of curves must first be specified, followed by the numbers of the individual curves.
For example, as shown in *Figure 306*, there are 6 curves in one group, and consists of the Curves 0, 2, 4, 7, 13, and 18.

The subdivision of the curves is carried out using the key process List Item. A List Item component is created for each group, with the same input, namely the output of the curves. The input includes the output of the curves and the index. The input index corresponds to the number of the curve that should be assigned to a particular group. The Gene Tool assists in this process, as it allows for the input of the curve numbers associated with each group, which are then recorded and subsequently outputted as the corresponding curves. This method is applied across all groups. For example, if there are 40 curves, they are manually assigned to the groups.
There are also other components that can automatically dispatch and alternately divide the curves into two groups. However, in this case, this method was intentionally chosen to provide as much flexibility as possible. This means that the curves can be assigned to any number of groups, and they can be distributed freely.
This approach is particularly advantageous when dealing with irregular or arbitrary laying techniques for each course, as it allows for a highly customizable allocation of the curves.

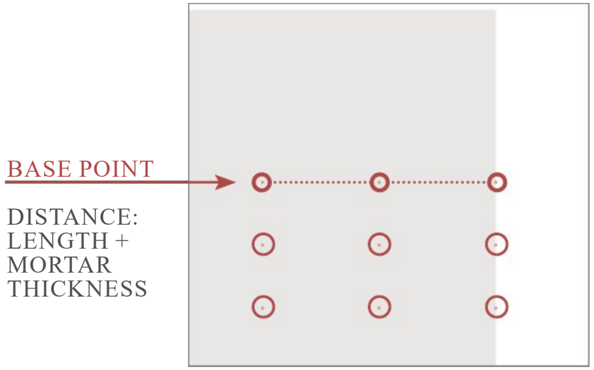
Now, the outputs (curves sorted into groups) are further processed. Depending on how many groups have been created, there will be corresponding curves as components. These curves are now used as inputs for the modeling of the laying technique for each group.

3.

DIVIDE LENGTH

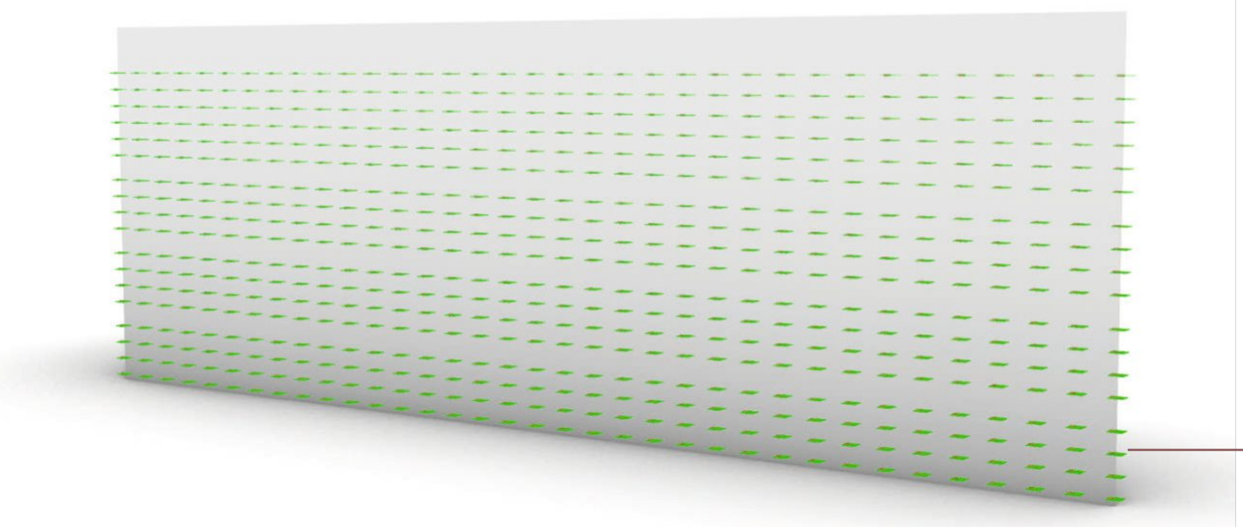


308 | Perspective; Position Base Points



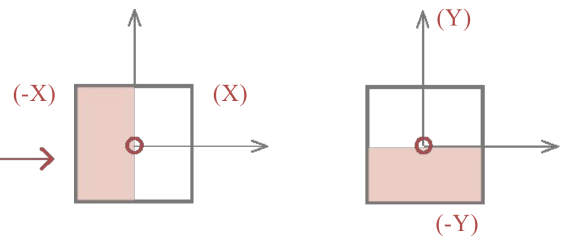
310 | Elevation View; Position Base Points

CREATE XY-PLANE

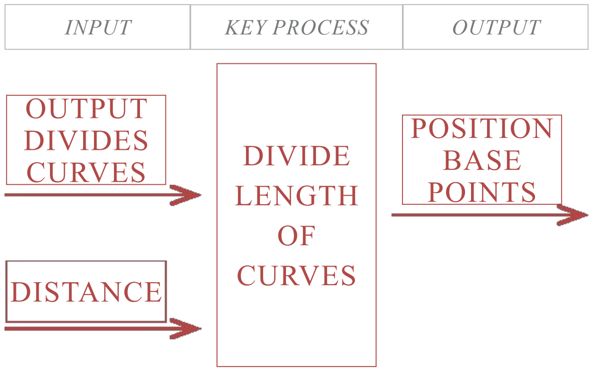


309 | Perspektive; XY-Planes Positioning

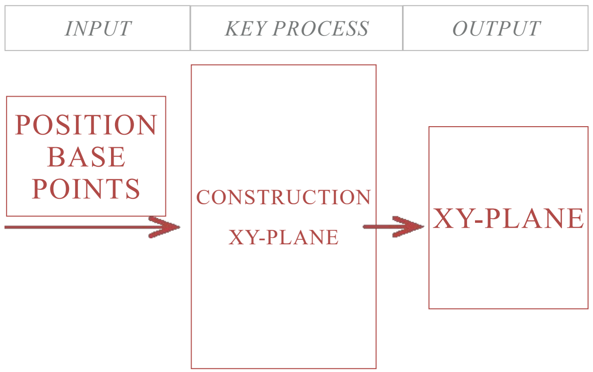
The created XY-planes are positioned at the base points. Now, the direction in which the brick is formed can be influenced, depending on whether a positive or negative value is entered. The starting point is always the intersection of X and Y at (0,0).



311 | XY-Planes at the Base Points



312 | Illustration Process Seperation Curves



313 | Illustration Process Construction XY-Plane

(3.) After grouping, the next step is dividing the XY-axis by defining steps along the curves. This means that along the curves, distances are entered, and at each section, a base point is created. XY-planes are then generated at these base points.

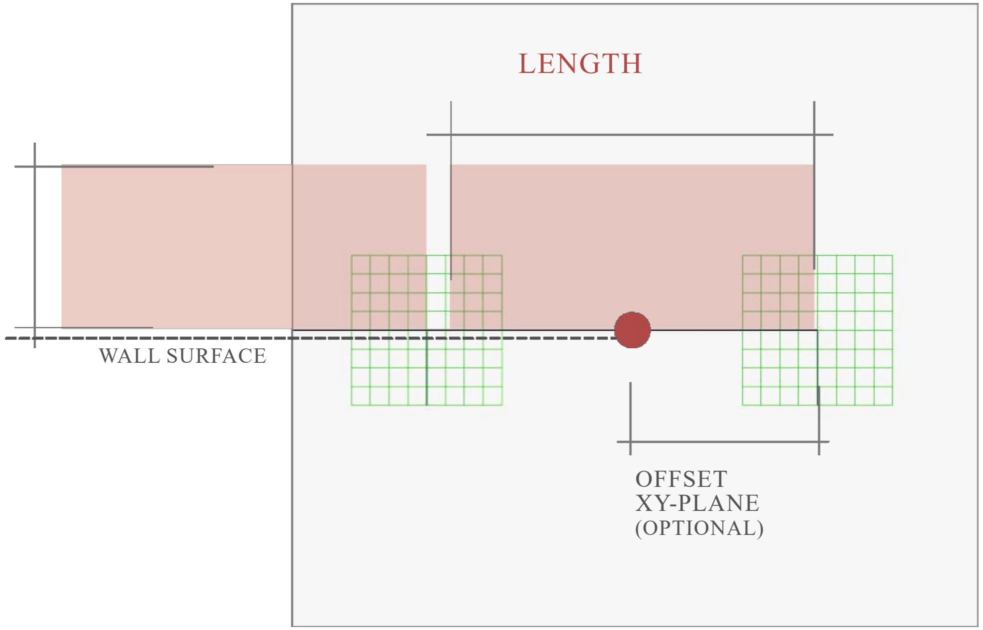
The input for the Divide Length Tool is the curve group and the distance. The distance consists of the brick length or width (depending on the desired laying technique) and the mortar thickness. Since the curves are grouped, different distances can be defined for each group to create the desired bond. Once the steps are defined, the output of the tool is the base points, which then serve as the input for the XY-Plane Tool. After the key process, which involves creating the planes, the output will be the XY-planes themselves.

The advantage of generating a separate XY-plane for each base point is that flexibility is maintained. An advantage is in the subsequent brick construction. By considering the input of positive or negative values, the direction in which the bricks are created can be influenced. The starting point for the construction of the box is at the (0,0) point of the XY-plane. Afterward, by entering the brick's length and width, the direction in which the box is created can be controlled.

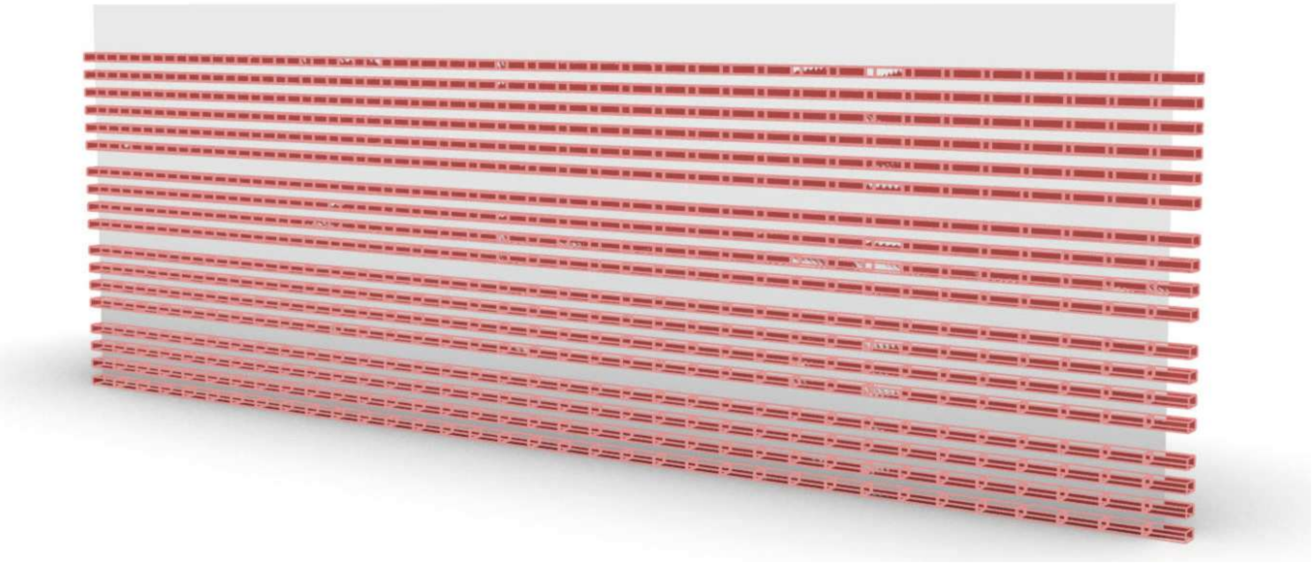
The curves in the first group are then divided along the X-axis. For example, in the case of the stretcher course, a brick length plus mortar thickness is specified. This generates an XY-plane, effectively creating multiple individual base points along these curves (for the first group). This process is repeated for the other groups. For the header course, the brick width plus mortar thickness is used, while for the rowlock course, the brick height plus mortar thickness is applied (as the brick is tilted and rests on its narrow side).

CREATE DOMAIN BOX

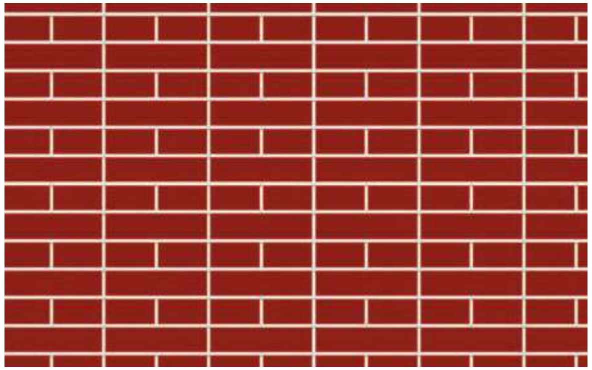
4.



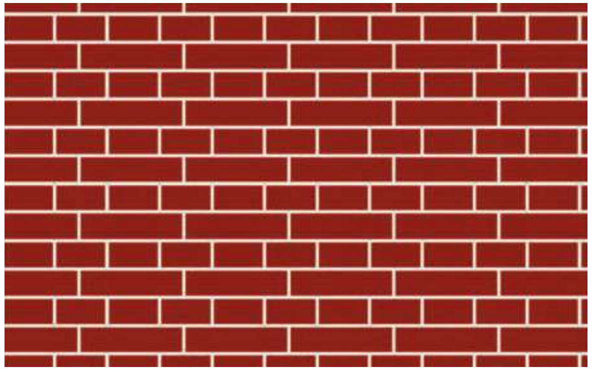
314 | Plan View; XY-Planes Positioning



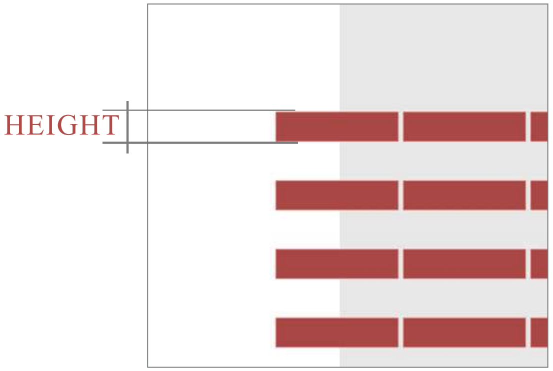
315 | Perspective; Brick Positioning



316 | Header and Stretcher Bond (stacked)



317 | Header and Stretcher Bond (offset)



318 | Elevation View; Brick Positioning

An additional advantage of the plane is that it can be moved in relation to the base point. In masonry, it is common to offset the brick layers to enhance stability. If an offset (for example, half a brick width) is desired, it can be accommodated in this step.

