The Leatherworkers of Oil Street: From a 3D(-GIS) perspective

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MA thesis and graduation project under supervision of Richard Jansen and Milco Wansleeben with support from Victor Klinkenberg.

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Preface

Before you lies the academic paper concluding my MA studies in Applied Archaeology at the faculty of archaeology at Leiden University. This document concerns an academic paper as academic elaboration of the research I conducted. During the academic year of 2022-2023 I conducted research on the potential for 3D-GIS within an urban an commercial archaeological context. For this, I created a 3D-GIS model of the site Grave-Oliestraat to subsequently execute a volumetric analysis on.

This thesis concludes two years of studying at MA Applied Archaeology at Leiden University which followed after five years BSc Archaeology at Saxion University of Applied Sciences. The transition from a vocational education to the academic has not been easy for me. This became especially clear during the thesis process, in which I struggled with designing a proper research around my ideas and ambitions. Nevertheless, the resulting products and personal development is something I look at with satisfaction.

I would like to thank my supervisors Richard Jansen and Milco Wansleeben for their guidance and keeping me on track. In particular I would like to thank Victor Klinkenberg for his help with 3D-GIS. His expertise and down-to-earth view on the subject were of enormous help. Johan van Kampen of VUhbs Archeologie provided me with the dataset of the site, which he knows is special to me on a personal level. I would like to thank my friends and family, in particular my parents for their continuous support. Finally I would like to thank my girlfriend, Fleur Meulmeester, who has been exceptionally patient with me during all this.

Luc

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1. Introduction

This chapter aims to set a clear and consistent basis for this thesis. The reader will be informed on a brief background an motivation for the graduation project before the research questions are presented.

1.1. Background

Over the past decades, the use of digital (3D) applications for both analysis and visualization within archaeology has increased, made possible by advances of soft- and hardware available to archaeologists (e.g. Lanjouw, 2016; Dell'Unto & Landeschi, 2022, p. 23). After the first archaeological 3D reconstructions emerged in the 70's, 3D methodology became an integral part of archaeological practice. Additionally, 3D technologies can be used as a gateway into archaeology for the public through means like 3D-models, VR and 3D-printing (Dell'Unto & Landeschi, 2022, pp. 22,33; Huber, 2014). One branch of this development in digital applications within archaeology is 3D-GIS, distinguishing itself from other 3D-methods by connecting 3D spatial data to a database system. This allows for spatial analysis, data analysis and data manipulation; an integral part of both GIS and archaeological practice (Conolly & Lake, 2006, pp. 11-14). Multiple examples of the use of 3D-GIS within archaeology can be found in the literature, going back over a decade (e.g. Gavryushkina, 2021; Klinkenberg, 2014; Maas & Vissers, 2011). It seems that 3D-GIS proves useful in solving research problems and answering research questions by adding a third dimension to spatial data, exhibiting the potential for 3D-GIS within archaeological practice. As of today however, 3D-GIS remains scarcely used in common archaeological practice, especially within (Dutch) contract archaeology.

This thesis will apply 3D-GIS as a research method, using the urban archaeological excavation of Grave-Oliestraat as a case study. Grave-Oliestraat is a large-scale contract excavation, carried out in the spring of 2021. It has taken place in the center of Grave, which is a small historical city on the bank of the river Meuse. Although the archaeological record of this region goes back to the Mesolithic, mainly the population growth in the Late Medieval period led to urbanization and ultimately the emergence of a castle and town in the 13th century. From the 13th century onwards the town Grave knew a rapid growth and showed signs of urbanization such as stone city walls and guilds in the 14th century. In later centuries, the city of grave has been a victim of multiple sieges, caused by its strategic geographical location (Oosterbaan et al., 2018, pp. 27-40 after Lieshout & Vankan, 2012).

During the 2021 excavation in the Oliestraat, the remains of multiple historical cellars, yards, a city wall and channel were found. Surprisingly, traces of older, wooden habitation were also encountered (van Kampen, 2021a, pp. 5-6). Besides this, many physical traces of craft activity were found. The site in particular yielded traces of leather working in the form of horn pits, leather discharge and metal knifes, scattered around the excavated area (van Kampen, 2021a, pp. 7, 14, 20).

This graduation project will assess the possibilities for and limitations of the application of 3D-GIS within Dutch commercial archaeological field. To do so, an analysis on the occurrence of leather working within urban context will be carried out based on a 3D-GIS model of the site. The 3D-GIS model will be constructed using the preexisting 2D archaeological documentation. Based on this, an academic paper will be written. Therefore, the thesis can be regarded as graduation project.

- The product will be 3D-GIS model of the excavation Grave – Oliestraat, based on the existing 2D archaeological documentation. It will be outfitted with a justification document following the London Charter (Denard, 2009) and meta-data following the FAIR-principles (Wilkinson et al., 2016).
- The academic paper will be a scientific reflection on the application of a 3D-GIS model to investigate leather working activity in an urban archaeological context. The paper will be based on insights gained through constructing the model and carrying out analyses.

1.2. Motivation

Archaeology practice and Geographical Information Systems (GIS) are heavily intertwined (e.g. Verhagen, 2018). Most archaeological (contract) excavations rely on GIS to store archaeological data such as features, finds and height values. An integral part of this is the storage of data in a database connected to GIS features (Conolly & Lake, 2006, pp. 11-14). Most 3D-reconstruction methods however, lack such connection to a database system, disallowing for data storage, data processing and by extension (3D) spatial analysis. Additionally, the remains we excavate are inherently three-dimensions and in current practice, this 3D-data is reduced to 2D. For these reasons, 3D-GIS could provide significant insight into archaeological sites, especially when stratigraphy is complex and three-dimensional. In the end, 3D-GIS could pose as a more standardized alternative to 'regular' 2D-GIS in future archaeological practice within certain contexts.

Besides the abundance of archaeological structures, Grave-Oliestraat also hosted an excess of archaeological layers, specifically anthropogenically elevated layers. The abundance of layers proved it difficult to disclose human activity through time and space (personal communication Johan van Kampen, September 2022). An analysis on the (3D) distribution of finds in correspondence with the 3D-reconstructed volume of anthropogenic deposits could give insight on where and when craft activity such as leatherworking has taken place. This can be complementary to regular distribution analysis, as it allows to calculate find density per cubic meter, as opposed to square meter.

Primarily, this research will be aimed at gaining more insight in the occurrence of the craft of tannery and leather working at the site of Grave-Oliestraat, and how the physical remains of this craft disperse within the archaeological record. An emphasis will lie on the application and applicability of 3D-GIS as a research method within an urban and commercial archaeological context.

1.3. Research questions

The graduation project will be on a set of research questions. Each 'phase' of the research will be covered by a question, ensuring a focused approach of the project. This can be divided into three parts. The first part covers the background of 3D-GIS as a concept and the geological and archaeological attributes of the case study. Next, the application of the model is addressed, covering the methodology and direct results of the 3D-model in conjunction with the find distribution. The last part covers the interpretation of the results, attempting to elaborate on the occurrence of leather working and the potentials for 3D-GIS at a larger scope. These parts resolve around a main research question which reads as follows:

How can a 3D-GIS model be constructed from existing archaeological documentation and what insight can this provide in the occurrence of leather working activity within the site?

The following sub-questions have been drafted, divided into three categories; background, application and interpretation.

<u>Background</u>

1) What is 3D-GIS and how has it been applied within a European archaeological context?

2) What is the archaeological and landscape context of the excavation of Grave-Oliestraat?

3) How did leather working take place in urban context in the Late Medieval and Modern period, what archaeological finds are connected to this practice and in what way are these finds represented in the archaeological excavation?

<u>Application</u>

4) How can a 3D-GIS model be constructed from the existing 2D documentation of the excavation Grave-Oliestraat?

5) How are the archaeological artefacts – specifically those related to leather working – distributed in correspondence with the 3D-GIS model?

6) To what extend do the applied excavation methods applied comply with the requisites for a 3D-GIS model?

Interpretation

7) What does the 3D-distribution of artefacts of leather working tell about the leather working in Grave-Oliestraat?

8) What does a 3D-GIS model contribute to the analysis of an urban archaeological site such as Grave-Oliestraat?

2. 3D-GIS

This chapter aims to give an overview of 3D-GIS within archaeology. First, the concept of 3D-GIS is dissected into two parts; GIS and 3D. Both sections are aimed on the use and development within the field of archaeology, but also diverge into a more general approach. Next, the two will be brought back together into a delineation of the issue at hand: 3D-GIS.

2.1. The principles of GIS

It is important for this thesis to properly define the concept of 3D-GIS. In practice and in the literature, no clear consensus seems to exist on what can be defined as 3D-GIS and how to properly refer to it (Leusden & van Gessel 2014, p. 33). The same concept is referred to by a multitude of terms in the literature, ranging from 3D-GIS to volumetric GIS, vector-based 3D modeling or a multifunctional 3D-environment. Additionally, 3D-GIS is often wrongly confused with either 3D-photogrammetry, 2.5D-GIS and 3D-visualisation for public outreach. Either of which take no part in this thesis, although they can exist simultaneously. In order to properly define 3D-GIS and determine how it will be used in this thesis, we dissect what 3D-GIS *is*. A combination of GIS, and 3D.

Geographical Application System (GIS) applications are firmly embedded into archaeological practice. 30 years after its introduction into archaeology, they have become inseparable (e.g. Verhagen 2018, 11). In practice, GIS is a method of displaying, managing and analyzing geographical data digitally, defined by longitude on the x axis and latitude on the y axis. Conelly and Lake (2006, pp. 11-13) specify five basis tasks of a GIS. Data acquisition; the ability to process existing (spatial) data such as archaeological plans or topographic maps. Spatial Data management*;* the ability to change the shape of spatial data by transforming the projection or altering the topology. Database management; the ability to link spatial data with an underlying (non-spatial) database. Spatial data analysis: the ability to execute analytical tools on the data such as distribution analysis or the creation of predictive models. And lastly data visualisation; being able to manipulate and publish the appearance of spatial objects based on the underlying data. In order to be characterized as GIS, 3D-objects will have to abide by these five aspects of spatial data.