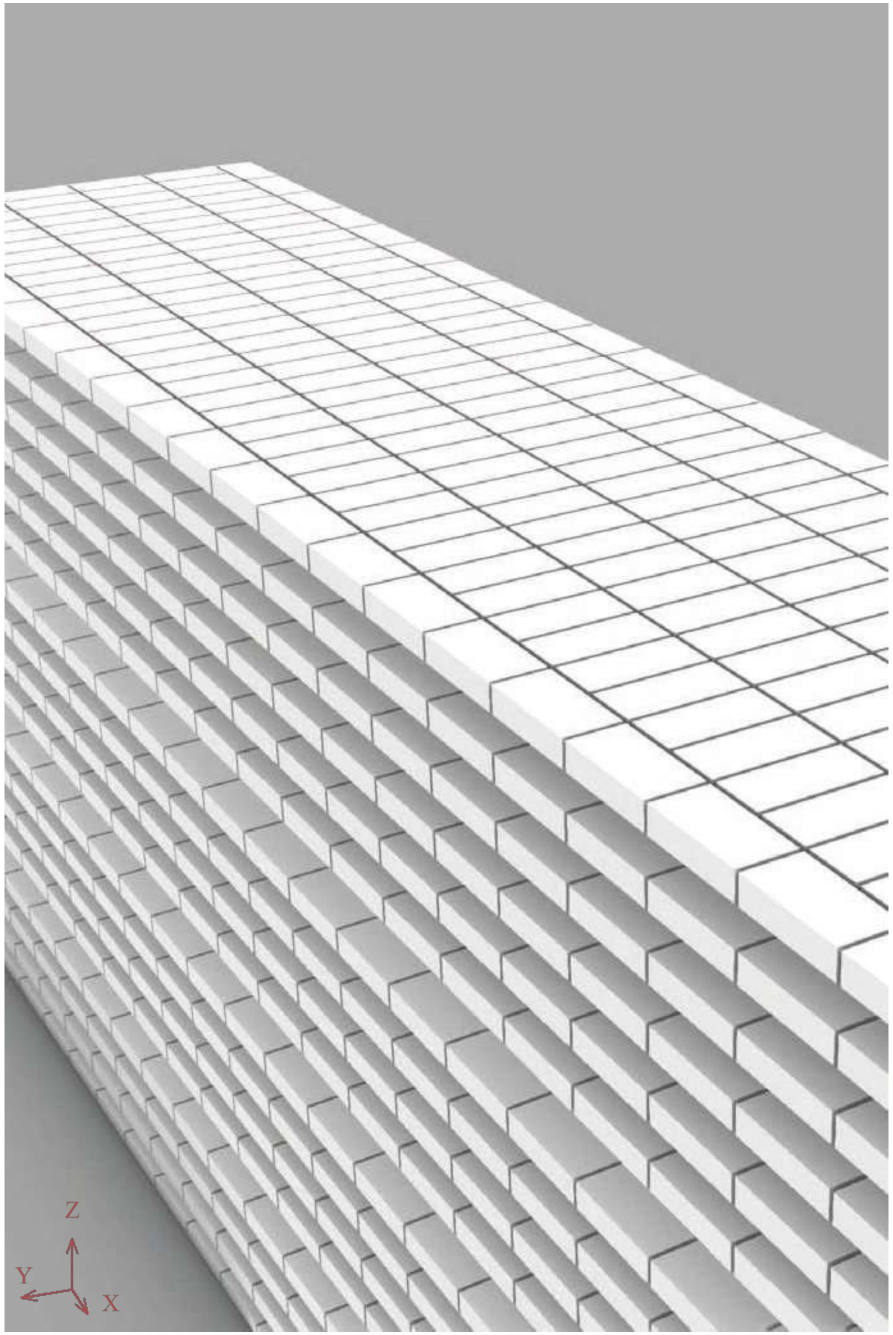
Once the positioning and distances have been ensured, the brick is then created at the starting position.

When creating the brick, there are several possibilities. It is important to decide in advance which formation you wish to create and which distances are required. The first step is to create the brick at the base point.

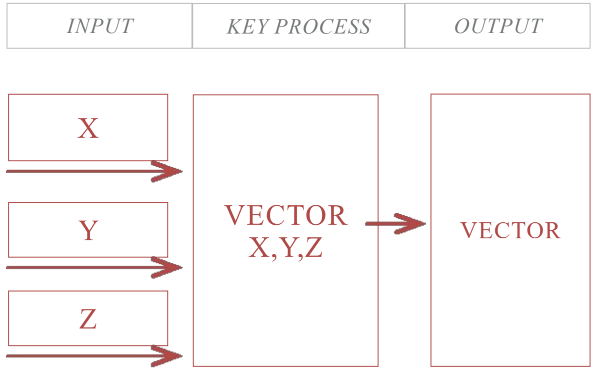
To clarify, curves were grouped, and these curves were then divided along the horizontal axis. This means that wherever a base point with an XY-plane exists, construction will take place. As shown in *Figure 315*, the stretcher bricks are arranged in several layers along the wall surface. This means that a process is generated for a brick, which is then placed at all the base points. If the brick configuration is modified, the changes will be applied at the positions of all XY-planes in that group.

The brick is created using the *domain box* tool, with the input from the XY-plane (to define the construction plane) and the remaining input coming from the brick dimensions, which are split into X, Y, and Z. The Z-coordinate always determines the height of the brick, while X and Y depend on the desired positioning of the brick. For example, in a bond where the long side is visible on the wall surface, the length will be entered at X, and the width at Y. Therefore, it is important to know the parameters in advance because the distances between the base points are the length/width of the brick plus the mortar gap. The brick is created with just the length/width, and the mortar gap is automatically accounted for.

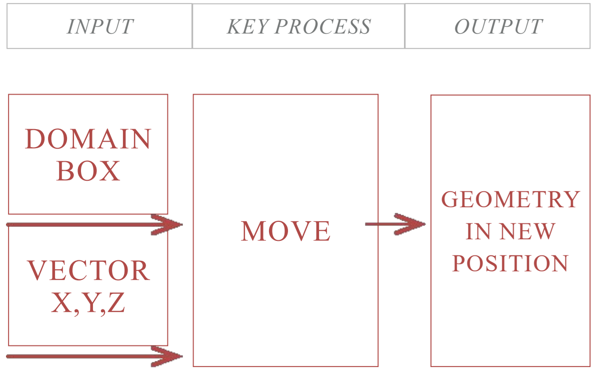
Once the brick is created and positioned, it can be further processed for additional adjustments. By shifting the brick using various tools, the brick bond is generated along the depth of the wall. This depth manipulation allows for the accurate creation of wall layers, ensuring that the masonry structure is built up layer by layer, with the correct brick orientation, spacing, and offsets. The brick layers can be continuously adjusted, providing flexibility.



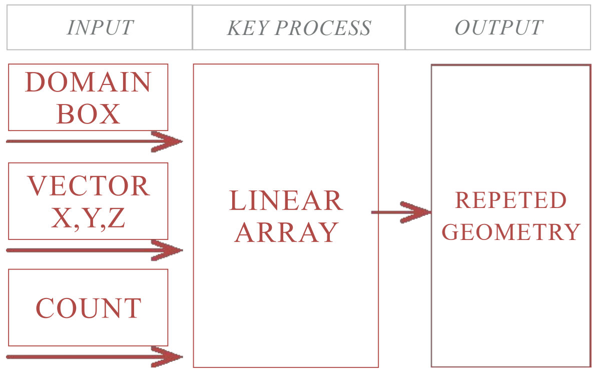
319 | Rendering *Digital Brick Tool - Block* Stretcher Courses



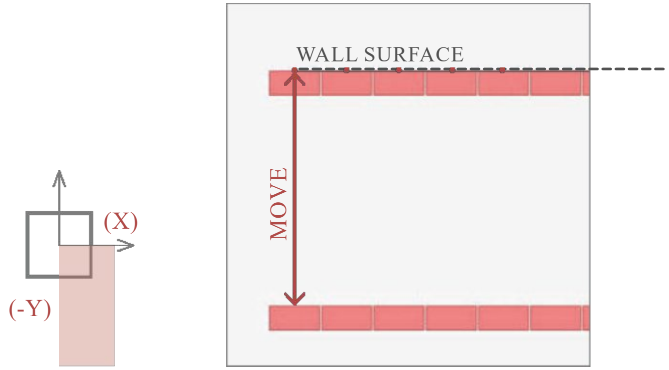
320 | Illustration Process Vector X,Y,Z



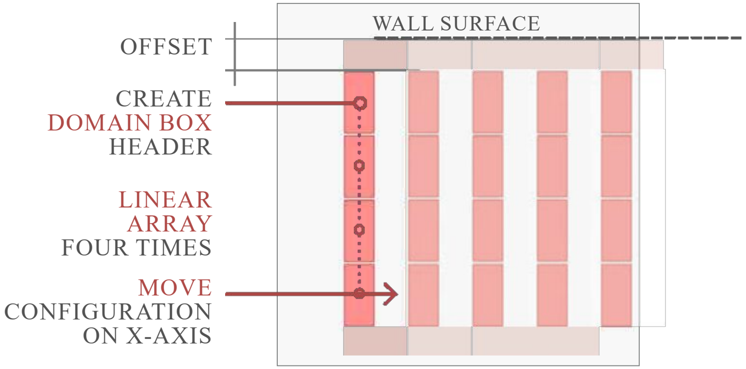
321 | Illustration Process Move



322 | Illustration Process Linear Array



323 | Positioning Stretcher



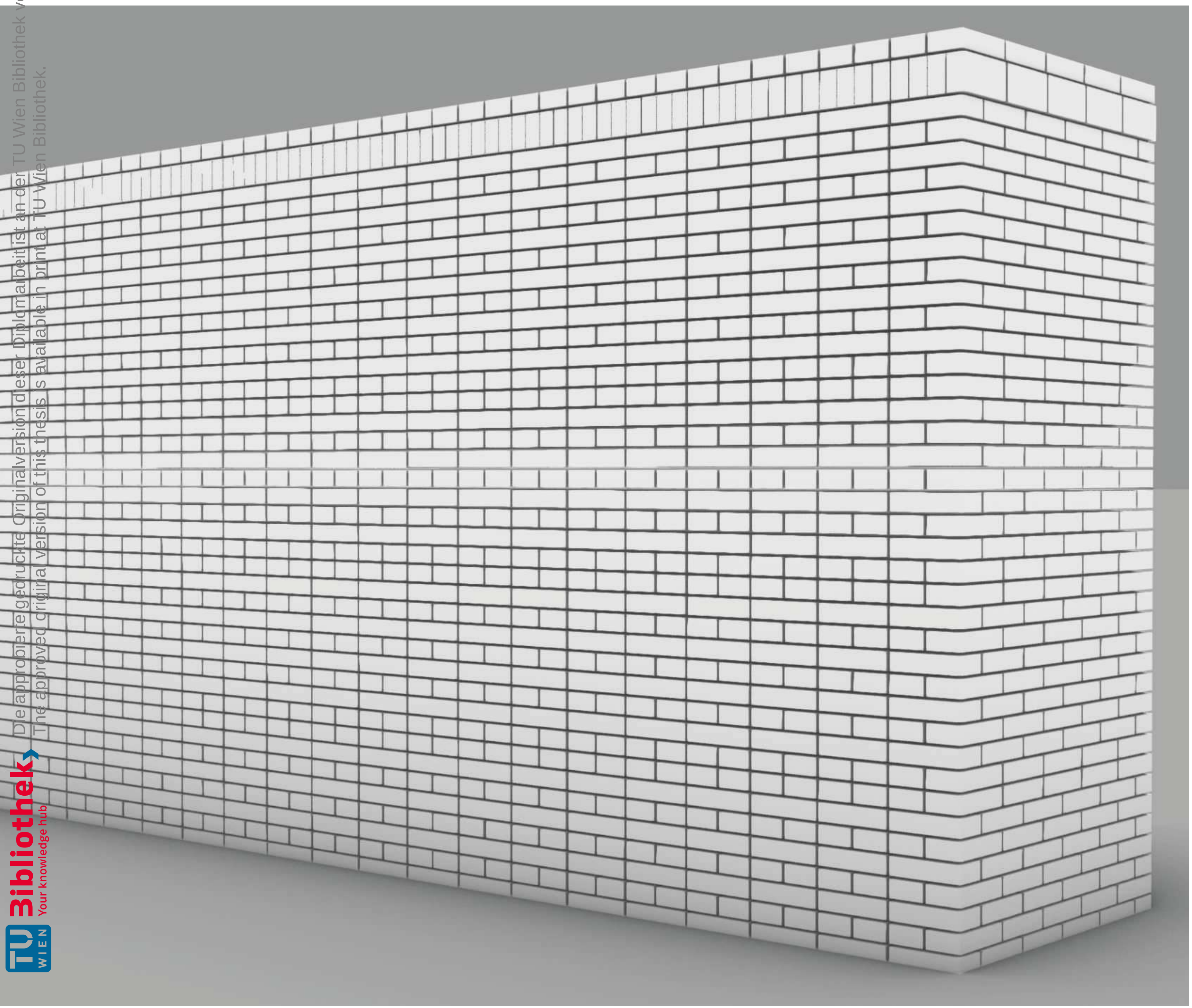
324 | Positioning Header Course inside

325 | Plan View; Stretcher Course

The laying technique in depth can be generated with simple commands. The input for this process is the created brick. The Linear Array tool creates a series of objects in a selected direction. This means that the input for the tool consists of the output from the Domain Box, the output of a Vector XYZ tool, and the number of objects that need to be created. The Vector XYZ tool allows for the generation of a chosen distance along the axes. The tool generates steps along one of the entered directions, and the number of steps to be created depends on the input. This allows for the arrangement of the same formation multiple times, thereby creating a wall bond that exactly matches the first brick row. However, in many cases, the orientation or positions of the bricks in a brick bond change. Shifting or rotating the brick by 90 degrees offers more stability of the construction.

In these cases, a step-by-step approach is required. For example, in the stretcher-header formation of the Meret Neith tomb, the inner bricks are placed vertically in relation to the outer edge bricks. There is the option to rotate bricks, but this decreases the flexibility of individual components and makes it harder to adjust them later. Therefore, it is recommended to create a brick for each brick orientation using the Domain Box tool. In this scenario, two Domain Box components are connected to the output of the XY-plane. It is important to note that for the internal structure, the XY-plane must be shifted into the correct position regarding each brick type, so that the bricks do not overlap and are positioned correctly. For instance, in the header formation of the header/stretcher bond, the plane was shifted by half a brick width plus the mortar gap in the negative Y direction, as this is exactly the distance needed for the placement of the outer rows regarding the stretcher bricks. The Linear Array tool is then used in the header course to fill the inner layer, which consists of four bricks. The outer rows, made from stretcher bricks, were created by shifting the outermost row by the correct distance (four times the brick length plus the mortar thickness) using the Move tool. The input for this Move Process is the Domain Box of the stretcher bricks and the distance by which it should be shifted.

Finally, the Merge tool can be used to combine all the geometries, so the created brick formation, consisting of different types of bricks, is enclosed in a single component. This allows for further processing if needed. Essentially, the output, which is the geometry of all components, is well-suited for further development.



When recalling all the components, it is important to note that they are all adjustable. The distance between the curves can be modified both globally and individually for each curve. Additionally, an unlimited number of wall surfaces can be added. Using the Gene Pool, which is equipped with sliders, allows the user to assign the desired curves per group.