2.1.1. Raster data

In practice, spatial GIS data can be expressed in either of two forms: as a raster or as a vector. A raster is a matrix grid, consisting of rows and columns of cells. The size of each cell (resolution), along with the amount of rows and columns, define the spatial extend of the raster (Connely & Lake 2006, p. 27). It's location and scale is defined by the geographical projection onto a map. Each cell has its own value, much like a pixel in an image, which in itself is considered a raster. This value can represent for example height, temperature or color. Examples of raster datasets that are commonly applied in archaeological practice are elevation models (DEMs), orthographic satellite imagery or topographic maps (figure 2.1).

Figure 2.1: Different types of commonly used raster data, projected on the Archaeology Faculty building of Leiden University (van Steenis Building). sources left to right: AHN, PDOK, opentopo. No scale.

Vector data

Vector data can have three forms, called geometrical primitives: point-, line- and polygon data. The size and position of a vector are defined by vertices which have an x and y coordinate. These represent the position of either a point (one vertex), a line (two or more vertices) or the edges of a polygon (three or more vertices). Because vectors have a precise location, they are considered *discrete* objects (Connely & Lake 2006, p. 25). Additionally, because vector objects can be individually identified, they can be supported by attributes from a database table and therefore hold (non-spatial) information. This value is especially useful when considering archaeological excavation plans, in which feature numbers and dating information can be stored. Vector data is commonly used in archaeology to display archaeological features on an excavation plan, or to define the spatial boundaries of archaeological monuments.

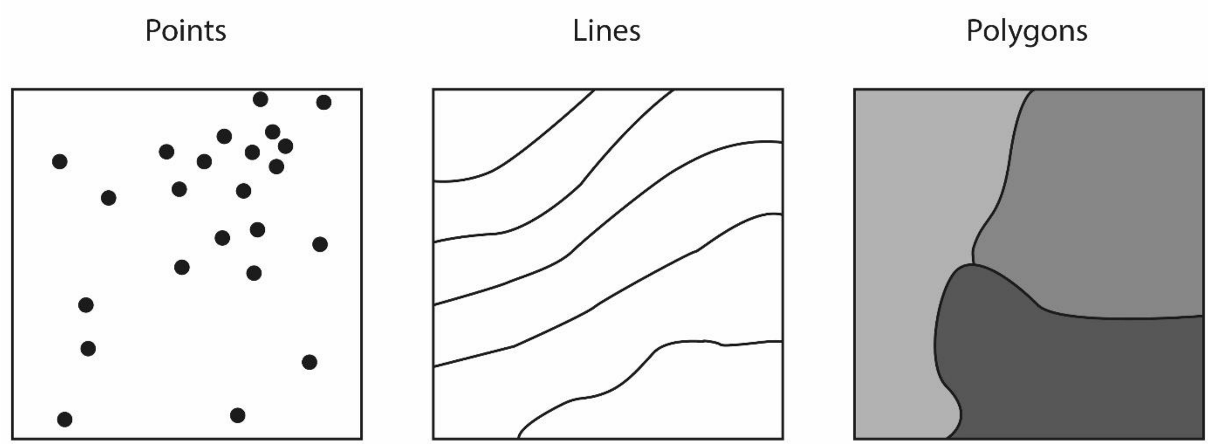

Figure 2.2: Different types of vector data. Redrawn after Connely & Lake 2006, p. 25, figure 2.10.

2.2. 3D applications in archaeology

Developing almost parallel to GIS, 3D applications such as photogrammetry and 3D-scanning are advancing as a research method both in the field and during post-excavation analysis (Lock, 2003). The roots of 3D technology within archaeology can be traced back to the late 1970's to early 1980's, when archaeologist started to experiment and philosophize about its potential and scientific value (Lanjouw, 2016 after Biek, 1978; Angell & Main, 1983; Reilley, 1991). These early examples mainly comprised of digital models of pottery and archeological remains, dubbed Virtual Archaeology (VA) (Lanjouw, 2016, p. 2). Recent advances in soft- and hardware technology, as well as an increase in practitioners, have stimulated the use of 3D methodology in academical archaeology. Likewise, commercial archaeological companies have started to apply photogrammetry as a way of recording archaeological data such as the archaeological level, often including the use of UAV aircrafts.

In archaeology, the most commonly applied 3D-models are *surface, boundary* and *volume* models (Dell'Unto & Landeschi, 2022, p. 19). As the name suggests, *surface* models represent the outside of an object or environment. It consists of a 'sheet' of adjacently connected polygons, determined by points and lines (Lock, 2003, p. 152). The outside of a surface model can be textured. However, a surface model does not contain information about the space 'behind' the surface. Therefore no additional analysis such as calculation of its volume can be carried out. Well-known examples of a surface model are landscape DEM's or photogrammetry models of a trench or find. Unlike *surface* models, *solid* or *boundary* models have an enclosed topologically consistent surface and therefore allow for example analysis on the volume of an object. It can result in a 'watertight' model by connecting the faces of separate 3D-objects. The *multipatch* 3D-features in ArcMap are – although not by definition - an example of *boundary* models, allowing to define the volume of a feature (ESRI, 2021).

Volume representations are somewhat less relevant to this thesis – although the name might suggest differently – but include methods such as CT-scans to gain information. For example, deriving 3D-models of the contents of burial urns.

Some practical examples of 3D methodology applied in archaeology can be given in order to illustrate the method applied in this thesis and to distinguish it from other 3D(-GIS) methods that currently exist. Notably, although these methods can exist together and can in some cases be considered 3D-GIS, they are not the main focus of this thesis. Firstly, 3D reconstruction-based visualizations are a tool often employed as a method of public outreach, similar to what Dell'Unto and Landeschi (2022, pp. 32-33) call '*Game-based visualization platforms'*. 3D reconstruction-based visualizations are manually generated models using 3D modelling software like Blender or Cinema4D, primarily aimed at informing and presenting archaeology to the public publications. By nature, they are an artist's interpretation of available archaeological and historical sources. 3D reconstruction-based visualizations can be presented by 2D image renders, but also in an (interactive) 3D VR environment (Barratt, 2021, pp. 14-16). A second 3D method often applied within archaeology is 3D-reconstruction and documentation by photogrammetry or laser scanning (Lidar). The latter being a more expensive and precise yet comparatively method to the former, which in turn is widely accessible through (open-source) software such as Meshroom and Agisoft Metashape. Photogrammetry allows the user to create a textured 3D surface model by taking a series of overlapping pictures of a subject (Rahaman, 2021, pp. 26-30). Using previously mentioned software, a computer algorithm aligns key points within the frame to reconstruct the relative position of certain elements. Photogrammetry can be applied to achieve a wide range of purposes, ranging from digitizing archaeological artefacts in 3D to archaeological features as a documentation method and landscape survey (Magnani et al., 2020, pp. 740-752).

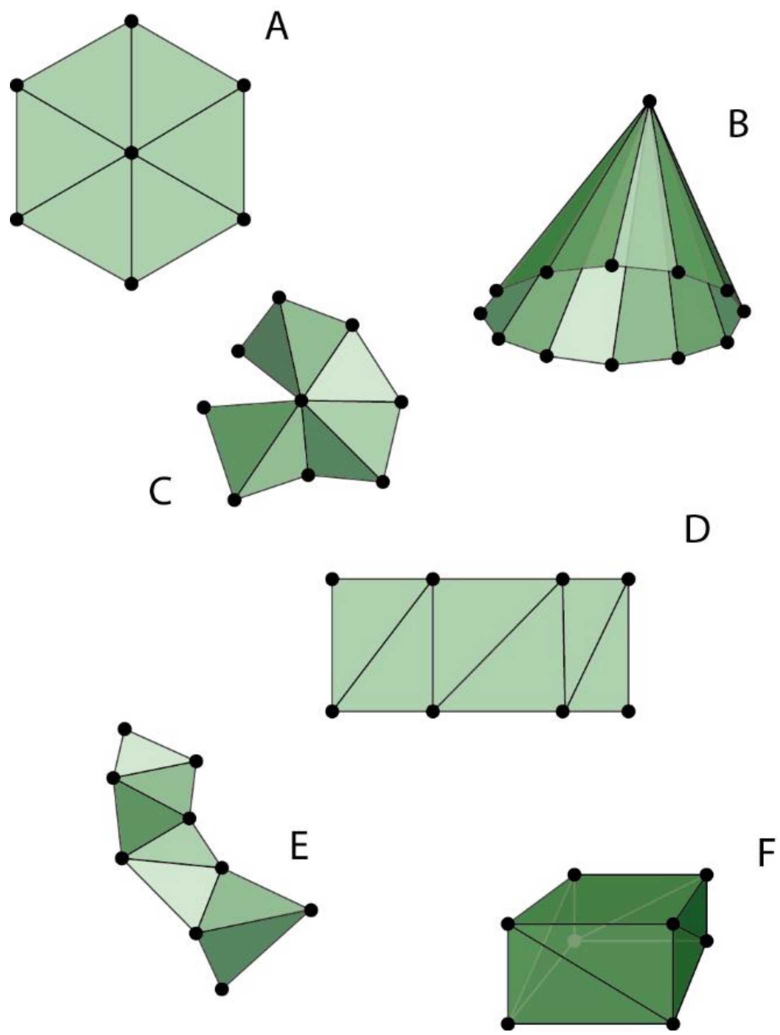

Figure 2.3: Different forms of a multipatch object. Not all multipatch objects are closed objects, only object F is considered a solid *model, as all sides are closed. The bottom of shape B is open and is therefore considered a* surface *model. Redrawn after Esri 2023, figure 1.*

2.3. Defining 3D-GIS

The concept of a GIS consisting of points, lines and polygons that functions in three dimensions has been theorized from the 1990's onwards (Dell'Unto & Landeschi, 2022, p. 29, after multiple authors). With more advanced soft- and hardware available over the last decade, the possibilities for using GIS in a 3D environment have increased. At the 2012 CAA (Computer Applications and Quantitative Methods in Archaeology) conference of The Netherlands and Germany, a discussion took place on the potential of 3D-GIS. As pointed out in the introduction of the proceedings in 2014, it seems that the term 3D-GIS was – and perhaps still is - rather ambiguous in archaeological literature. It was pointed out that there exists a common misconception, mistaking 3D methods which are in reality 2.5D for '*true 3D (volumetric) spatial representation*' (Leusden & Gessel, 2016, pp. 33-34). Unsurprisingly, this misconception is still encountered when approaching the available body of literature on 3D-GIS within archaeology today.

Dell'Unto & Landeschi's (2022) distinguish 3D-GIS from 2.5D GIS based on the (in)ability to display more than one height value (y-coordinate) per geographical 2D location (x-y coordinate. Additionally, in order for a 3D-model to be considered 3D-*GIS*, it has to comply to the principles of GIS (e.g. Klinkenberg, 2016, pp. 40-41), which are presented as five basic tasks in chapter 2.2. From the 3D-models addressed in chapter 2.3, both *surface* and *boundary* models can be considered 3D-GIS, as long as they can hold structured information. This, in the case of the Esri multipatch files, is possible (ESRI, 2021). As Dell'Unto *et al* (2017, pp. 642-643) point out however, volume calculation is required to perform statistical analysis on 3D artifact density per archaeological unit, which this thesis aims to perform. This would only be possible if the 3D shapes dealt with are *solid* rather than *surface* models. For the purpose of this thesis, such a *solid*, 'watertight' model is warranted to research the occurrence of artifacts distributed over the archaeological layers.

In conclusion, the aim of modelling the site of Grave-Oliestraat as a 'watertight' 3D-model from multipatch shapes can best be defined by the term 'volumetric 3D-GIS' using 3D *boundary* models, being one aspect of the more general term 3D-GIS that also encompasses a wider range of 3D models that follow the principles of both 3D and GIS.

2.4. Literature examples

In order to get an idea of the capabilities of 3D-GIS and how it is applied within archaeology, some practical literature examples of (volumetric) 3D-GIS will be presented which have been carried out over the last decade.

Following a MSc thesis at Leiden University, Marina Gavryushkina (2021) published the results of a 3D-GIS analysis on the archaeological stratigraphy at the site Chlorakas-*Palloures* in Cyprus. The aim was to develop a 3D GIS modeling workflow to research the archaeological of the excavation. To do so, three different methods were utilized to reconstruct the stratigraphy in 3D using the methods *extrude between TIN's*, *Minimum Bounding Volume*, and *Digitizing Section Stratigraphy.* The models were based on a combination of GIS data, photogrammetry models and plan/section drawings. Comparing each method of reconstruction, significant differences were noticed amongst volume calculations of archaeological layers per model. Each method showed their own strengths and weaknesses, stressing the importance of the underlying documentation methods (Gavryushkina, 2021, pp. 8, 9-10).

In the context of a research into the Syrian site of Tell Sabi Abyad, Klinkenberg (2016) gives four examples of 3D-GIS being applied as a research method. One example addresses a calculation of pottery density in weight per cubic meter of archaeological horizon. The model was constructed based on an extrusion of TIN surfaces in correspondence with the slope and elevation of the horizon. Through this, an increase in pottery deposits was established, which seemed to correspond to a gradual decrease of stone vessels. Other examples include a distribution analysis on neolithic burials, and cuneiform tablets. Klinkenberg states about one of his models that, although it is not an exact reconstruction, it helps to answer specific research questions about the archaeological site as a schematically rendered representation (Klinkenberg, 2016, p. 46).

Maas and Vissers (2011) address a case study of the Rokin, a filled river branch within the historical urban center of Amsterdam in the Netherlands. In order to research the distribution of a specific artifact group - in this case ceramic syrup jars and jugs - 2D-distribution maps were made in a GIS. However, in order to more accurately calculate find densities, a volumetric 3D-model was constructed by interpolating archaeological layers between 2D profile drawings. The model proved to be applicable to solve multiple research problems such as interpolation, data exploration and spatial statistics, as well as showing potential for visualizing archaeological contexts which they stress are inherently three-dimensional (Maas & Vissers, 2011, pp. 73-74, 76).

3. Grave-Oliestraat and leather working

This chapter aims to present an introduction to the historical city of Grave and the characteristics of historical leather working as background for the eventual analysis. To do so, first the geography and, history of the city Grave will be will be addressed. Then, methodology and preliminary results of the excavation Grave-Oliestraat will be discussed after which a brief literature study on leatherworking will be presented.

3.1. The city of Grave

3.1.1. Geological and historical background

The site *Oliestraat* is located on the historical city of Grave, a historical town on the edge of the river Meuse. The Dutch River area is predominately covered by Holocene and Late-Pleistocene fluvial deposits (Berendsen, 2005, p. 95). These deposits are characterized by sandy riverbelt deposits and clay and peat from basin areas (Berendsen, 2005, p. 96). Another excavation in the center of Grave showed the occurrence of sandy Pleistocene deposits up to 4.3m +NAP, covered by a 2m thick deposit of (sandy) clay basin deposits and peat. From 6.40m +NAP silty clay and sandy riverbank deposits occurred, which are covered by a stack of anthropogenic soil deposits (Hebinck, 2018, pp. 52-54).

The earliest known archaeological remains found in the vicinity of Grave are hunter-gatherers flint sites, dating from the Mesolithic area. From later prehistoric times, bronze and copper objects indicate the appearance of small settlements on riverbanks and old stream belts during the Bronze Age. In Roman times, Grave and surrounding towns Gassel and Escharen are known to have settlements dating from this period, continuing throughout the Early Middle Ages along with the emergence of several parishes and the Lords of Cuijk, the local lieges. In Late Medieval times, the Lord of Cuijk built a castle in what is now the historical center of Grave. This also gave rise to a walled in settlement in the following ages, including the emergence of a church, guesthouse and beguinage, as well as a multitude of defensive works (Oosterbaan, 2018, pp. 27-32). The following ages Grave developed as a city with the emergence of guilds – among which a shoemakers guild – and expansion of the living quarters within the city. During the eighty years' war Grave was heavily besieged, leading to a complex collection of defensive works surrounding the city, extensively documented on historical maps (Oosterbaan, 2018, pp. 33-42), see also Figure 3.1.

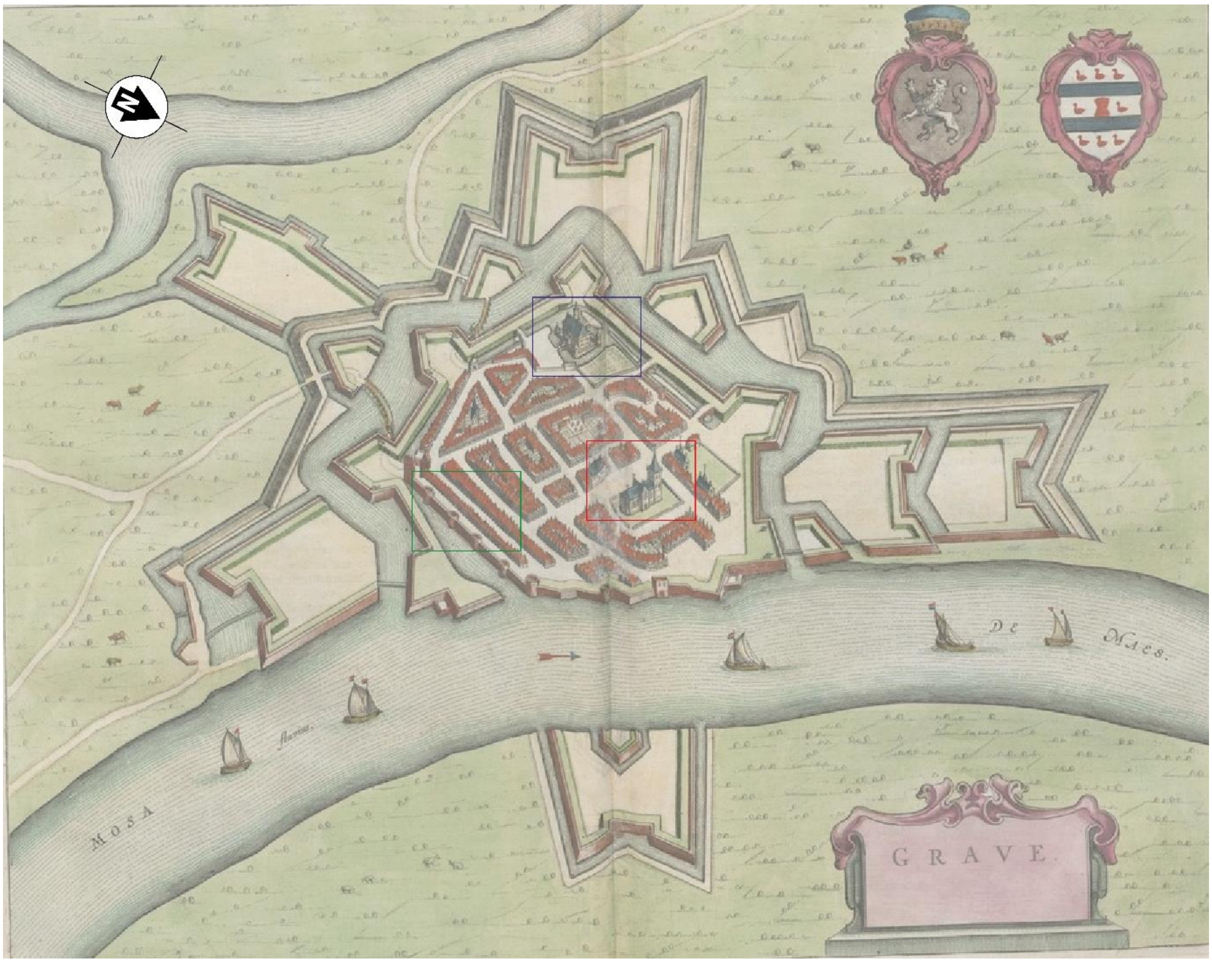

Figure 3.1: Historical (perspective) map of the city of Grave in the seventeenth century as seen from the northeast looking southwest. (Blau, 1649, p. 427). The castle of Grave is visible (blue), as well as the church (red) and the approximate location of the site (green). No scale.