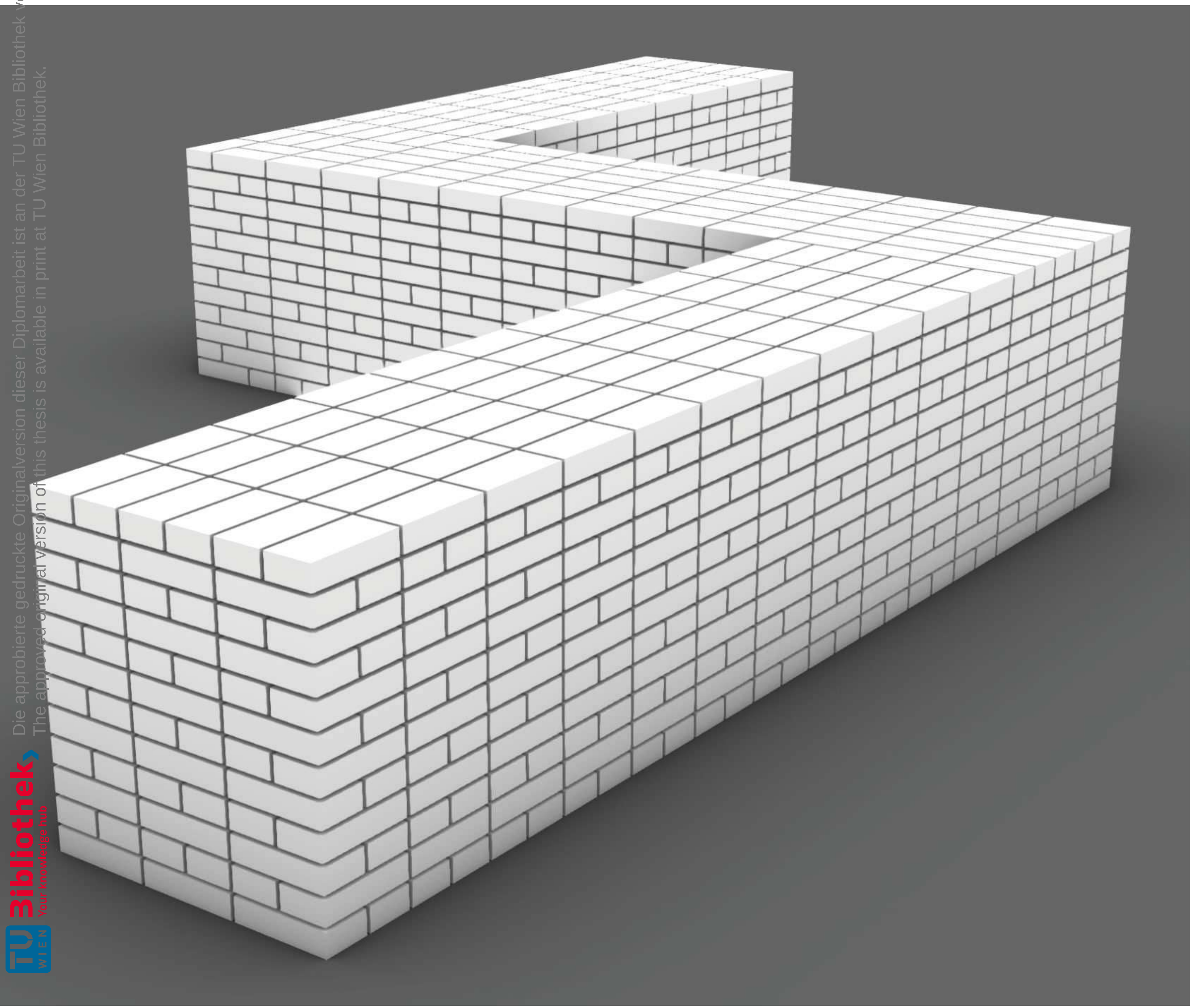
Once the curves have been assigned, the Divide Length Component can be used to adjust the spacing between the curves, and these distances can be varied interactively using the Number Slider. The Number Slider is a powerful input parameter that lets you quickly adjust the values by moving the slider, which is highly useful for real-time design adjustments. This interactivity helps refine the model as the changes are immediately visible in Rhino, supporting a more dynamic and hands-on approach for research.

This method is particularly valuable for managing distances, as the Number Slider allows for easy modifications. For instance, when dealing with two variables like brick length and mortar thickness, separating them and using the Addition Key Process to combine them provides a cleaner and more organized way to manage adjustments. The advantage here is that if, for example, the mortar thickness changes but the brick size remains constant, the adjustment can be made without altering the entire system, making the process more efficient and structured.

One of the major advantages of this tool is that it enables the quick creation of entire brick bonds with various structural configurations. Since the elements are interlinked, making changes, adjusting, and experimenting with different bond patterns becomes straightforward.

However, there are some limitations. The system operates as a block, which means that when different brick bonds meet or intersect, it can be difficult to model them accurately. This becomes a challenge when creating complex junctions or when the bonds need to interlock seamlessly.

To address this issue, it became crucial to develop an additional tool called Digital Brick Tool - Line designed specifically to support the generation of interlocking brick masonry, which would allow for a more flexible and precise design of complex brick connections and wall intersections. This additional tool would enable a higher level of control over how different brick layers interact, ensuring that the transitions between different wall sections remain consistent and structurally sound.



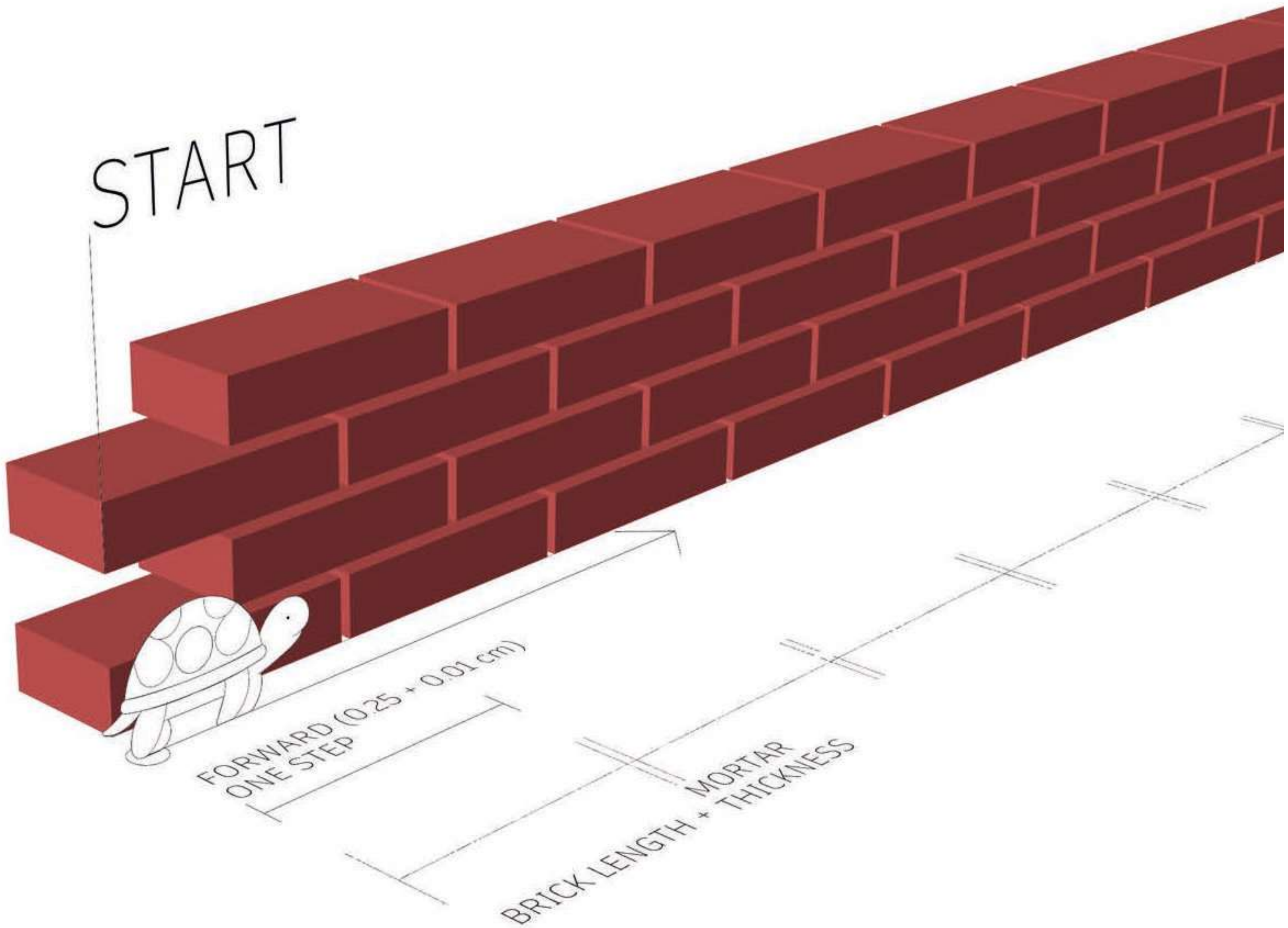
 Rendering *Digital Brick Tool* - *Line* Model

7.4.3 Digital Brick Tool - Line

The *Digital Brick Tool - Line* was developed to facilitate the modeling of individual brick rows and, more importantly, intersections.

The tool, as described here, is fundamentally based on the *TurtleGraphics* script developed by Ass. Prof. Dipl.-Ing. Dr. techn. Peter Ferschin at the TU Wien. This script serves as the core framework for creating and manipulating geometric objects in *Rhino* and *Grasshopper*. It utilizes principles of *Turtle Graphics* to generate precise and intricate configurations within the 3D modeling environment.
The *TurtleGraphics* script forms the core logic of the tool, providing the foundational framework for defining geometric relationships and structures. It was adapted by Project Assistant (FWF) Dipl.-Ing. Balint Istvan Kovacs, BSc., to address specific needs related to brick placement functionality. This modification enabled the script to accommodate the particular requirements for the design of masonry walls, including precise control over brick alignment and positioning.
Building upon this primary script, an additional Python script was integrated as an extension to address more advanced requirements. This secondary script, authored by *ChatGPT* (GPT-4, OpenAI) and later modified and adapted by Author Julia Anna Strasser, BSc., enhances the tool by adding further functionality tailored to the specific needs of the project. The Python add-on automates the placement of bricks along a boundary curve within the *Rhino/Grasshopper* environment, ensuring computational precision and adaptability. The integration of both the *TurtleGraphics* framework and the Python script provides a highly customizable solution, allowing users to tailor the modeling process to their exact specifications.

In this process, curves are drawn in *Rhino* and then added as inputs to the *Grasshopper* components. For each brick arrangement, a corresponding component is created. These components allow for the creation of various brick configurations, ensuring that different laying patterns, including intersections, can be modeled with ease. By using this method, the tool not only simplifies the modeling of individual brick rows but also provides flexibility for creating more complex forms and intersections, offering greater precision and control in the construction of brick masonry structures.


START
FORWARD (0.25 + 0.01 cm)
ONE STEP
BRICK LENGTH + MORTAR THICKNESS

The TurtleGraphics script, which serves as the foundation for the developed tool, is designed for modeling brick formations. The script follows a path, and along this path, bricks are placed. The name *TurtleGraphics* is derived from the metaphor of a turtle, which moves along the desired path, executes predefined movements, and places bricks at specified intervals.

To work with this tool, a component is created in Grasshopper that is connected to the script. Users can input parameters such as brick length, brick height, mortar thickness, and spacing, allowing for interactive adjustments. To model a wall, the path, including layers, must be described so that the turtle can be guided accordingly.

Initially, the script initializes the starting position. Commands such as forward(distance), backward(distance), left(distance), right(distance), up(distance), and down(distance) move the turtle along the designated path, while left, right, roll_left, and other commands control the turtle's orientation. The turtle then places bricks at the desired locations. The pen control allows for interrupting the path drawing, enabling precise placement of bricks without continuously drawing the path.

This approach requires that the wall to be modeled is also described in the script, which demands some degree of programming knowledge. For large-scale projects or complex interlocks and wall bodies, this can become problematic, as it is time-consuming and requires significant spatial imagination to construct and define the path accurately. This makes it difficult to visualize the construction and communicate a satisfactory result verbally.

Therefore, the approach has been specifically targeted at these challenges, aiming to make the design process more flexible and adaptable to complex masonry structures.

IMPORTING THE TURTLE GRAPHIC SCRIPT

DEFINING INPUT PARAMETERS

VALIDATING INPUTS

CONFIGURING TURTLE

APPLYING OFFSET

CALCULATING BRICK POSITION

LOOPING THROUGH LAYERS

MOVING AND PLACING BRICKS

OUTPUTTING BRICKS

The additional script, which functions as an extension of the *TurtleGraphics* system, focuses primarily on the positioning of the bricks along the path and the creation of the path without the need for programming. The *TurtleGraphics* system is utilized to place the bricks along the predefined curve.

Brick sizes, mortar thickness, and other parameters can be controlled via sliders in *Grasshopper*. The curves that are connected to the *Grasshopper* component need to be created in *Rhino*.

The *TurtleGraphics* script is imported first. Input values such as brick length, width, height, mortar thickness, the position of the bricks relative to the curve, the curve itself, and the number of layers can be entered as parameters in the key process components within *Grasshopper*.

The script operates by first checking whether a valid curve exists. After this, the Turtle object is created, with the entered parameters such as brick dimensions and mortar thickness being essential. In the next step, the placement of bricks along the curve is activated.

After that it calculates the offset from the curve. A feature has been created that allows for the position of the bricks relative to the curve to be adjusted. Depending on the placement type, the curve is shifted accordingly.

The length of the shifted curve is then calculated, and based on its length, bricks are placed at intervals determined by the brick length plus mortar thickness, until the curve ends. The placement of the bricks is controlled using Turtle movement commands such as *goto()* and *lookto()*, which guide the Turtle to the correct positions along the curve. Additionally, there is the possibility to create multiple layers. A loop is incorporated for multiple layers of bricks, if applicable. The Turtle is then moved to the correct height to place the bricks at different levels, which enables the generation of multi-layered wall structures.

Finally, the entire process of wall creation using the *Digital Brick Tool - Line* is described, outlining the benefits and drawbacks of the developed system.

CREATE CURVES

ENTER PARAMETER

- BRICK HEIGHT
- BRICK LENGTH A (ALONGE LINE)
- BRICK LENGTH B (90 DEGREES TO LINE)
- MORTAR THICKNESS
- NUMBER OF LAYERS (Z-AXIS)

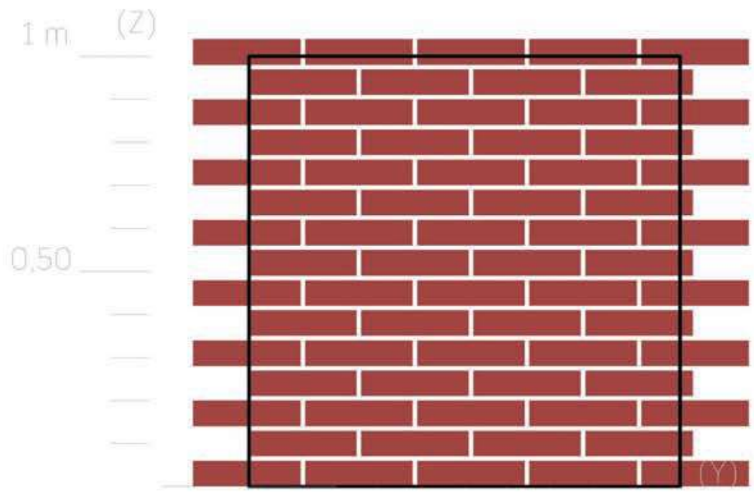
DEFINE POSITION

- INSIDE/CENTER/OUTSIDE

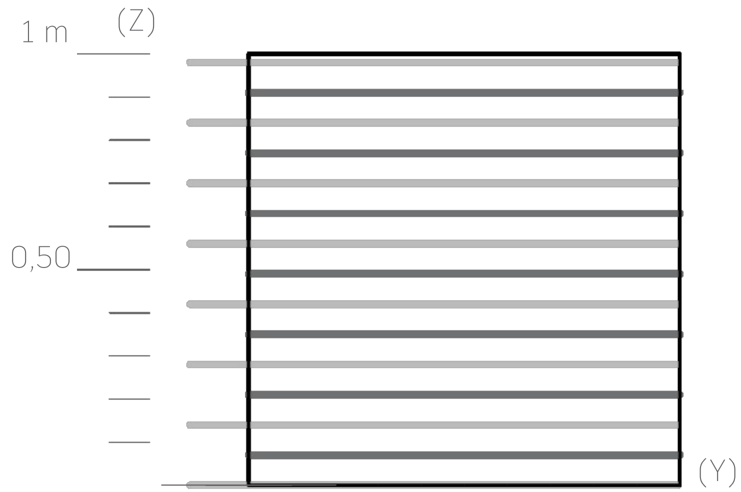
The workflow begins with curves created in *Rhino*, which define the boundaries of the brick placement. These curves are then imported into Grasshopper and connected to the tool, establishing the basis for subsequent steps. Ensuring that the curves align correctly with the intended geometry is critical. Following this, brick dimensions and placement parameters are defined. Brick length A corresponds to the side running along the curve, while brick length B represents the side oriented at a 90-degree angle to the curve. Based on these inputs, the placement type is specified, determining the type of brick (e.g., stretcher, header, or rowlock) and its alignment relative to the curve, such as left-aligned, right-aligned, or centered.

Once the dimensions and placement parameters are set, the tool automates the brick placement process. The script calculates the positions of the bricks along the defined boundary curve, aligning them precisely according to the user-defined settings. The generated brick formations can be seamlessly replicated along the Z-axis, enabling the construction of multiple layers when stacked arrangements are required. This feature supports the modeling of walls and other masonry structures with consistent and efficient workflows.

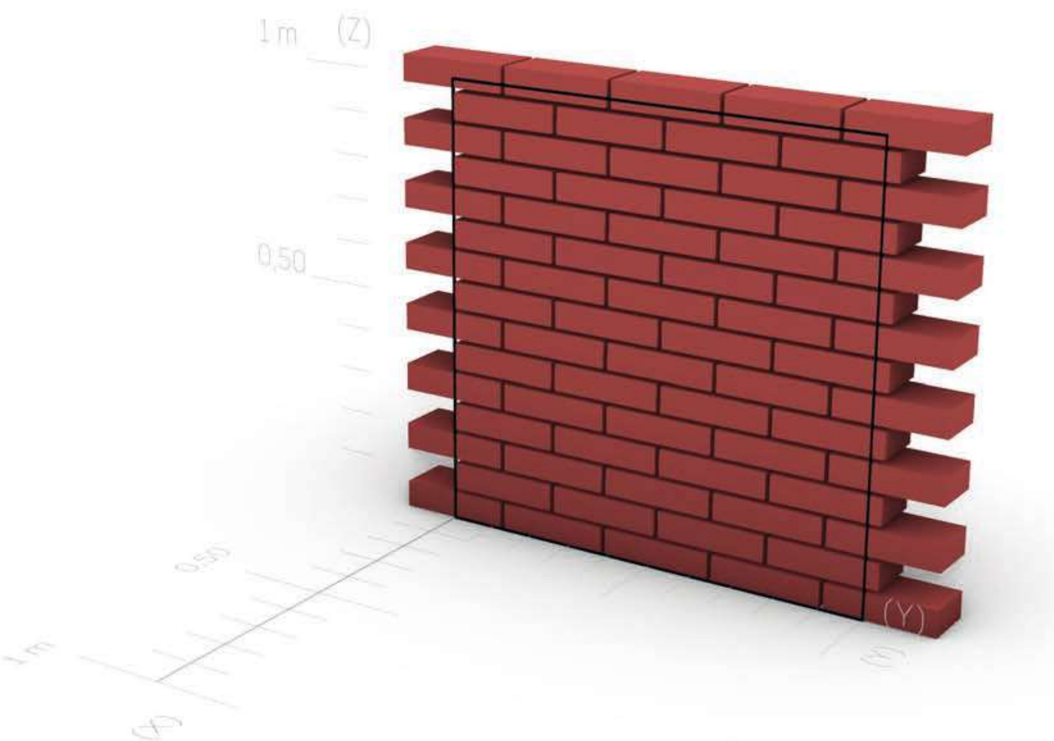
Care must be taken to specify the correct starting point of the curve in *Rhino*, especially for left- or right-aligned placements. Users can also assign multiple curves to the tool, facilitating the creation of complex brick arrangements or intersections. Once an intersection is successfully modeled, it can be easily replicated across other curves.



Front View

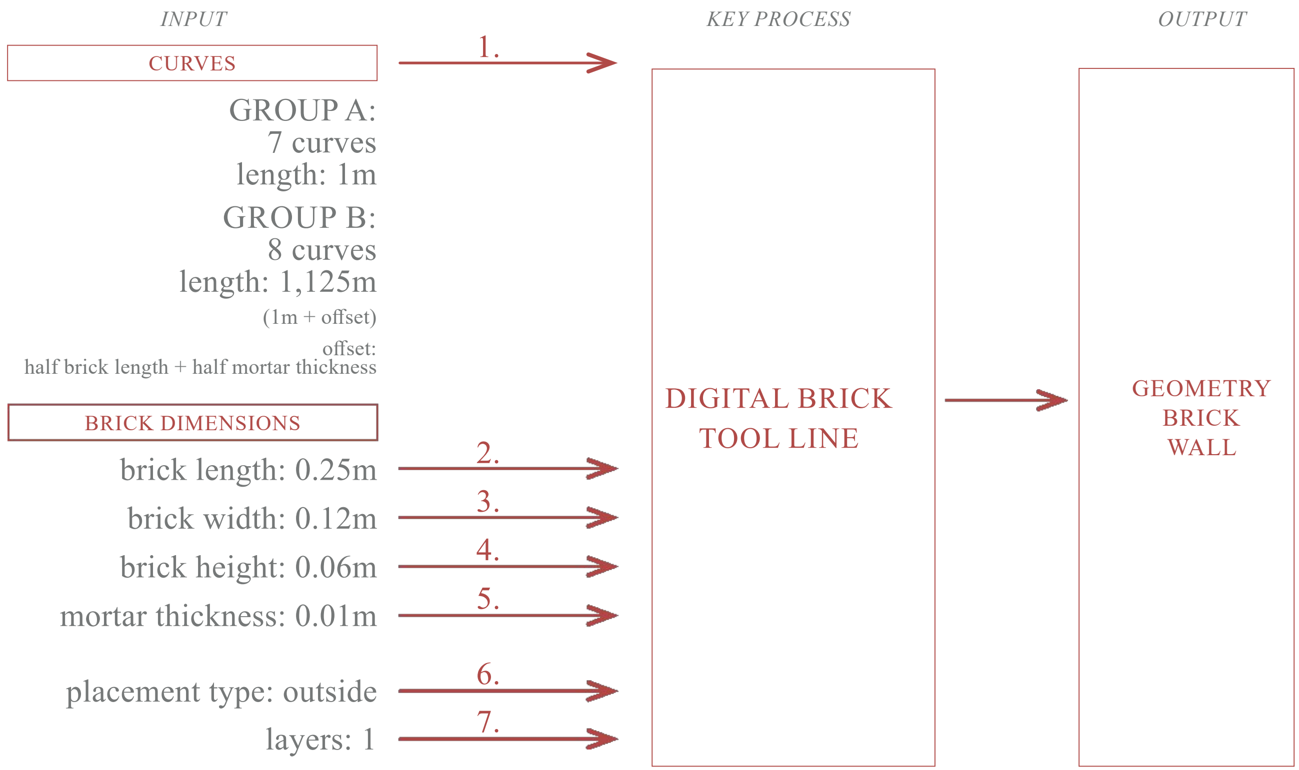


Front View

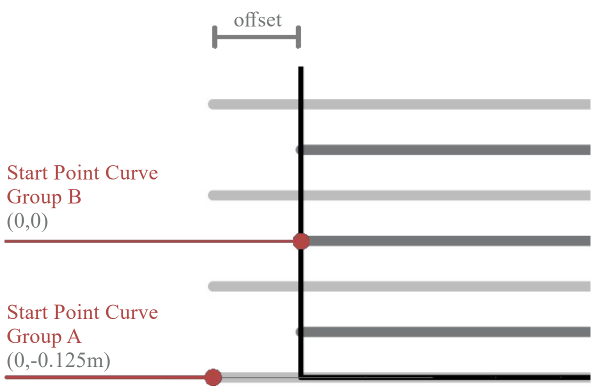


Perspective

GROUP A
GROUP B



332 | Illustration Interface Grasshopper; Workflow of Sqaure Meter



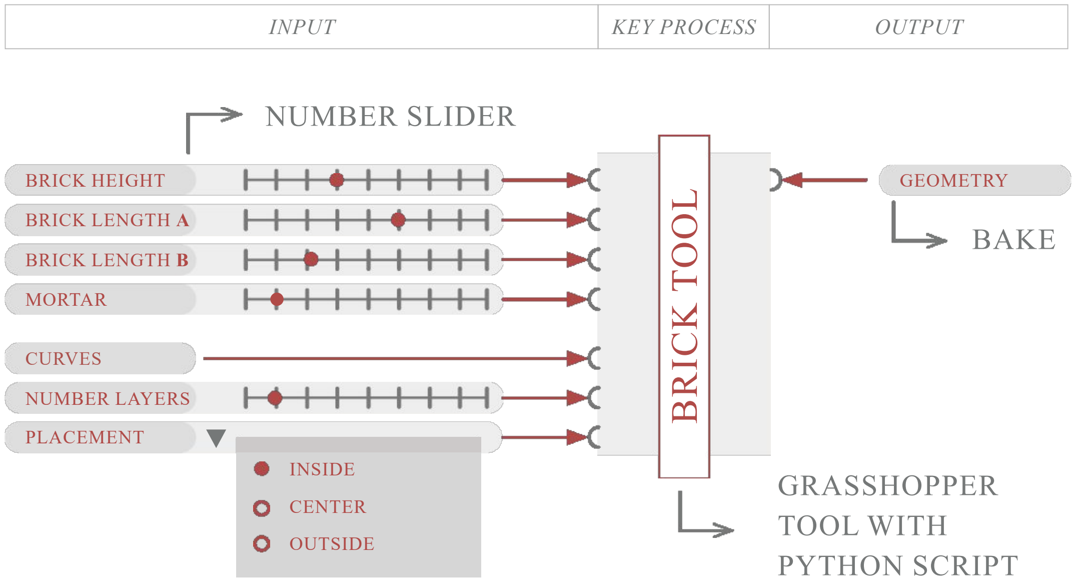
333 | Illustration Start Points of Curves

To better understand the upcoming workflow, an example is now provided where a square meter of a wall was modeled using a brick with the *Digital Brick Tool - Line*. By inputting the correct parameters, the desired bond is achieved. The Parameter and bond are are exactly like the

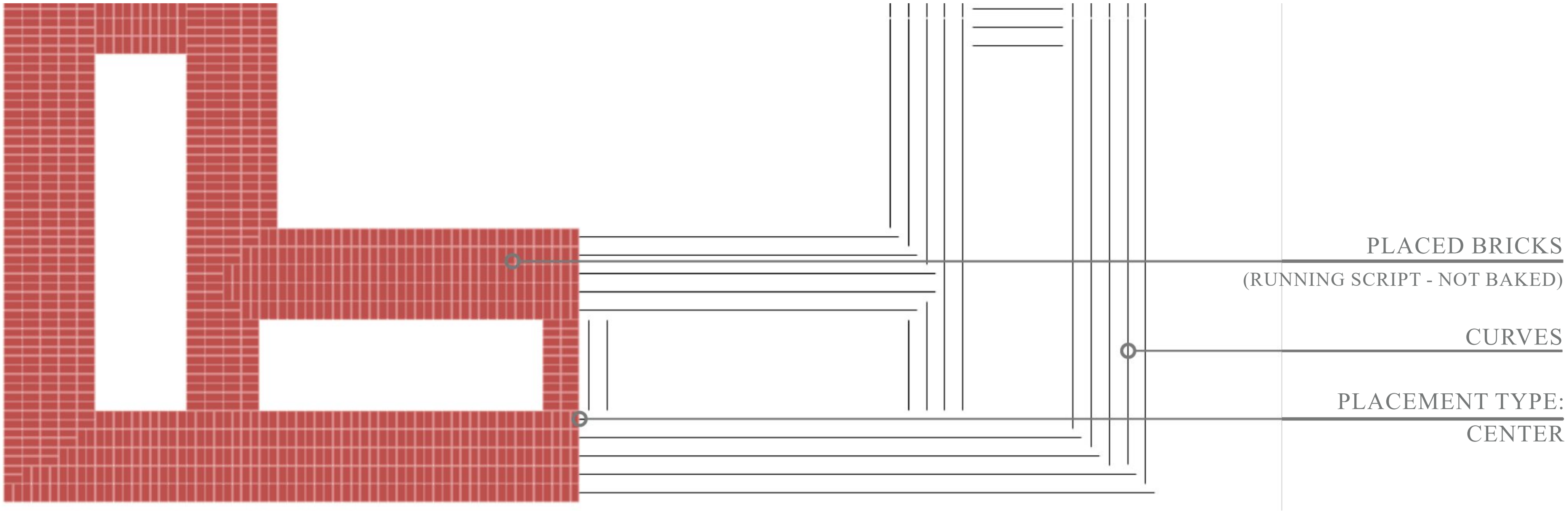
The parameters and the bond being replicated are exactly the same as the example previously simulated with the *Digital Brick Tool - Block*. This ensures a direct comparison and allows for a better explanation of the tools.

Parameter 1: First, the curves were drawn in Rhino. These curves represent the path along which the bricks are placed.
Therefore, the first point of the curve must be where the first brick is to be placed. In the case of a staggered bond, the line must either be offset beforehand or shifted afterward.
In this case, two groups were created in Rhino, where one group of curves is 12.5 cm longer (half the brick length + half the mortar thickness).
These lines are connected as input in Grasshopper.
Parameters 2-5: In Grasshopper, the dimensions of the brick are entered as parameters. In this case, 25 cm for the length, 12 cm for the width, and 6 cm for the height, with the mortar thickness set to 1 cm.
Parameter 6: The position of the bricks - whether they should be placed on the inside, outside, or centrally along the curve. Here, the bricks were placed on the outside.
Parameter 7: If the design is not a staggered bond but a repeated pattern, multiple layers can be input. Since a staggered bond is used, only one layer was selected.

Once all parameters are entered, the wall is configured through the key process, and a geometry is generated as output.