3.2. The site Grave-Oliestraat

In 2021, archaeology company *VUhbs Archeologie* executed an archaeological excavation on the edge of the historical center of the city Grave. As part of redevelopment works, previously existing buildings were demolished and new buildings were to be erected, which would cause significant damage to the underlying soil and therefore the archaeological record (Wesdorp, 2018, p. 5). Research had to be carried out under the regulations determined by the Valletta treaty (Council of Europe, 1992), stiving for *in-situ* preservation whenever possible, or alternatively *ex-situ* preservation of archaeological records. *Ex-situ* preservation was chosen by means of an archaeological excavation, following a short trial trenching campaign (van Kampen, 2021b, p. 4). The excavation was carried out under the guidelines drafted in the KNA 4.1 (SIKB, 2018) - the Dutch archaeological protocols – and regulations drafted in the program of demands (van Kampen, 2021b). Initially, three archaeological levels were foreseen yielding historical brick foundations and archaeological layers, starting at 1m below ground level. Each archaeological plan was levelled by GPS or RTS in a grid of at most 5m spacing (Wesdorp, 2018, pp. 11-13).

All ground features were measured digitally by GPS or RTS, before sectioning and documenting by drawing and picture. All finds were collected per layer of each feature and measured by GPS at the feature. Special finds such as metal which were measured in at the specific find location whenever possible. Brick walls were cleaned manually, measured digitally by of GPS or RTS, recorded with pictures and described by their brickwork bond, brick size, mortal type, and a 5- or 10 layer measurement. After documentation, brickwork was removed in order to investigate the underlying remains. Large profile sections, predominantly of anthropogenically deposited soils, were recorded by drawing and picture, along with a height measurement by GPS or RTS. (van Kampen, 2021b, pp. 7-10). The narrow size of the research area, along with other limitations such as preexisting construction piles and retrieved ground management influenced the excavation strategy. Only specific portions of the excavation area were possible to be deepened at once, resulting in a patchwork of small, adjacently research archaeological levels (van Kampen, 2021a, p. 8).

The original expectation for the plots in the Oliestraat was to uncover the cellars of 17th century buildings that had been demolished only 50 years previously. These buildings were thought to have been erected on top of the then filled-in canal. However, as drafted in the preliminary results of the excavation, this assumption was refuted (van Kampen, 2021a) based on the excavation results. It turned out that the old canal was situated some 20 meters westwards, meaning underneath the at least 16th century brickwork, traces of older stone but also wooden structures were uncovered, dating up to around 1250 AD. In addition, clear indications of craft activities were found, specifically that of leatherworking. This is based on an overrepresentation of horn pits amongst the animal remains, alongside an abundance of leather strips and metal blades (van Kampen, 2021a, pp. 5-9). Most archaeological finds, including that of leather discharge, are collected from the abundance of anthropogenically deposited soil layers that have accumulated over the centuries. These anthropogenic deposits will play a large role in the construction of the 3D-GIS model. Other noteworthy findings from the excavation are a large ceramic pot, many cess- and waterwells, including one holding a golden ring with inlay and a wooden lion statue (van Kampen, 2021a, pp. 8-11, 14-15, 18-19, 20-21).

3.3. Leatherworking

3.3.1. The leatherworking process

From the 16th century onwards, the increase in demand for various leather products led to an increase tannery workshops (Demiddele, 2014, p. 14) and a more systematic approach. Tannery workshops were often located on the edges of cities due to their smell emissions, caused by the use of animal excrement in the tannery process and the hides themselves. Ideally, workshops were located close to the water – channel or river – for water supply and to deposit waste (Demiddele, 2014, p. 15). Because of this and the supplies of leather skins, the workshops are expected to be concentrated near the edges of cities. Multiple steps are taken for hides to be processed and worked into the desired leather objects. The specific tanning process will have been subject to change over time and geographic location. Therefore, no definitive method for this specific time period at Grave-Oliestraat will be given. Rather, the literature gives insight in leatherworking in a more general sense and the activities and materials which are included in this process, which will be discussed henceforth.

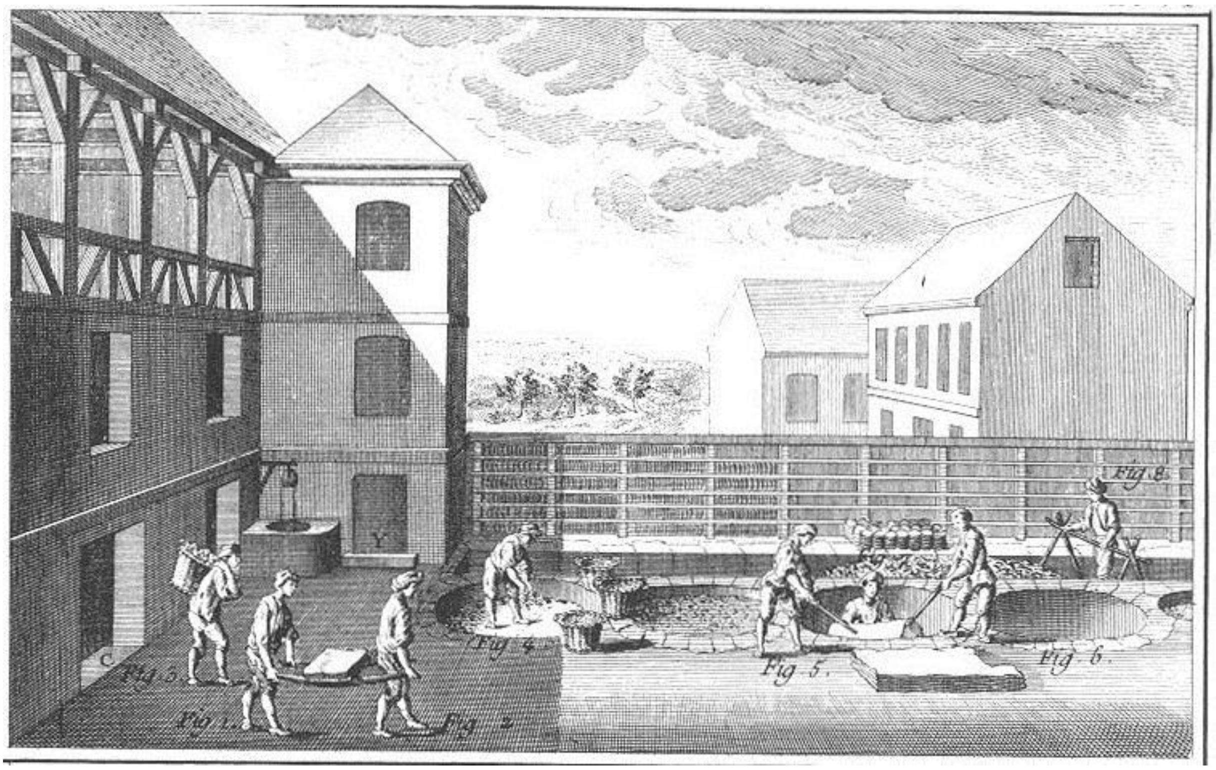

Figure 3.2: Illustration of a tannery workshop. After Dimiddele 2014, p. 61. Original illustration in Diderot/le Rond d'Alembert 1769.

Leather must be tanned because the hides are naturally subject to rot and may be fragile under variable specific temperature conditions (Demiddele, 2014, p. 15). Tanning the hides prevents this. The hides are first prepared by cleaning them, stripped of any remaining flesh and hair. To remove hair the hides were soaked in still water or streams for long periods of time, possibly adding alkaline substances such as chalk to the water (Demiddele, 2014, pp. 14-15, Blonk, 2016, pp. 44-45). Alternatively, wooden or metal tubs were used as container. To remove flesh, a knife was used to scrape the remaining tissue from the hide. Before the tanning, the hides were soaked in urine to obtain a softer and more flexible hide (Blonk, 2016, p. 46). Tanning usually implies transforming raw hides into leather using a substance obtained from naturally accessible plant-based material such as leaves or usually tree bark. These materials contain the chemical called tannin – thus the term *tanning* – which causes a chemical reaction with the hide (Blonk, 2016, pp. 47-48). The hides were soaked in large tubs or pits containing these tannin substances or a combination of water and tannin material and tannin powder. The hides were left for extended periods of time, depending on the thickness and quality of the hide. The process may be repeated multiple times to achieve the desired effect (Demiddele, 2014, pp. 16-18). After the tanning process is done, the hides were left to dry in ventilated spaces deprived of sunlight for multiple days, incidentally smoothing its surface. The hides were then pressed using wooden planks and heavy stones or were hammered using large wooden hammers. The edges of the leather hides may be cut, removing the rough edges, and impregnated using oil or talk. This way, the leather hides were prepared for sale or processing.

3.3.2. Archaeological indicators for leatherworking

In order to analyze leather working for this project, specific artefacts and material groups are to be appointed from the find assemblage of Grave-Oliestraat that could be related to that activity. For this purpose, mostly a thesis by Blonk (2014) is draw upon which, outlines the various artefacts related to preparation, tanning and processing of leather. The inventory made in this thesis has been summarized in **Error! Reference source not found.** for the purpose of the current research. Only material remains are considered for the purpose of this project.

Table 3.1: Different types of archaeological evidence for leatherworking activity. Based on Blonk 2014.

Preparation	Tanning	Processing
Knifes	Horn pits	Leather strips
Tanning block	Tannin	Metal/wooden tools
Tannin	Stones	- liners
Ecological indicators	Metal hooks	- knifes
- Meat	Ecological indicators	- scissors
- Skin	- bark	
- Chalk	- chalk	
- Hair	- branches	
	- insects	

Generally, the archaeological evidence leather tannery and processing workshops leave behind can be attributed to the tools and substances used during the leatherworking process and its discharge. Tools are often metal or wood, such as metal knifes and scissors or wooden elements of the tanning and shoe liners. Additionally, heavy stones may be found used for pressing the hides. Discharge comes in the form of animal bone, mainly being horn pits or *phalanges* – or alternatively leather strips. Generally, it is assumed that hides were delivered to the tanner with the horns and hooves attached to the skin (Zeiler, 2000, p. 7). Additionally, ecological indicators can be found which are either substances used during the tanning and cleaning process such as chalk, bark and urine, or again discharge such as the hair and flesh attached to the skin. These would be expected to be found in archaeobotanical samples. The manner in which these artefacts are found are heavily affected by conservation circumstances but also the degree to which the artefacts may be reused or discarded elsewhere. The wet circumstances present at the excavation of Grave-Oliestraat generally favor the conservation of materials such as bone, wood, metal and leather.

4. The 3D-GIS model

This chapter will be a summary of the methodological choices made during the 3D-GIS modelling of Grave-Oliestraat. A more elaborate report of the modelling strategy has been written as the product part of this thesis and will be provided as an attachment. First the methodology will be discussed, after which the resulting 3D-GIS models will be presented.

4.1. Methodology

The 3D-GIS modelling of the archaeological site Grave-Oliestraat has been a process of trial and error, as the author was initially inexperienced with 3D-GIS software. Therefore, the definitive methodology of the modelling has developed over time. In preparation of the project, a provisional workflow was drafted in collaboration with supervisor Victor Klinkenberg, who is experienced with 3D-GIS modelling (Klinkenberg, 2016). A schematic representation of this initial workflow can be found in Appendix 1 and was included in the project proposal. The provisional workflow served as a basis on which was expanded during the current modelling process to be optimized for the *Oliestraat* case study.

4.1.1. Preparation

The 3D-GIS models for this thesis project have been constructed using *ArcGIS Deskop* software, specifically *Arcscene*, along with the 3D Analyst Toolset. Although alternatives exist such as such as QGIS (QGIS, 2023), BlenderGIS (Blender Addons, 2023) and GrassGIS (GRASS Development Team, 2022), ArcScene was the software of choice for licensing restrictions and the experience of supervisor Victor Klinkenberg. ArcScene allows for data acquisition, management, database management, analysis and visualization, and thereby abides to the five principles of GIS according to Connely and Lake (2006, pp. 11-13), see also paragraph **Error! Reference source not found.**. The 3D-GIS models are based on the original documentation from the excavation of Grave-Oliestraat. Four types of data can be distinguished: GIS data, profile drawings, field pictures and the field database. The GIS data comprised of a collection of MapInfo table files table files, outlined in Table 4.1.

Table 4.1: types of GIS data available in the original dataset.

Original data	Elaboration	Type	Amount
Vlaktekening.tab	Plan drawing	Polygon	7
Coupes.tab	Profiles	Line	1
Vlakhoogte.tab	Height measurement	Point	7
Vondsten.tab	Finds	Point	1
Extra punten.tab	Extra points	Point	1

Henceforth, the documentation sources will be elaborated upon. The original filenames are in Dutch language. *Vlaktekening* represents the archaeological plan drawing, expressed in polygon shapes. Each archaeological level was documented in a separate file. *Coupes* represent the location and direction of the documented profiles, expressed in line shapes. *Vlakhoogte* represent the height of the documented archaeological surface, expressed in point shapes. *Vondsten* represent the find material, expressed by a point shape per context. *Extra punten* represents additional points measured, for example as relative height measurements for profiles or to document the bottom of wall features

.Field pictures were used to determine mutual relationships of specific archaeological features. Profiles drawings were used to determine mutual relationships and heights of (brickwork) features and to compare the modeling output to the documented situation (paragraph 6.1.1). The excavation database contained descriptive information about archaeological features such as feature definitions, color and texture, but also brick sizes and the stratigraphic relationship between features. The database was connected to the *ArcScene* environment using an OLE DB connection, allowing for One-to-Many relationships between the database and GIS data (ESRI, 2019; Silberschatz, Korth, & Sudarshan, 2019, pp. 252-253).

4.1.2. The modelling process

The modelling process can be divided into three steps: (1.) Brickwork modelling, (2.) surface modelling and (3.) layer modelling. Each will be elaborated on henceforth. A schematic representation of each modelling step has been included in appendix 2. Layers are modeled separately from brickwork, because they required a different modelling method that includes constructing surfaces.

1. <u>Brickwork modelling</u> (appendix 2.1)

Brickwork features occur on the upper three levels of the excavation. However, what is considered as ‘brickwork’, is not always evident. Brickwork features are described under different description terms in the database such as floor, wall, wallpiece or foundation. Features considered to be brickwork were recategorized under the label ‘brickwork’. These were then connected to the 3D-GIS environment in order to query brickwork features as a separate file. Next, the top and base height values of the brickwork was determined. Initially, a *Spatial Join* is used to determine the height measurements taken within the boundaries of a wall feature. These represent the top height and are measured on top of the walls during fieldwork. Because not every feature had a height measurement available, some top heights had to be determined manually. Multiple sources could be inquired to determine the height value, which were categorized in order of reliability as follows:

1. <u>Documentation</u>, either a height value or profile drawing.
2. <u>Calculation</u>, add or subtract brick height*number of bricks relative to a known height value.

3. Derivative, use the same height value of a different feature that is similar based on a picture or drawing.
4. Assumption, use a height value assumed to be right in comparison to neighboring/similar features.

A similar method was applied to determine the base height of walls. Base height measurements were available as *extra punt (XP)*, labeled 'OK <*feature number*>'. Because not all walls had a base height measured, the aforementioned system was used to manually determine the values. Through this system, determining the proper spatial values became a process of enquiring a combination of documentation sources, illustrated by Figure 4.1. This also called for a method of quantifying the certainty of the modeled features, which is elaborated on in the justification document. Some wall features had multiple height measurements available, or exhibited a gradient in their top or bottom surface. In these cases, either the highest (for top) or lowest (for base) available height value was attributed to the feature. After each wall segment was attributed a top and base height value, the features were converted to 3D multipatch files using *Feature to 3D by Attribute, Extrude* and *Layer 3D to Feature Class,* generating a *boundary* models for each brickwork feature.

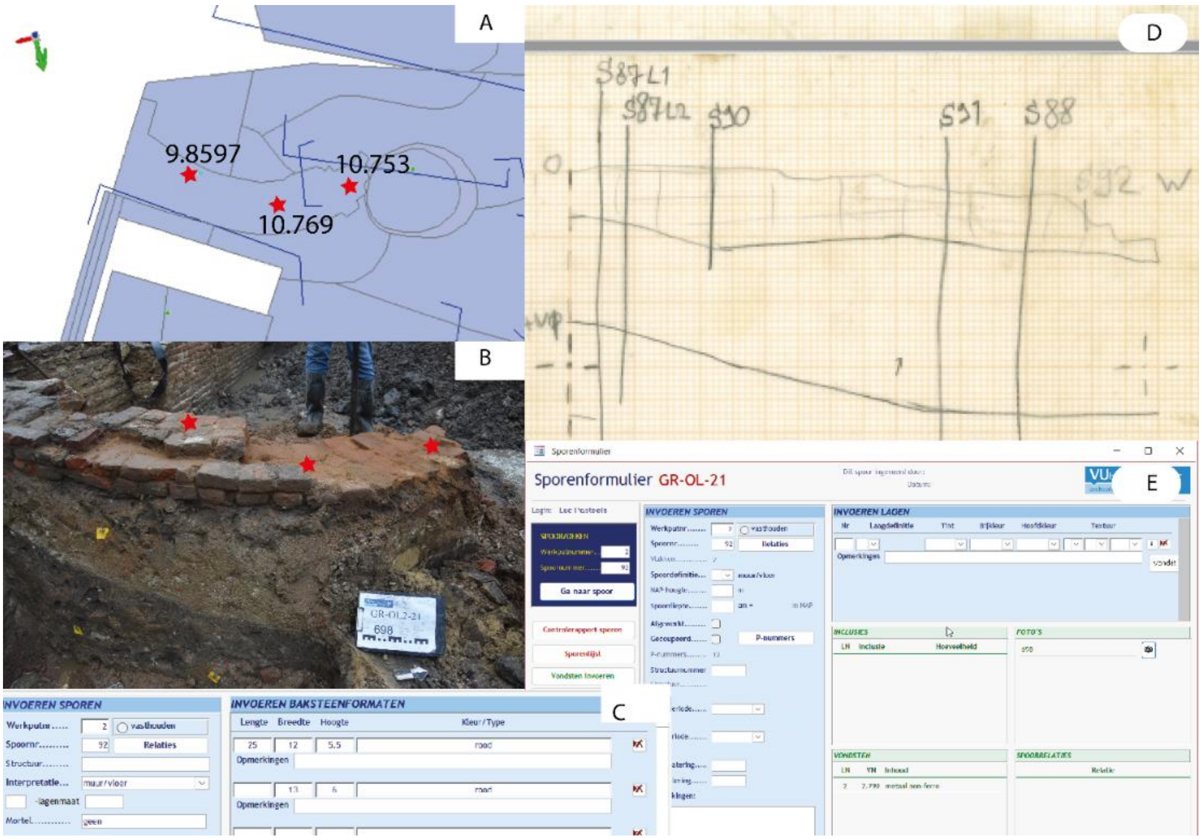

Figure 4.1: Different steps and sources for determining the base and surface heights of a brickwork feature (example S2.092). A: GIS with height values and profiles, B: field picture with approximate locations of height measurements, C: database with brickwork description and brick sizes, D: profile drawing, E: database with feature description, photo- and profile number.

2. Surface modelling (appendix 2.2)

The site of Grave-Oliestraat was excavated on up to seven archaeological levels. Upon modelling, the assumption was that each archaeological level is vertically located on the transition between archaeological deposits. This assumption is based on the field methodology, that a new archaeological level was determined whenever relevant archaeological features started to appear on the surface (van Kampen, 2021b). To model the anthropogenic deposits in between, the surfaces have to be reconstructed as a 3D *surface* model.