334 | Grasshopper Illustration Interface Components



335 | Plan View; Left: Running Script with Header Course, Right: Path as Curves

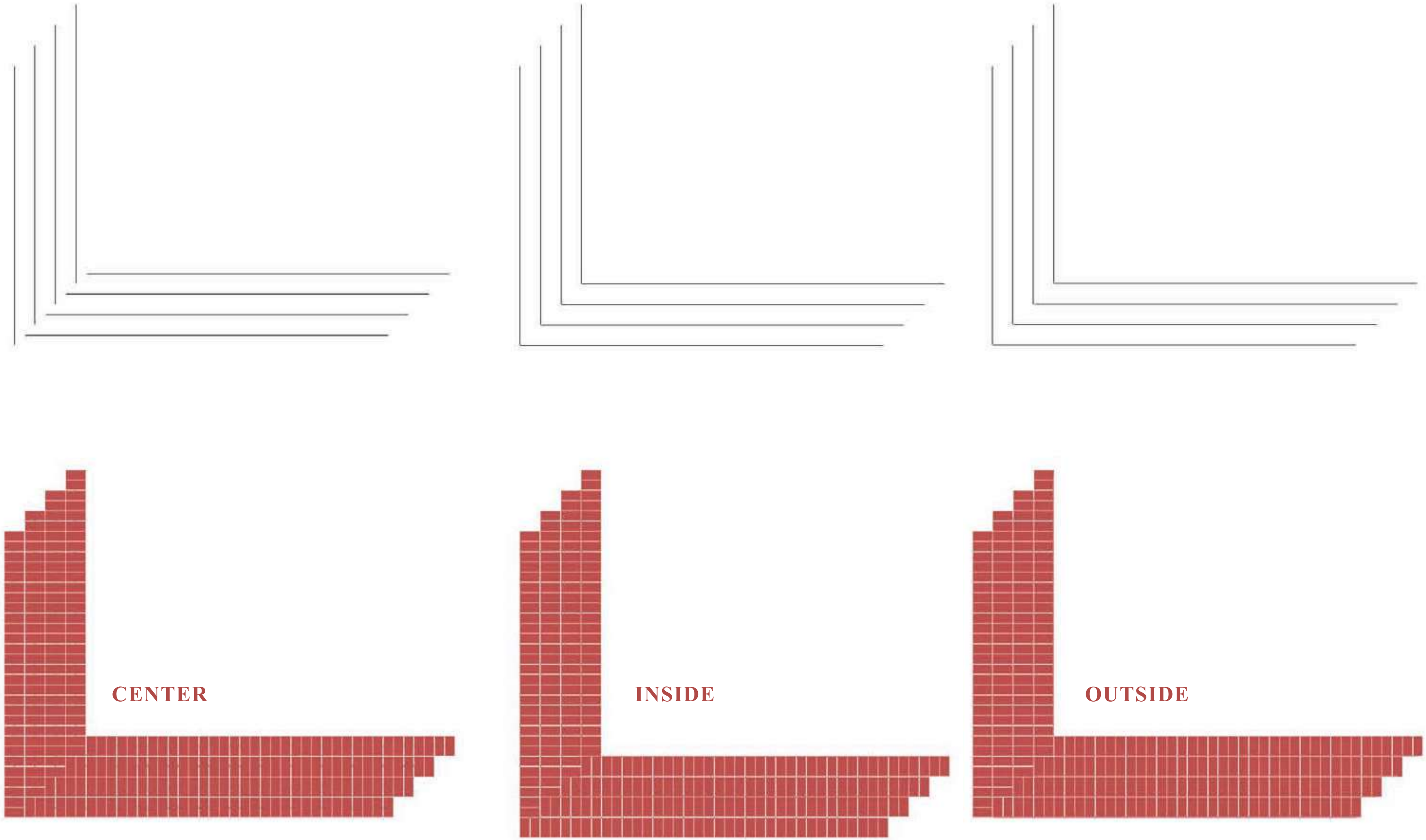
In *Figure 334*, a representation is provided, which visually mirrors what can also be found in Grasshopper.

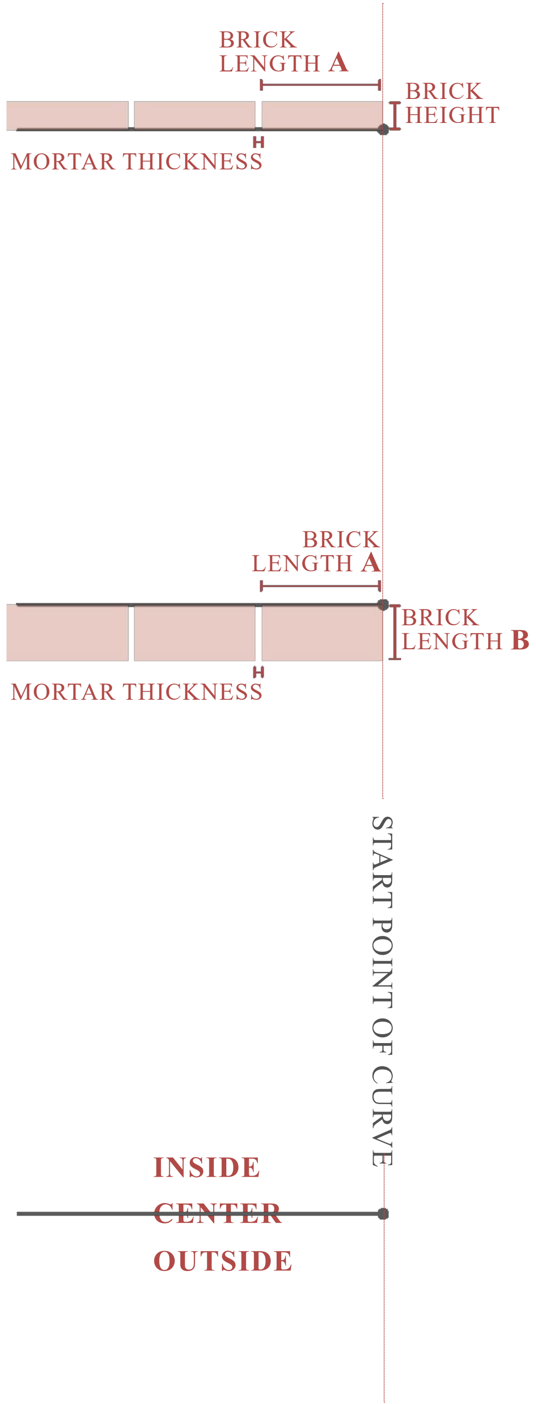
The input is defined by various parameters, offering a wide range of possibilities. Parameters such as brick height, brick length, mortar thickness, and the number of layers are primarily entered through Number Sliders. To define the placement type, a dropdown menu is provided, where the user can select whether the bricks should be placed at the center, inside, or outside of the curve. Additionally, the input for the curves is included, where the curves created in *Rhino* are assigned and connected through the components. If additional curves are created in *Rhino*, they can be added later, or specific curves can be removed. All curves are displayed in a list, where they can be manually edited.

Once the input parameters are defined, they form the complete basis for the key process. This process is embedded within a component, where the script is anchored. As a result, a custom component is created, and the specific processes to be executed are carried out accordingly. The final output is geometry. However, caution is required here, as the geometry must still be baked to become a solid object within the *Rhino* environment.

Grasshopper operates in such a way that the script runs through, performing the brick placement, and subsequently, the geometry must be baked. With every parameter change, the script is executed again and modifies the structure. This means that once a satisfactory final result is achieved, the geometry can be converted into a solid object.

In the case of multiple designs, it is recommended to duplicate the entire component with its inputs in Grasshopper and then adjust the parameters. This approach allows for the exploration of various formations within the same framework, while maintaining the ability to make adjustments.


CENTER
INSIDE
OUTSIDE



337 | Graphics Brick Placement along Curve

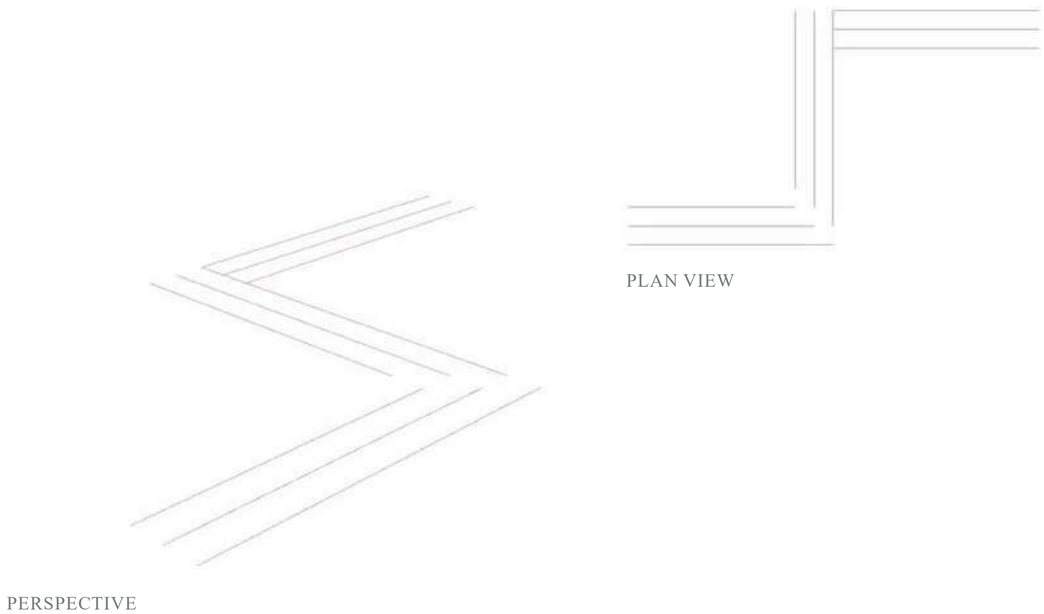
The key steps for creating a construction using the *Digital Brick Tool - Line* are outlined, with the inputs playing a crucial role. Two of these important inputs are the brick dimensions and the position of the bricks relative to the curve.

First and foremost, it is important to note that the curve always has a starting point, which is determined when the curve is drawn. This starting point is exactly where you begin when drawing the curve in Rhino. For example, if you draw a curve starting at point (0,0) and extend it along the X-axis to end at (-2,0), the starting point is at (0,0). This means that the positive Y-direction represents the inside, which lies above the line. If a central alignment is selected, the brick is placed exactly at the center of the line. The outside will be in the negative Y-direction, lying beneath the line.
The starting point of the brick corresponds directly to the curve's start, with no gap, followed by the mortar thickness.

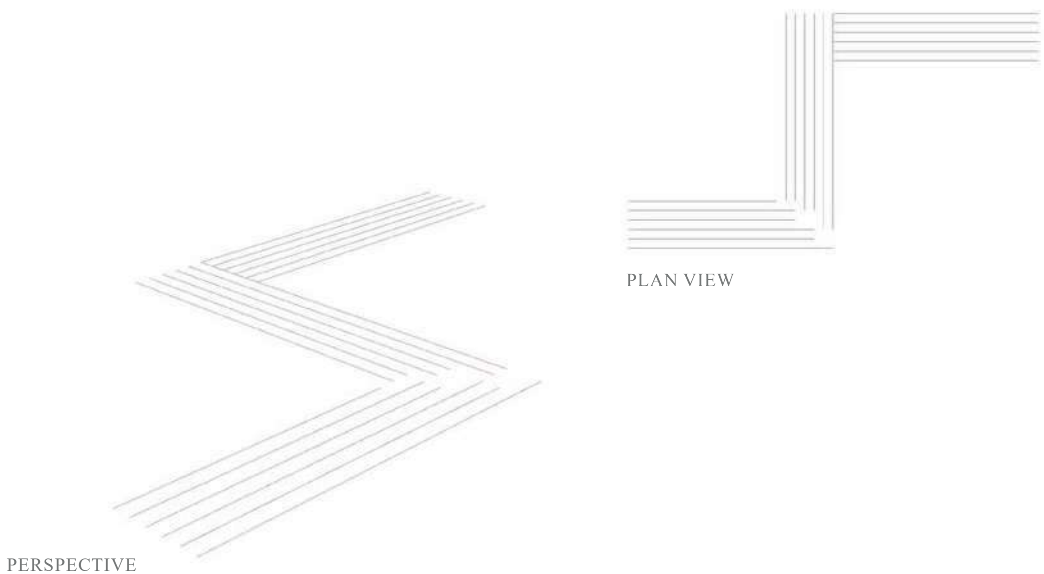
Once the curve is established, the bricks are placed along the line. Even if the curve is almost complete, and only a few millimeters remain, the last brick will still be placed. It is recommended to design interlocks in such a way that the start point always aligns with the corner or the junction of building elements. This allows the start point to be flexibly moved, and various connections can be constructed.

- The parameters for the brick dimensions should be entered as follows:
- Brick length A refers to the brick length that runs along the curve.
- Brick length B corresponds to the brick length that runs perpendicular to the curve.
- Brick height defines the height of the brick.

These inputs ensure that the bricks are placed correctly, in line with the curve's layout, while maintaining flexibility for adjustments and customizations in the design process.



338 | Perspective and Plan View; Group A - Curves in one Layer

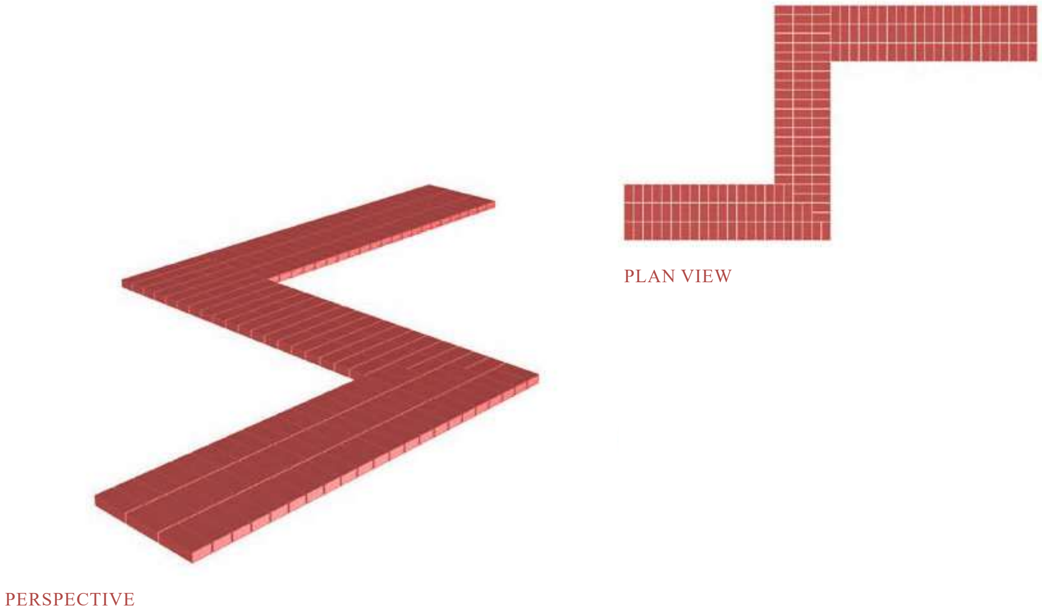


339 | Perspective and Plan View; Group B - Curves in one Layer

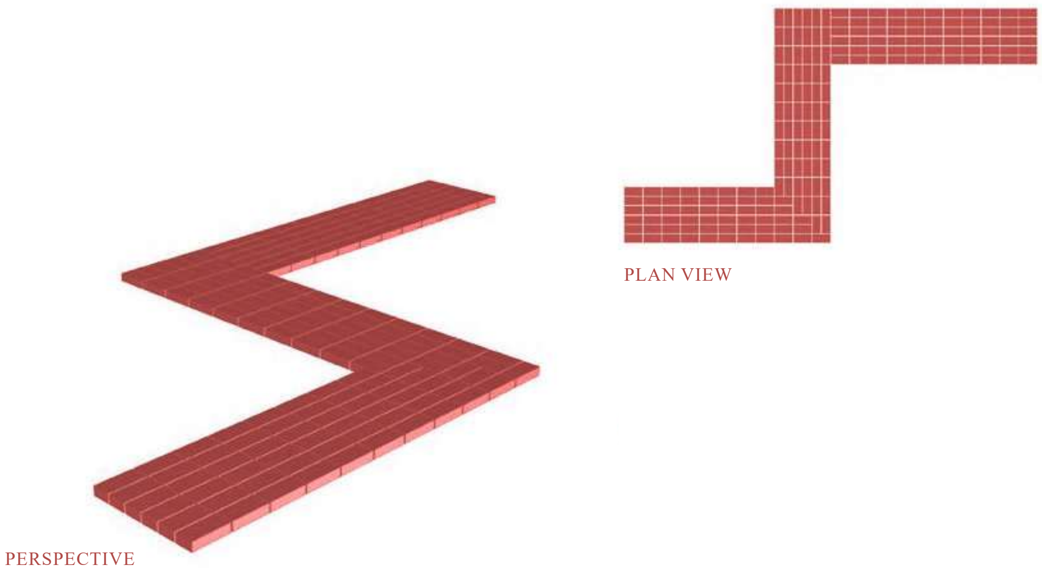
The curves are drawn first. When creating the curves using the *Rhino* program, it is important to consider the corner situations from the outset. Depending on the selected placement type, the bricks will meet in different ways. To avoid overlap of bricks at the corners, the correct spacing must be maintained from the start. The following figures show two types of corner situations and two different bond patterns, demonstrating how the Digital Brick Tool - Line works and what aspects need to be considered.