Generally, an archaeological site is documented as a continuous plane. In practice however, the site of Grave-Oliestraat was excavated in individual patches of various sizes, due to the inability to store enough soil for excavating larger areas at once. This meant that each archaeological level consists of a collection of patches documented surface (Figure 4.2). For the areas between these patches, no archaeological documentation was available. In order to obtain an archaeological surface model that covers the whole modelling area, an reconstruction was made based on the available height measurements.

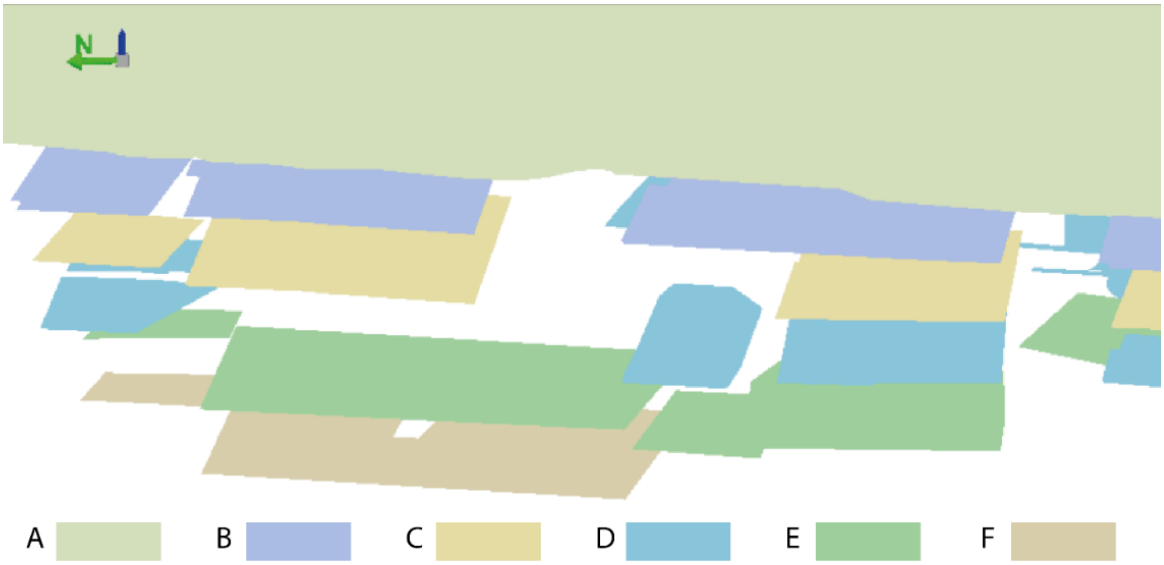

Figure 4.2: Illustration of the different excavated extends among different levels and patches around cellar 6 in 3D view. No scale. A; level 1, B: level 2, C: level 3, D: level 4, E: level 5.

To reconstruct the various archaeological surfaces, TIN interpolation was used. TIN (Triangulated Irregular Network) is an interpolation method that constructs a surface model by repeatedly connecting the three closest points by a triangular plane (Conolly & Lake, 2006, p. 107). The advantage of TIN compared to other methods is that it has a vector structure, meaning it can be used in combination with other vector-based formats (Conolly & Lake, 2006, pp. 29-30) such as multipatch. Height measurements tend to be taken away from edges or corners of patches however, meaning the resulting TIN covers only part of the excavated area. To combat this, measurements were added manually on each corner of the excavated extend, attributed with a height value equal to the closest known height measurement of that archaeological surface. Next, the *Create TIN* tool from the 3D Analyst Toolset was used to generate a TIN for the surface of each archeological level.

Layer modelling (appendix 2.3)

Soil deposits are modeled by extruding the GIS plan drawing between the TIN surfaces. This means that each modeled unit represents the volume between two archaeological surfaces. Although profile drawings are available in which the more complex stratigraphy is documented, the modelling was limited to the above. Counterpart profiles between which the stratigraphy may be interpolated are often lacking. Additionally, although the plan drawings often contain multiple archaeological features such as pits, postholes and ditches, manually digitizing profile drawings is expected to require a long processing time (Gavryushkina, 2021, p. 8) and was therefore abstained from. Profiles often disallow for determining each stratigraphic relationship, let alone to consistently reconstruct it on a large scale. Therefore, the layer modelling – and by extend the volumetric analysis – is limited to reconstructing the volume between the excavated surfaces.

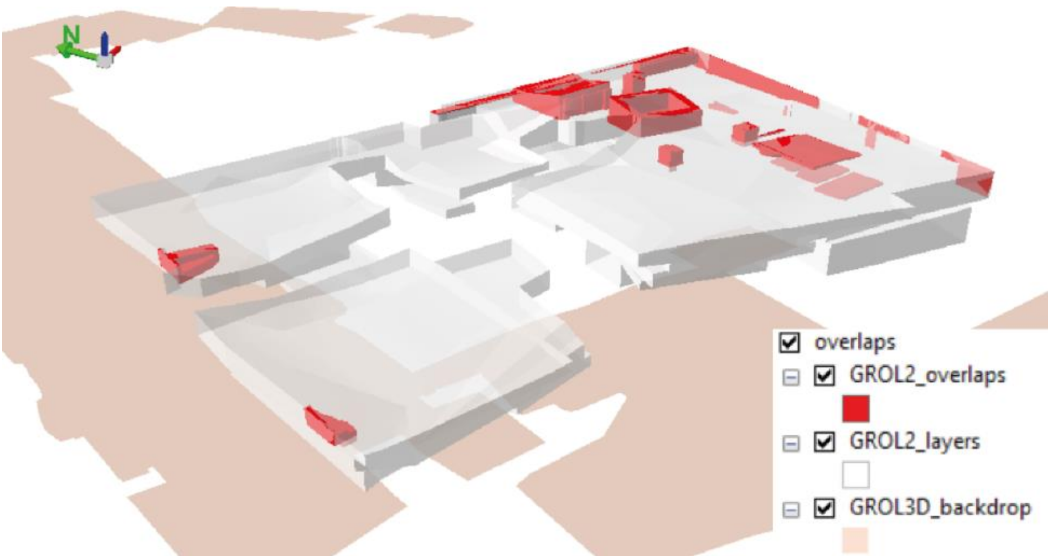

Figure 4.3: Overlapping topologies among the brickwork features and layer units within GROL2. No scale.

Archaeological layer units were modeled as follows. First, the archaeological plan drawings of each level were merged together per excavated patch. where a patch is defined as: *a topographically delineated part of the excavation which was lowered individually during the fieldwork, recognizable by a vertical stack of consecutive plan drawings at that spot.* Next, the merged drawings are extruded between the corresponding archaeological surface TIN's, using *Extrude Between* from the 3D Analyst Tools. Because the resulting layer units often overlap with the previously modeled wall features, the overlapping volumes were removed using the *Difference 3D* tool. This often included first creating a *Minimum Bounding Volume* of each brickwork feature to avoid topological errors.

Volumetric analysis requires 'closed' 3D objects in order to calculate volume properties. Whether or not a 3D Multipatch object is closed can be reviewed using the *Is Closed 3D* tool. Obtaining a closed object by executing functions such as *Difference 3D* proved to be challenging however. Aligned multipatch faces or 'unnatural' subtraction results, often caused the layer models to remain open. Fixing these issues proved challenging and in some cases impossible, in which case the original layer model was used in the analysis, without subtracting brickwork. Each modeled unit is given an identifier. For GROL2 these were attributed based on the archaeological level and patch number the unit was located in. For PLOT6, two layers could be correlated to a preexisting feature number and the other features were given a 9000-number (e.g. 9001, 9002, 9003). Finally, the volume of each layer unit was calculated using *Add Z Information* from the 3D Analyst Tools.

4.1. Modelling results

Originally, the aim of the project was to model all cellars and underlying archaeological deposits that along the street *Oliestraat*. This was assumed to be a realistic amount of modelling, as well as offer significant insight into the 3D distribution of finds related to leather working. However, during the modelling process it became apparent that it was far more time-consuming than expected. Additionally, the cellars and deposits below seemed less relevant to the research question based on the lateral distribution of finds (personal communication Johan van Kampen, 20-3-2023. Therefore the focus shifted to another part of the excavation after modelling the initial PLOT6. This reduced the amount of modelling and focussed on a more relevant part of the site for analysis. The resulting 3D-GIS model consists of two separate parts: PLOT6 and GROL2 respectively located halfway the *Oliestraat* and the southern part of the excavation (Figure 4.4). In the following paragraph, both resulting models will be presented.

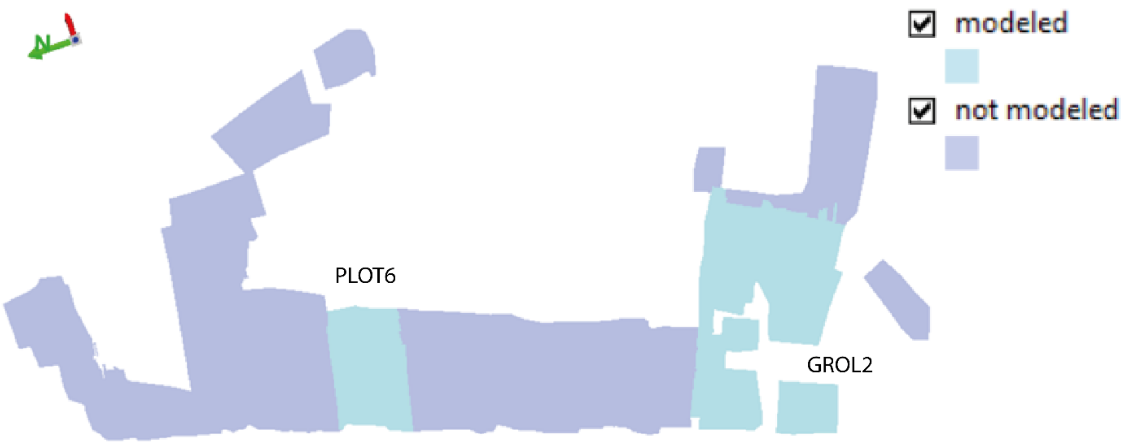

Figure 4.4: Locations of the 3D-GIS models respective to the excavated area.