In Group A, a Header Bond is used, while Group B features a Stretcher Bond, where, in contrast to the more complex tomb Y pattern, the rows consist entirely of stretchers. One arrangement is

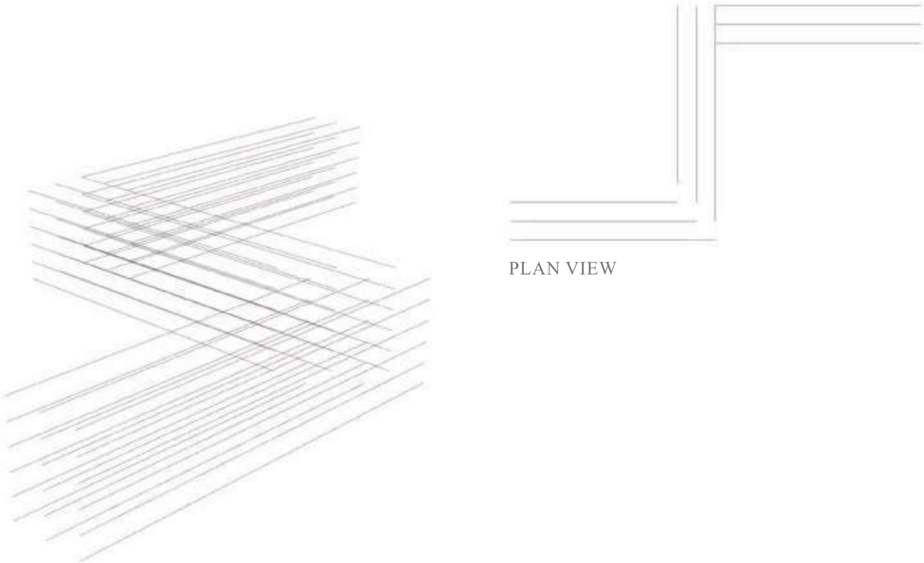
interlocked, while the other meets flatly. In the interlocked version, each brick row must extend outward. The curves are then stepped in a staggered manner. If the brick dimensions are known in advance, these can be considered when drawing the curves, with adjustments made according to the brick width or length. If the design is more intuitive, the curves can be modified during the script's execution, allowing for real-time adjustments. This flexibility enables manual modifications of the desired interlocks. The advantage of this method is that changes to the curves are immediately visible, helping achieve faster results.
It is important that the curves are connected to the components.



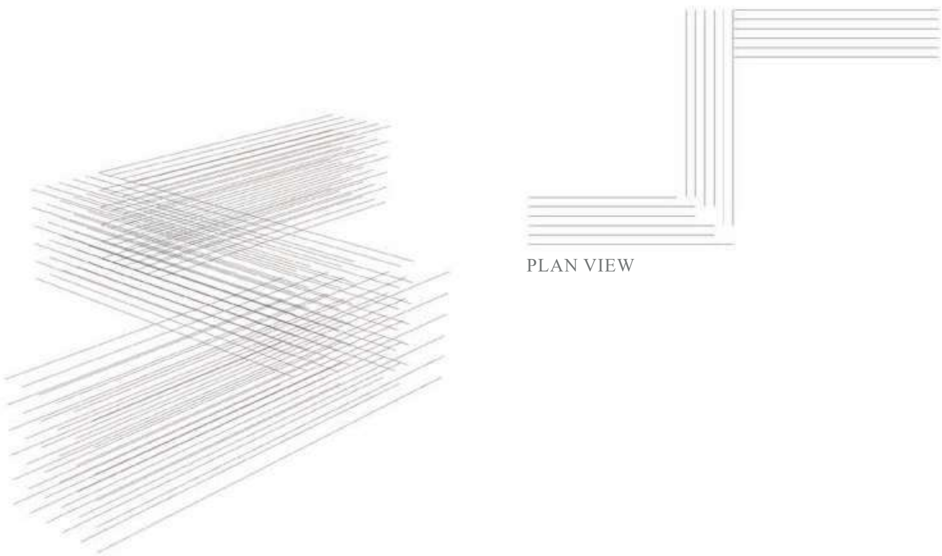
340 | Perspective and Plan View; Group A - Bricks in one Layer



341 | Perspective and Plan View; Group B - Bricks in one Layer



342 | Perspective and Plan View; Group A - Curves all Layers



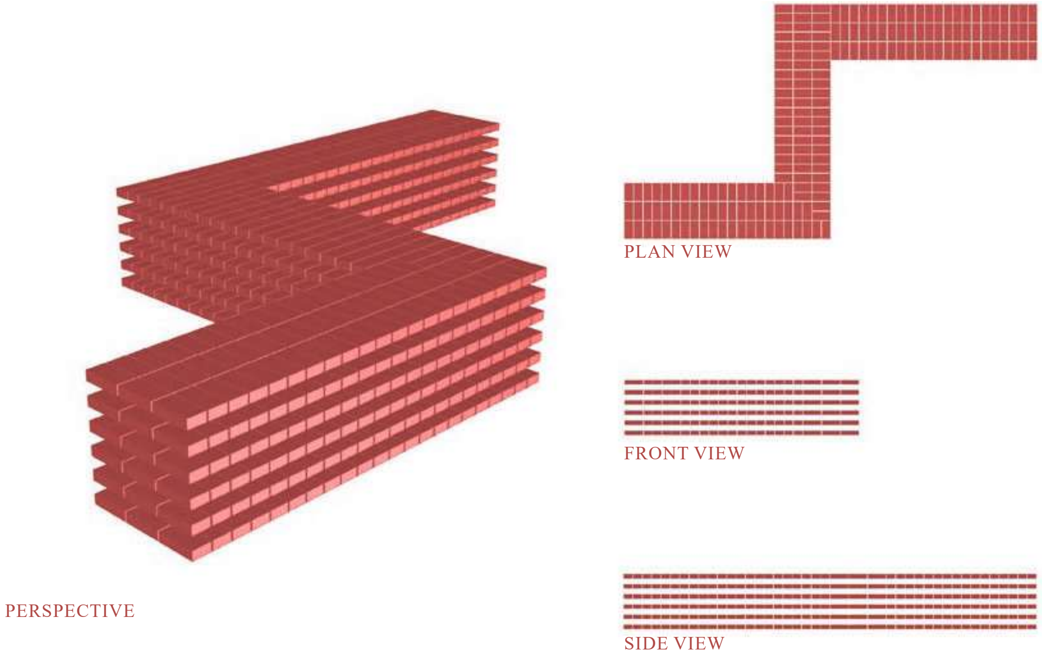
343 | Perspective and Plan View; Group B - Curves all Layers

WGenerally, the entire framework of the curves can be created beforehand and then added to the component. Two different components have been created in Grasshopper: Group A, featuring the Header Bond, and Group B, featuring the Stretcher Bond.

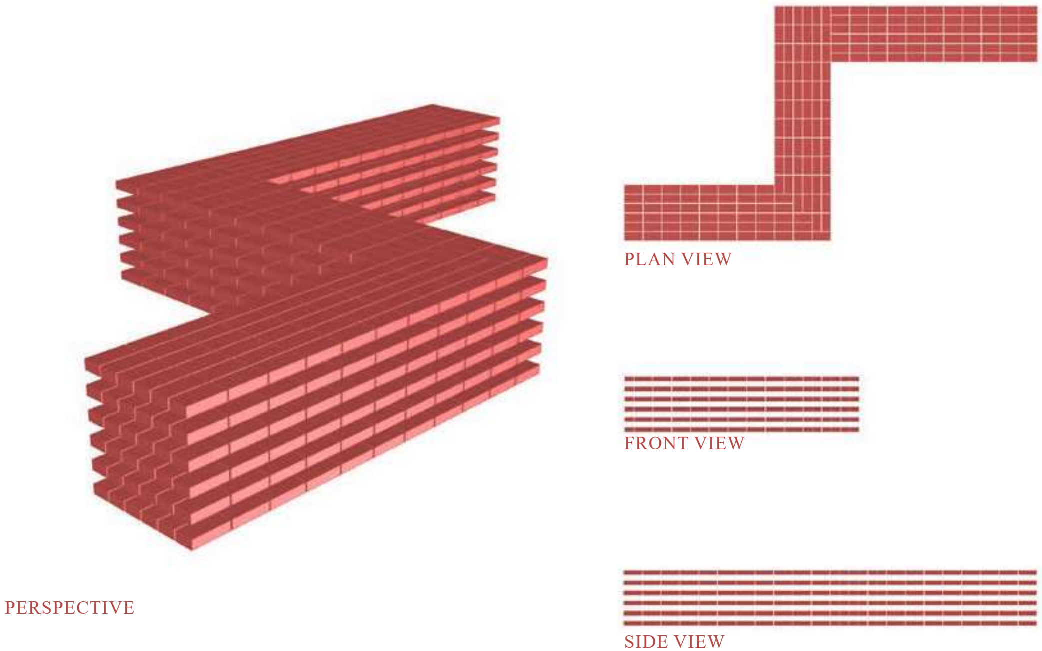
When creating the curves, it is recommended to group the different layers and groups within *Rhino*. For instance, Group A consists of curves for the first layer, and another group for the second layer, and so on.

The same approach applies to Group B, where the curves are sorted and divided accordingly. This sorting and division allow for entire layers to be easily copied and assigned to the tool, while also maintaining an organized workflow. As many curves will be generated during the modeling process, grouping them helps ensure that the overview is maintained, making it easier to manage and avoid confusion.

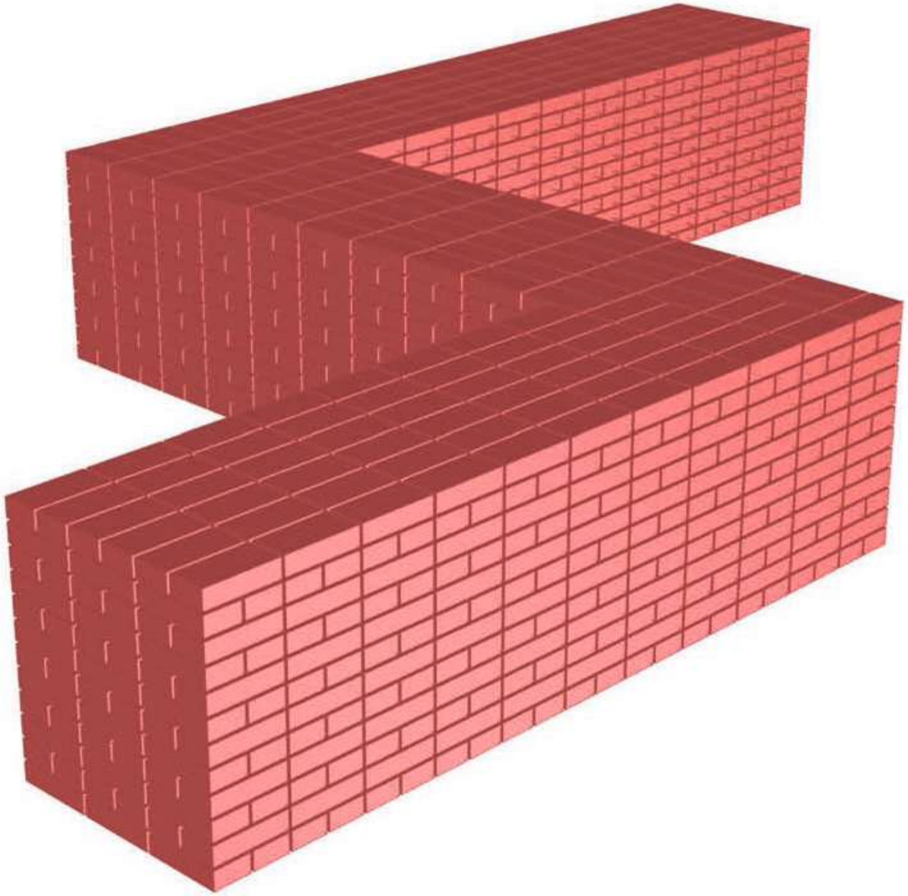
Once a layer has been constructed to a satisfactory level, it can be easily copied along the Z-axis at the desired intervals. The advantage of this approach is that many different brick layers can quickly be transformed into a bond pattern. This method allows for efficient replication and adjustment of the wall structure, making it easier to create complex masonry patterns while maintaining control over the design process.



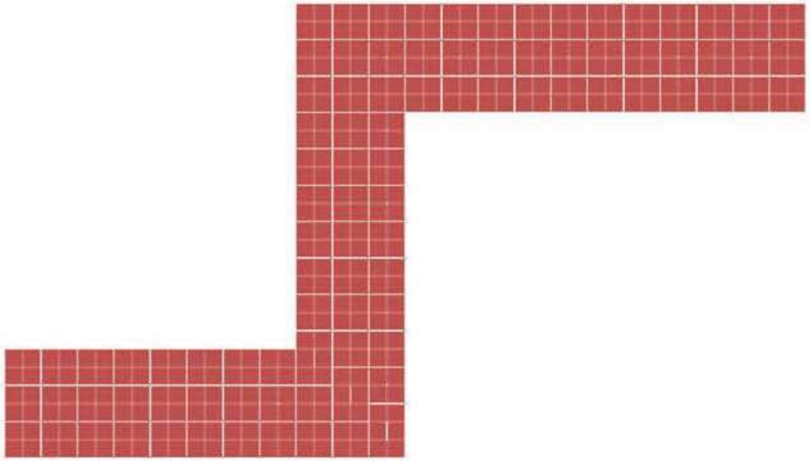
344 | Perspective, Plan View, Front View, Side View; Group A - Bricks allLayers



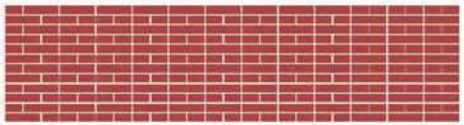
345 | Perspective, Plan View, Front View, Side View; Group B - Bricks all Layers