4.1.1. PLOT6

PLOT6 is one of twelve cellars excavated along the street *Oliestraat* in Grave and is located roughly halfway the street. The name for this model part is derived from the numbers attributed to the plots during excavation. Because PLOT6 was deemed representative for the rest of the site it was initially selected as a sample to test the preliminary workflow. Modelling was expected to take roughly 1-2 weeks but eventually required 10 weeks. The model can be divided into two parts: the cellar and the yard. Both areas are separated by a gap in documentation on lower archaeological levels, which was not excavated.

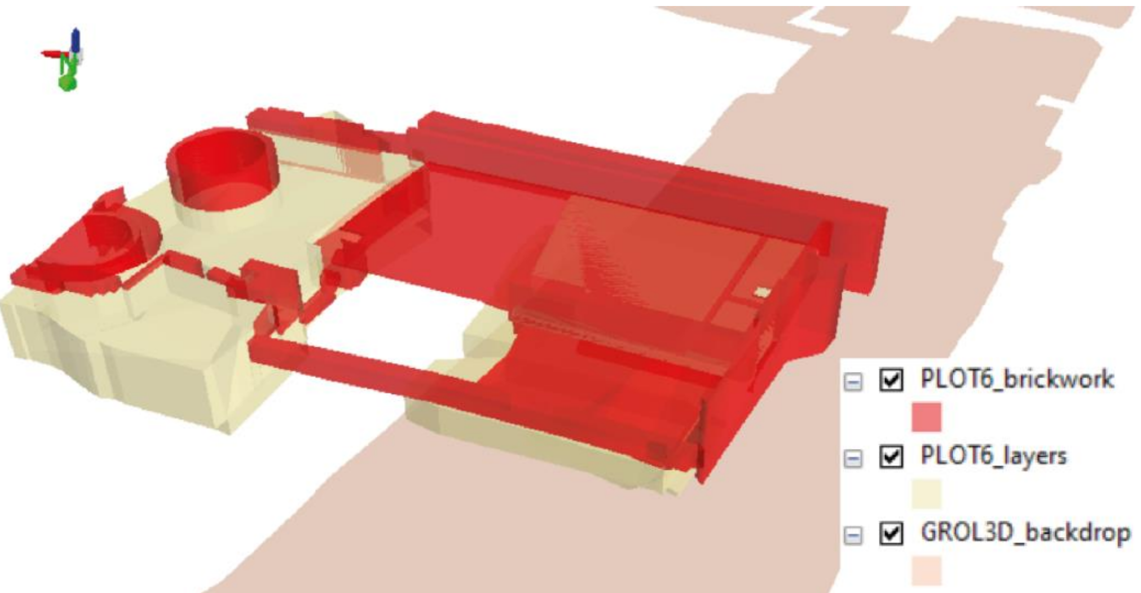

Figure 4.5: Resulting model of PLOT6, No scale..

The <u>cellar</u> part consists of a sequence of three floors, five soil deposits and a large brick pile. The floors are spaced respectively ca. 0.5 and 0.3 m apart. Although no GIS or analog documentation is available for the areas between the floors, intermediate layer units 1350 and 9003 were modeled there based on database descriptions that mention deposits existing between these floor levels. The lower two floor levels are modeled based on a TIN surface, maintaining surface curvature which is assumed to have effect on the surrounding layer volume. Some gaps still exist in the 3D-GIS model of the cellar where no or insufficient archaeological documentation was available. The attribute table of the 3D-GIS model is included in appendix 3.

The <u>yard</u> of PLOT6 consists of two deposit units and a collection of brickwork features. Although documented down to the third archaeological level, no GIS data was available for the second archaeological level and therefore the upper deposit unit represents the excavated volume of both the first and second archaeological level. Brickwork was only present on the first archaeological level and consists of two brickwork cesspits and a collection of 12 relatively small walls.

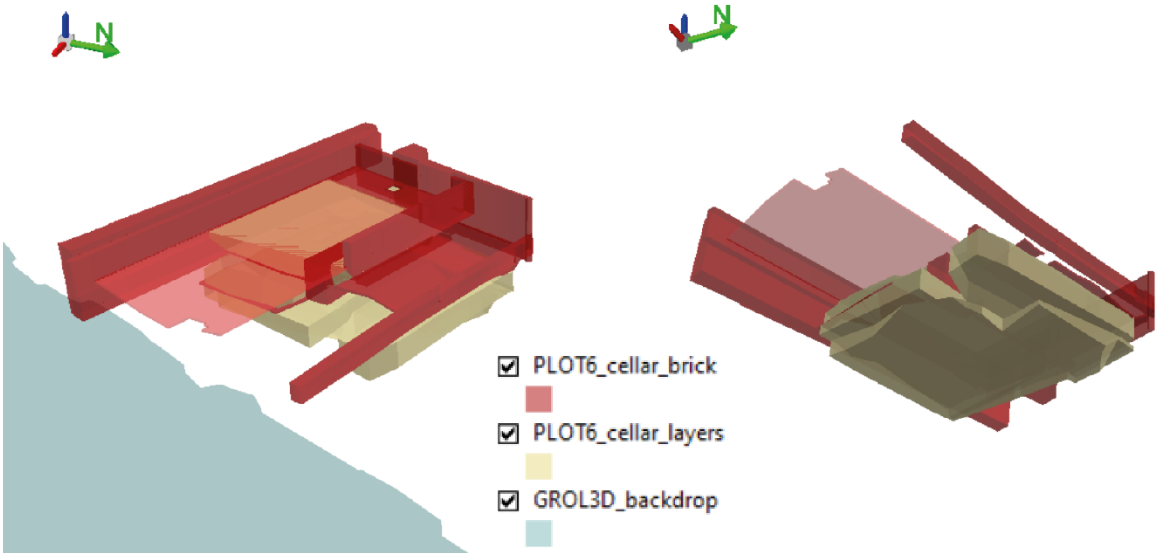

Figure 4.6: 3D-GIS model of cellar part of PLOT6 as seen from different angles. No scale.

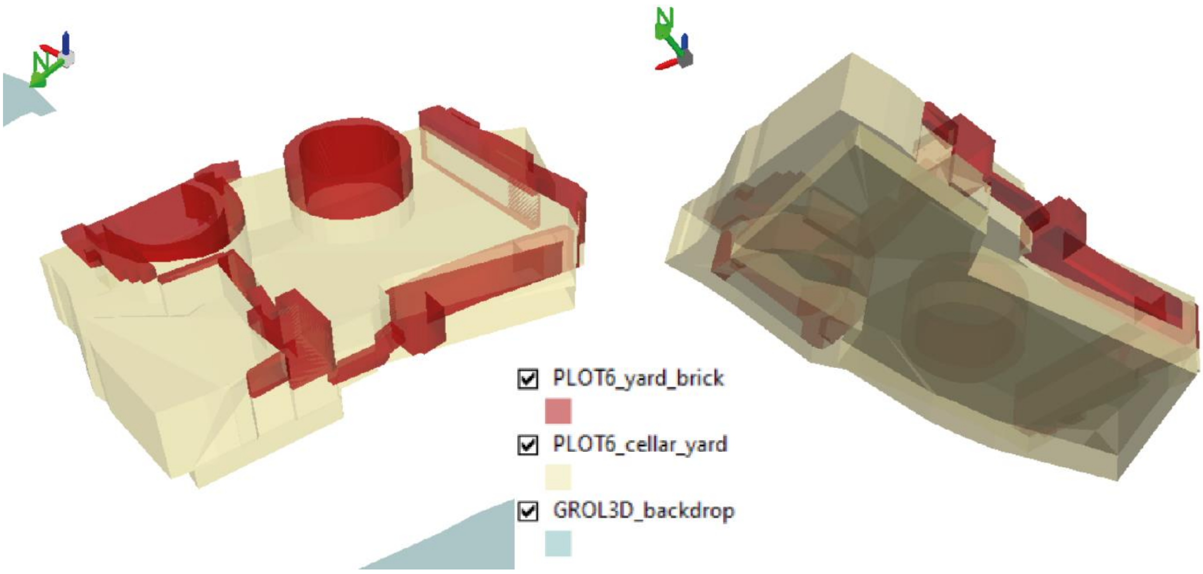

Figure 4.7: 3D-GIS model of the yard part of PLOT6 as seen from different angles.

4.1.2. GROL2

GROL2 represents the southern part of the excavation, which was excavated during a separate campaign. Although the surface area of GROL2 (ca. 250m^2) exceeds that of PLOT6 (ca. 75 m^2), modelling took roughly three weeks. Generally, the also dataset of GROL2 allowed for rather consistent modelling.

The 3D-GIS model of GROL2 consisted of a sequence of archaeological layers encompassed by brickwork walls in the northwest, north and east. The eastern wall is actually the old city wall of Grave. The south is bordered by the edge of the excavation trench. Brickwork occurred on the first three archaeological levels, including walls, cesspits, cellars and floors. In total, 129 brickwork units were modeled. Distributed over nine excavated patches and five archaeological levels, 26 soil deposits were modeled. The attribute table is included in appendix 4 along with their respective volumes. Due to the extent of the GIS documentation, many gaps exist in the model. Therefore a 'watertight' model encompassing the whole excavated area has not be realized. Rather, the model is divided in patches, as described in paragraph 4.1.2. Henceforth, a short elaboration will be given for each individual patch including the surrounding brickwork along with a visualization of the modeled layers, outlining the different patches which will be referred to in the analysis (paragraph 5.2.3).