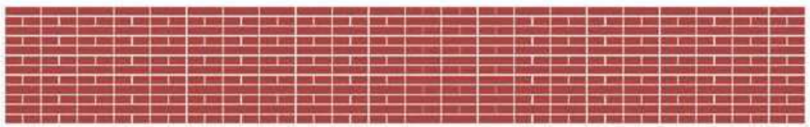
PERSPECTIVE



PLAN VIEW



FRONT VIEW

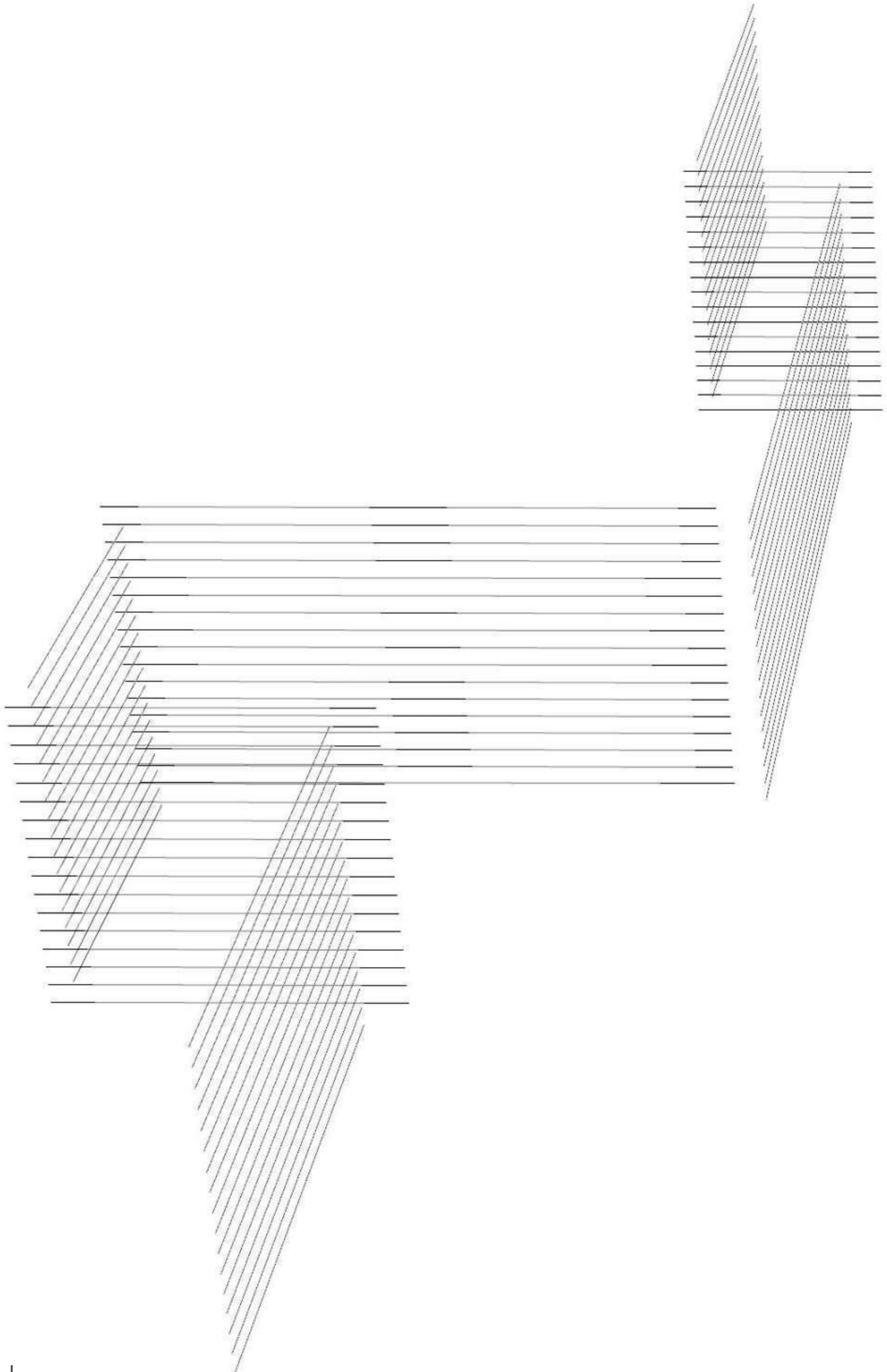


SIDE VIEW

In conclusion, it can be asserted that the *Digital Brick Tool - Line* is an effective and valuable tool, particularly when it comes to modeling brick masonry with intricate interlocks and corner situations. The ability to create precise brick formations and handle complex junctions is a significant advantage, especially when working with geometric patterns that require accurate alignment of each brick. By utilizing *Rhino*'s curve-drawing capabilities, this tool allows for a highly interactive and flexible approach to designing masonry structures. Users can manipulate the curve within *Rhino*, making it easier to experiment with different configurations and adjustments in real time.

One of the strengths of this tool lies in its integration with *Rhino*, where curves can be grouped for organizational purposes. This grouping helps manage the complexity of the design and ensures that similar elements are handled together. However, while grouping curves in *Rhino* provides a level of structure, it can quickly become overwhelming, especially for large-scale projects. As the number of curves and layers increases, maintaining an overview of the entire structure can become challenging. In such cases, organizing and navigating through the curves manually may require additional effort, potentially slowing down the workflow.

Moreover, although the tool allows for the adjustment of distances, dimensions, and brick positions after the initial setup, changing the relative placement of the brick layers and rows introduces a manual aspect to the process. Specifically, to alter the positioning of the layers relative to each other or adjust the alignment of the brick rows, the user must manually shift the curves. This process can become time-consuming particularly when working with multiple layers or large projects, where precise control over the placement of each brick is crucial. While the tool provides flexibility, this manual intervention can detract from the overall efficiency when it comes to managing more complex or large-scale masonry designs.



Perspective of Wall Trajectory; *Digital Brick Tool - Line*. Left: Curves and Right: Output Running Script

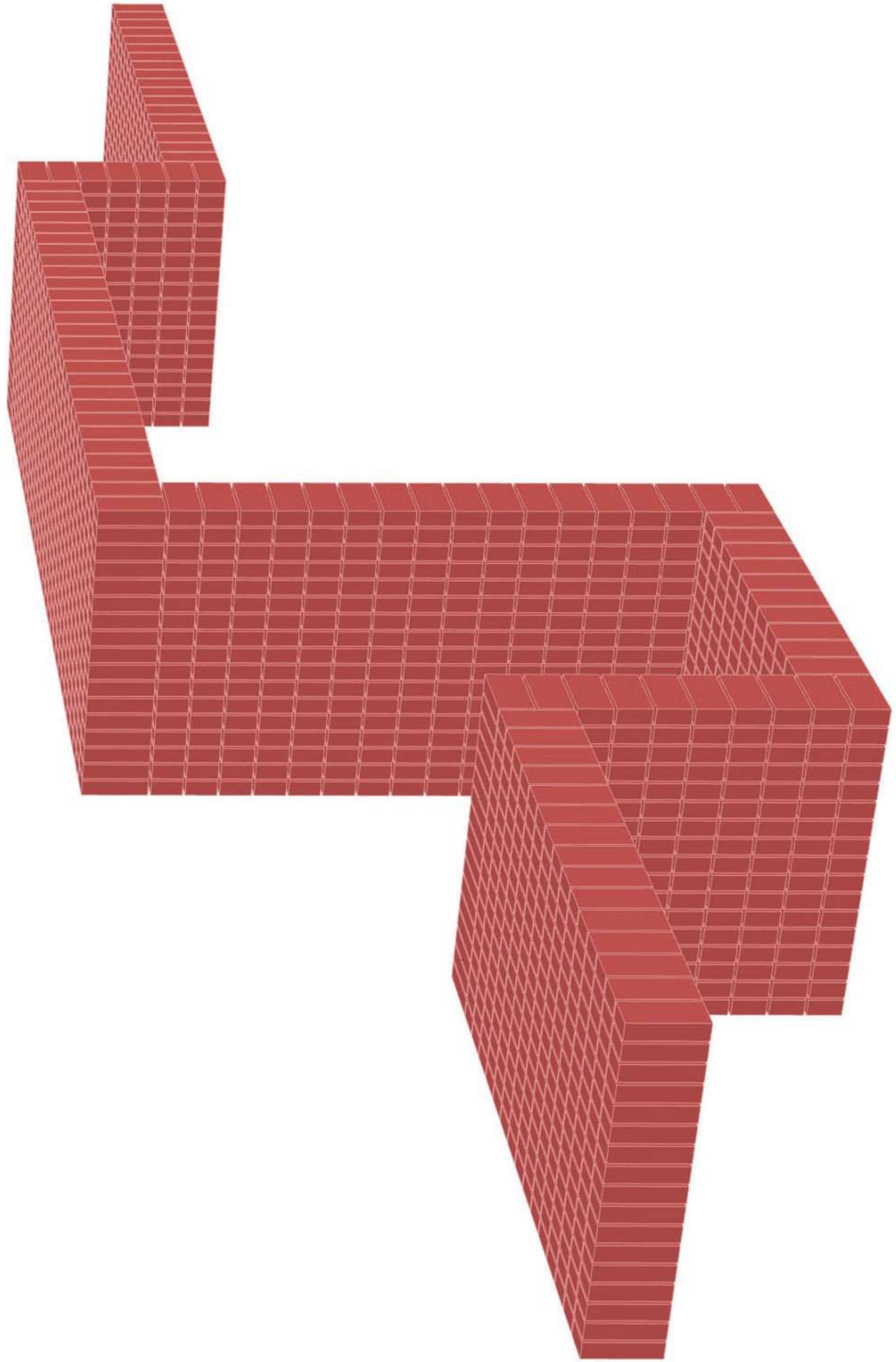
The conclusion highlights the key advantages of these developed tools.

The *Digital Brick Tool - Block* is ideal for quickly creating wall bonds, allowing for experimentation with various structural configurations using just a wall surface as input. Its major advantage is the ease of modifying and experimenting with different bond patterns due to the interlinked elements. This flexibility makes it particularly useful for rapid prototyping and testing different design options. However, it has limitations, particularly when different brick bonds intersect, as modeling complex junctions or seamless interlocking can be challenging. These challenges can hinder the ability to create intricate or highly customized masonry designs, especially when precise control over intersections is required.

The script of the *Digital Brick Tool - Line* accurately processes user-defined inputs to ensure precise brick positioning according to specified requirements. Its ability to handle complex intersections between different bonds efficiently and precisely is a significant advantage.

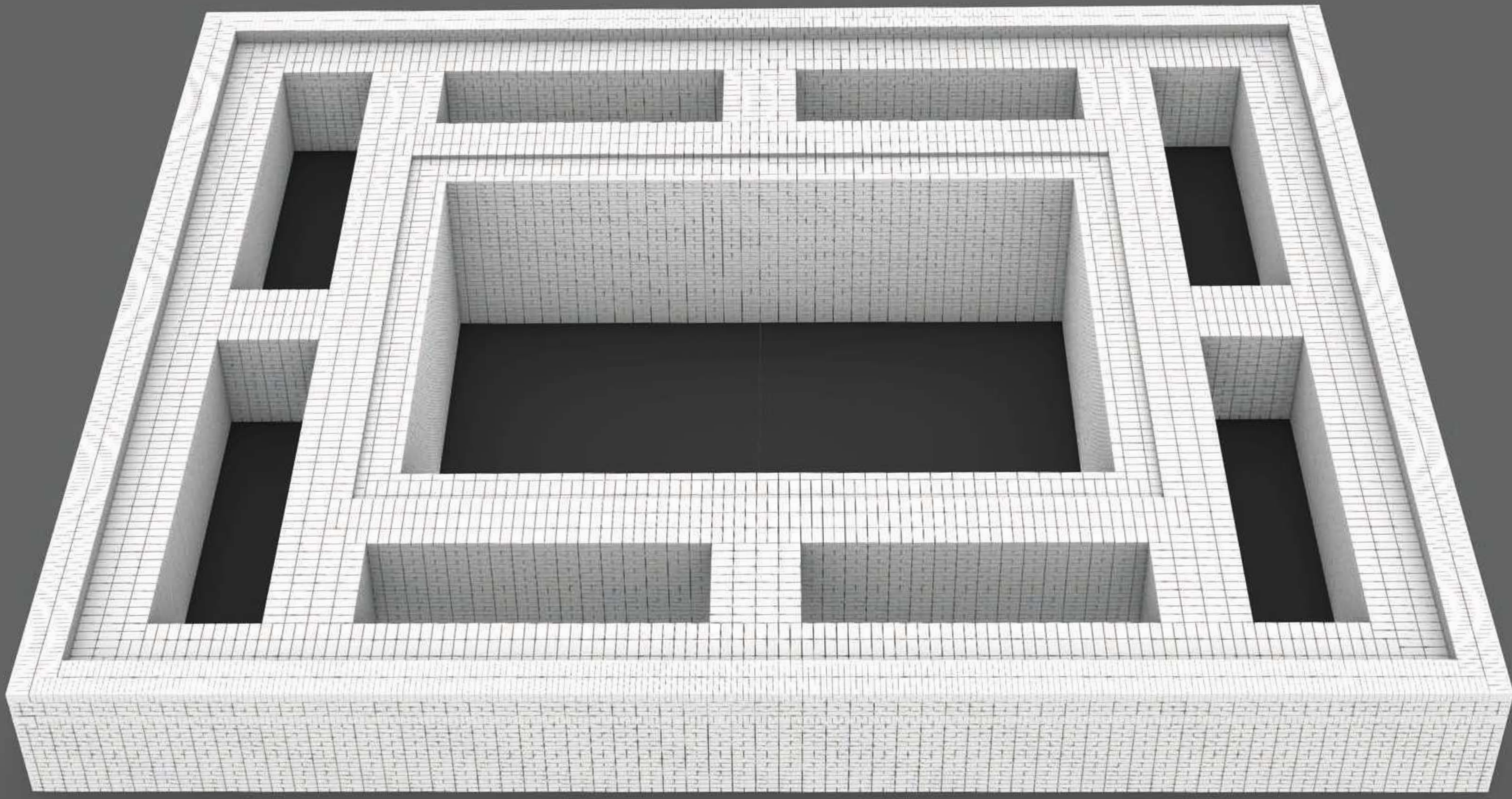
The tool's flexibility in replicating intersections and assigning multiple curves enhances its versatility, making it an invaluable asset for modeling masonry structures in *Rhino* and Grasshopper. While offering parametric control over brick dimensions, mortar thickness, and layout, the manual setup for large-scale projects or complex arrangements can be time-consuming and may require significant spatial visualization, limiting its efficiency in some cases.
Moreover, all the paths need to be drawn manually, and if the curves are not grouped in *Rhino*, it can be challenging to maintain an overview, especially in large projects.

The advantage of the *Digital Brick Tool - Block* lies in its quick creation process, while the *Digital Brick Tool - Line* excels in accurately modeling brick interlocks. Ideally, a fusion of both tools would combine the strengths of rapid wall bond creation with precise interlocking features. This combined approach would provide an even more powerful solution for modeling masonry structures.



8

CONCLUSION



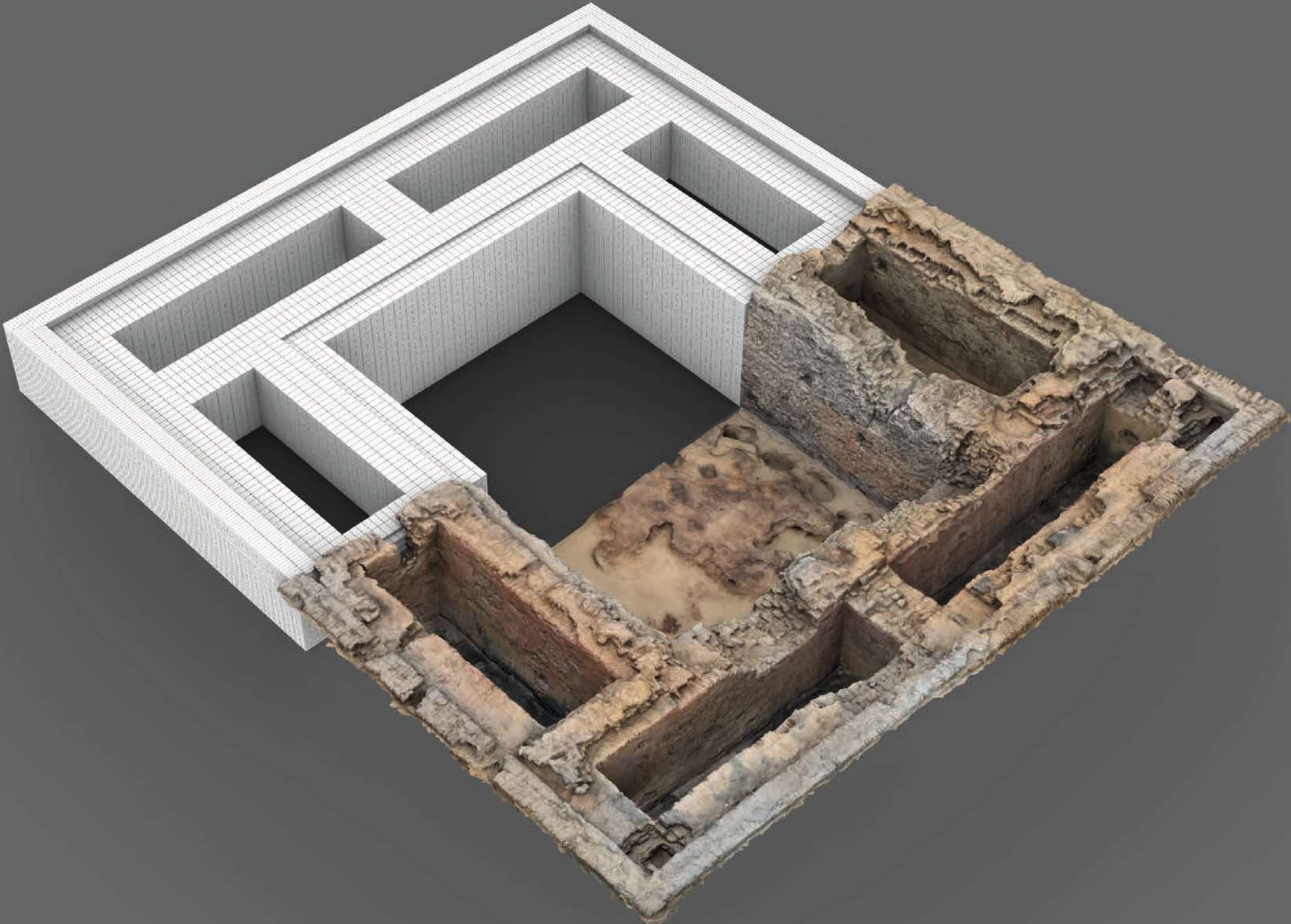
8.1 Results

This study provides detailed insights into the construction techniques employed in the tomb of Queen Meret Neith, with a particular focus on the mudbrick architecture of ancient Egypt.

The analysis of bond patterns, brick dimensions, and wall structures contributes to a comprehensive understanding of the construction methods used in the tomb. The consistent application of stretcher, header, and rowlock bonds in both the exterior and interior walls, with a reduction in depth of the interior walls by one brick length, suggests a systematic approach to construction. The calculations of the average brick dimensions and the composition of 80% mudbrick and 20% mortar provide valuable data on the materials and construction practices. These findings indicate consistency in the production of building materials and define the quality of craftsmanship. Additionally, the estimated total number of remaining mudbricks, approximately 150 000, reflects the scale of the construction project.

The corner joints, however, remain unclear, with partial evidence of interlocking patterns visible in some sections of the tomb, warranting further investigation. The ambiguity surrounding the intermediate walls (IMW) corner connections requires additional study to fully understand the structural integrity and construction techniques at these points.

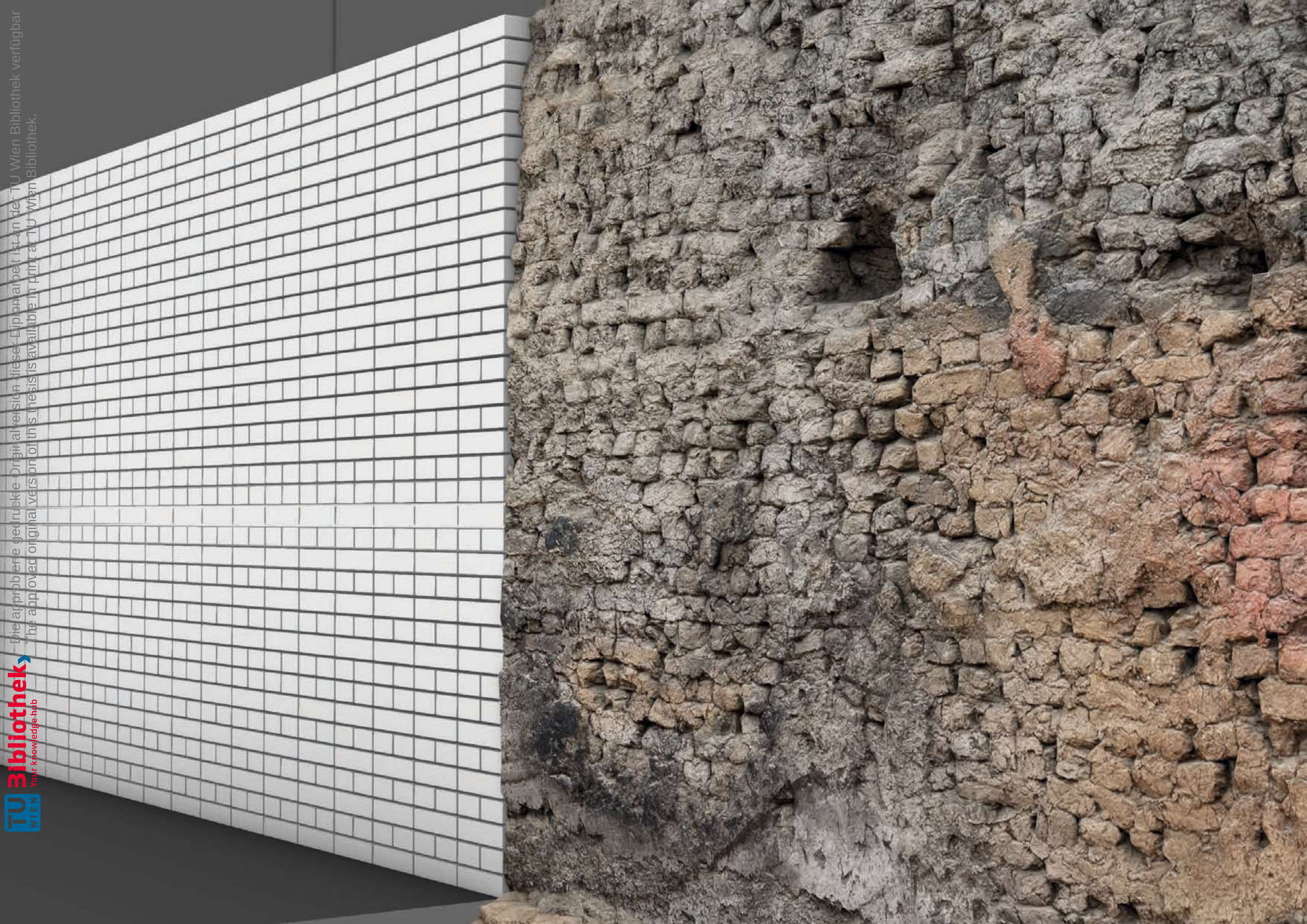
Photogrammetry played a key role in documenting and analyzing the tomb's structure. The 3D model generated through photogrammetry enabled precise measurements of the brick dimensions, wall layouts, and architectural features, facilitating a thorough examination of the construction methods. Additionally, it was crucial to be able to manipulate and process this data effectively. Familiarity with digital tools and software was essential in making detailed cuts, section views, and further modifications to the model. This capability allowed for a deeper analysis and provided greater flexibility in presenting and interpreting the findings.



The ability to work with these digital tools ensured that the model could be adapted for various analytical purposes and facilitated a more accurate understanding of the tomb's structure. The ability to visualize the tomb from multiple perspectives allowed for the verification of findings and the identification of subtle details, such as the interlocking patterns and variations in wall thickness. Photogrammetry not only enhanced the accuracy of the analysis but also contributed to the preservation of the site, ensuring the long-term accessibility of the data for future research.

To complement the photogrammetry-based analysis, the Digital Tool Brick Block and Digital Tool Brick Line were developed to systematically model brick constructions. These tools provide a methodical approach to virtually reconstructing mudbrick structures, offering valuable insights into the construction processes and techniques. By using these tools, a deeper understanding of the building methods is achieved, allowing researchers to simulate various configurations and evaluate their feasibility.

In conclusion, this thesis demonstrates the value of integrating traditional architectural research with modern digital tools in the study of ancient Egyptian architecture. The findings provide a detailed understanding of the construction techniques used in the tomb, and the use of photogrammetry ensures the preservation and continued accessibility of this information. This work establishes a framework for future research, illustrating the potential of digital methods in the preservation, analysis, and dissemination of cultural heritage.

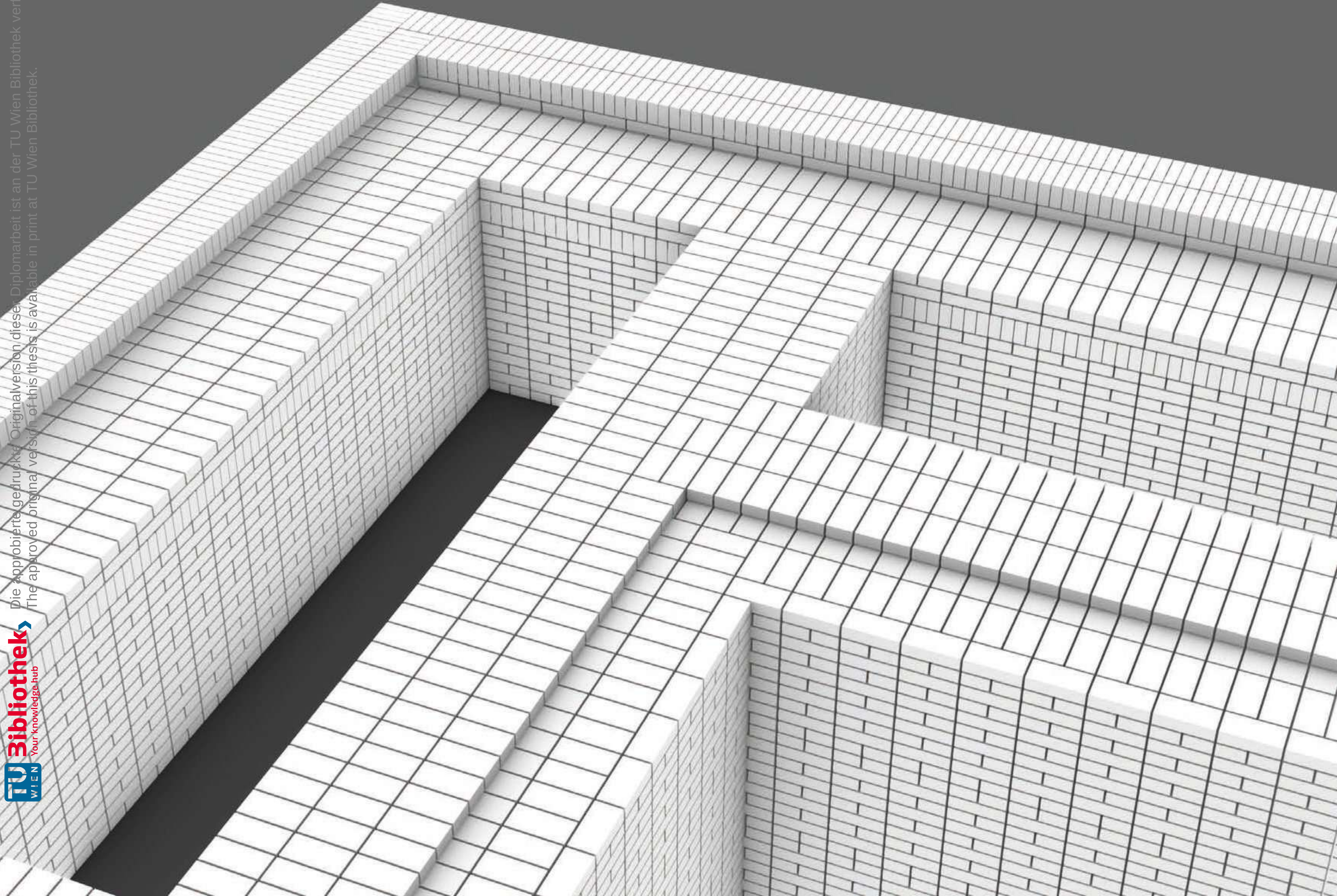


8.2 Summary of Findings

The developed tools are not limited to this specific project but can be applied to other tombs to systematically reconstruct and analyze their construction. The primary advantage of such developments lies in their ability to simulate numerous variations systematically. Through this modeling process, valuable insights into construction methods are gained, as the act of virtually recreating the structure helps to identify practical solutions and evaluate potential methods. This hands-on digital replication enhances the understanding of the structure, including which techniques are feasible and which are not, leading to conclusions about the construction and structural organization of the original building. Furthermore, these tools provide a straightforward way to simulate brick bonds and generate visual representations of the original structure.

The analysis identified consistent parameters and recurring patterns that were systematically defined. These findings were only possible through an in-depth building-historical analysis, which uncovered regularities within damaged or incomplete sections. This approach offers significant advantages for restoration, as digital tools can simulate various models and incorporate proposed modifications into structured plans. In cases such as ancient tombs in Egypt, where the original structure is often reburied for protection, photogrammetry becomes a vital tool. It not only preserves an accurate, scalable digital representation but also provides researchers with a resource for detailed architectural analysis. The 3D models generated through photogrammetry offer features unavailable in physical reality, such as cross-sections and other precise views, which are essential for gaining in-depth insights into construction techniques.

The building-historical analysis posed significant challenges, particularly in reconstructing the sequence of construction phases. The material, predominantly mudbrick, made it difficult to visually



differentiate between construction stages, as many layers were covered with mud or obscured. Additionally, the tomb's location in the desert introduced environmental challenges for photogrammetry. Direct sunlight and heat caused equipment to overheat frequently, necessitating constant cooling and shadowing of photographed areas. The presence of sand further complicated the process, as it altered the surroundings and made image stitching in the software more difficult.

The primary goal of this research was to deepen the understanding of ancient mudbrick construction techniques. Digital tools played a central role, as manual reconstruction of the tomb would have been excessively time-consuming. The tools enabled the efficient creation of multiple variants, effectively serving as analytical tools for testing hypotheses. A key motivation for participating in this project was contributing to the preservation and accessibility of cultural heritage. Understanding ancient construction methods was also a scientific goal, achieved primarily through the application of photogrammetry to create accurate digital models. These models, coupled with virtual reconstruction, provided unique opportunities for analysis, especially given the limited accessibility of the site and the fragile condition of the tomb.

The development of these digital tools addressed a critical need for flexibility and scalability in modeling a structure composed of approximately 150 000 bricks. While the Digital Tool Brick Block is ideal for generating extensive masonry bonds and walls, it struggles with complex intersections and corner situations. Conversely, the Digital Tool Brick Line excels at modeling precise intersections but requires individual lines for each course. The next logical step would be to combine these two tools into a unified system, leveraging the strengths of both to create a more versatile and efficient solution.

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10

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All final content, including its interpretation, adaptation, and programming outcomes, remains entirely my responsibility.

10.2 List of Figures

LIST OF FIGURES

All figures without a specified source have been created by the author.