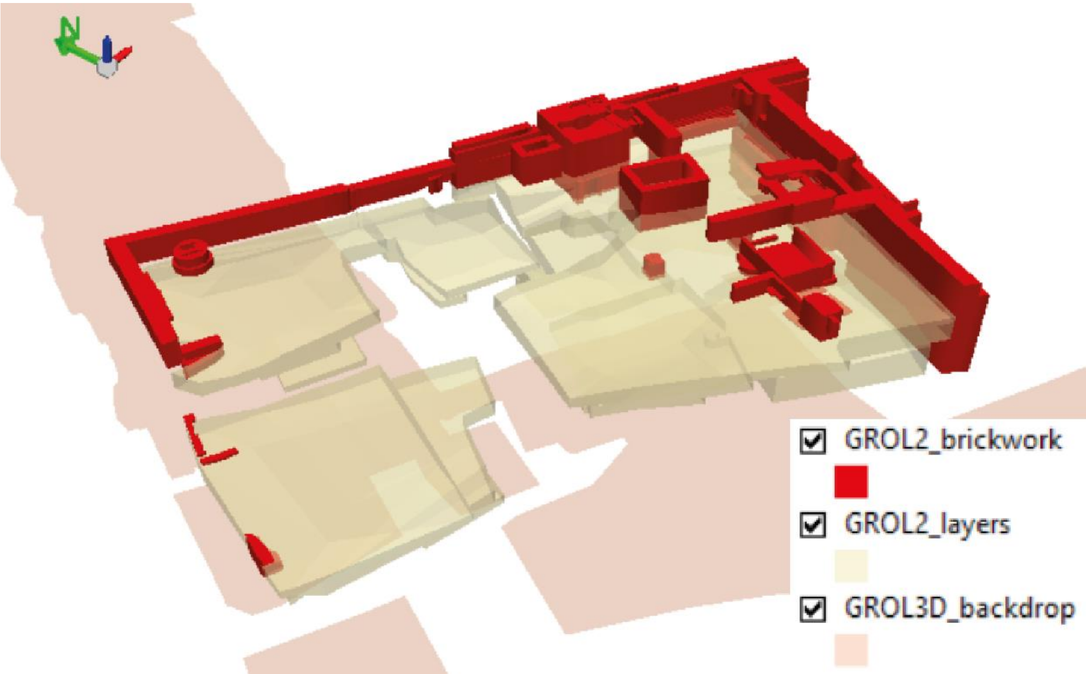

Figure 4.8: Modelling result of the GROL2 model. No scale.

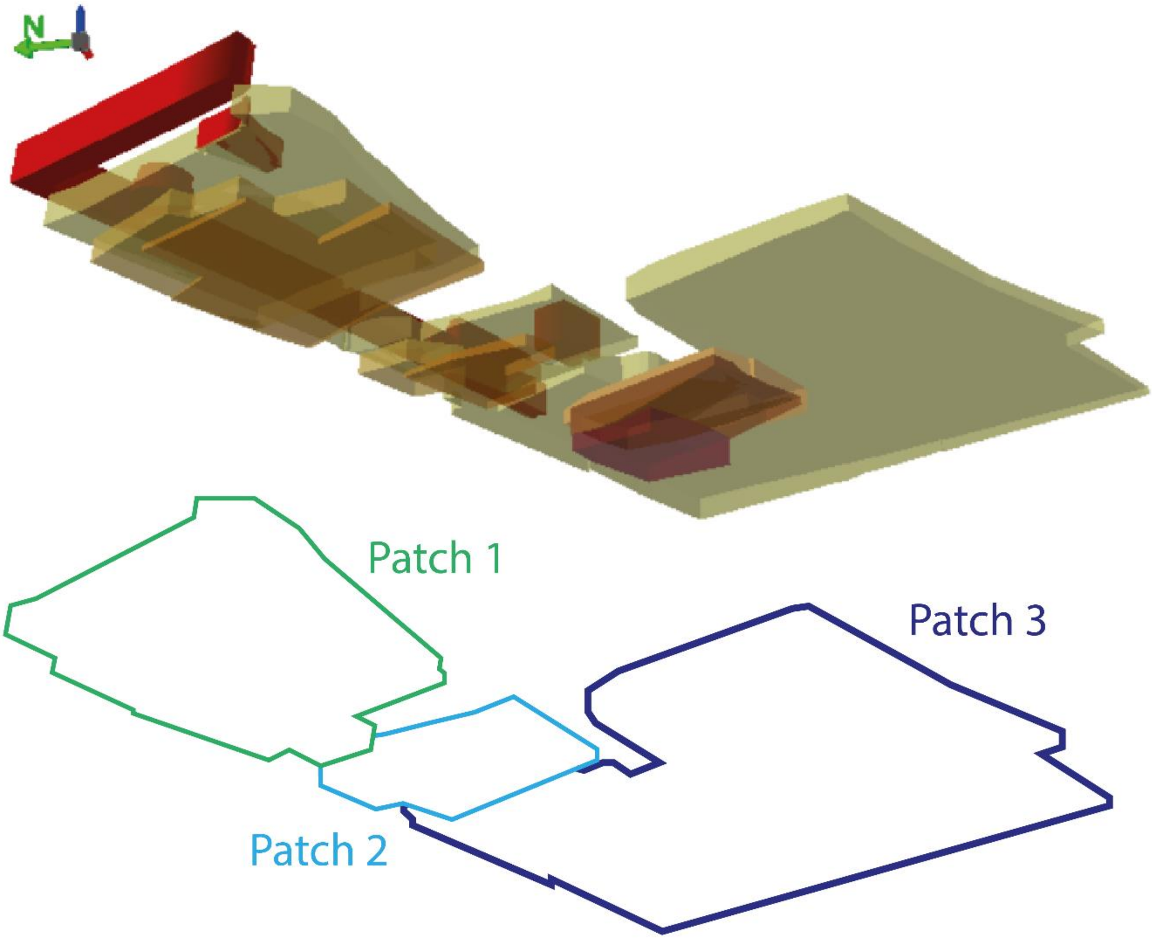

Figure 4.9: Modelling result of GROL2 as seen from below. Deposit layer units are colored after archaeological level. Patches 1-3 are highlighted. Brickwork units are displayed in red. No scale.

- Patch 1 is located in the northwestern corner of the plot and consists of a sequence of three soil deposit units which are bordered on the west and north by brick walls. Remains of a brickwork cellar and a brick cesspit are present on the first layer.
- Patch 2 is located to the east of plot 1 and consists of three consecutive soil deposits with differing geometries. The deviating geometry is due to differences in surface area of plan drawings on each level.
- Patch 3 consists of four soil deposits, the uppermost of which (unit 13) covers the majority of the eastern half of the GROL2 area. This deposit unit is counted as part of patch 3 because it is the earliest patch number the deposit unit covers. On the first level a small brickwork cellar is present in the north, as well as a brickwork pile in the southeast. From the second layer onwards the patch consists of three soil deposits.

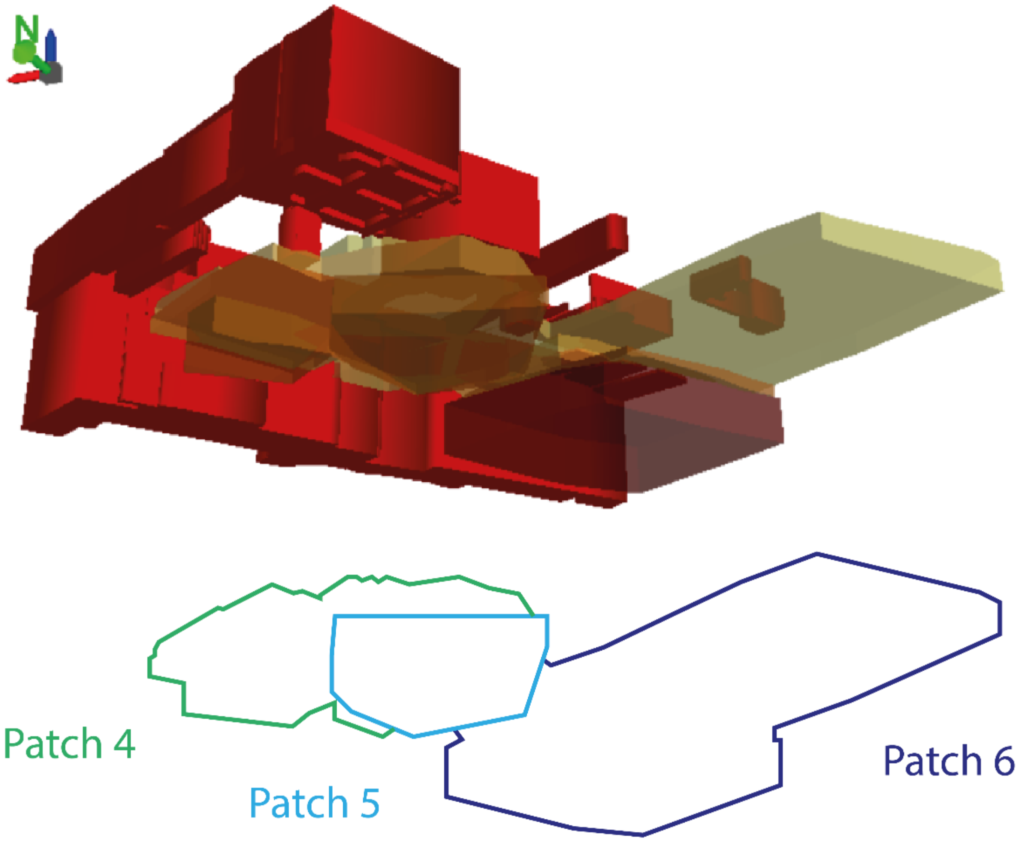

Figure 4.10: Modelling result GROL2 of patches 4-6 as seen from below. Deposit layer units are colored after archaeological level. Patches 4-6 are highlighted. Brickwork units are displayed in red. No scale.

- Patch 4 is located in the northeastern corner of the plot and is covered by unit 13 on the first archaeological level. The patch is flanked by brickwork in the north and the city wall in the east. On the first layer, a brickwork wallpiece and pile are present. Two more layer units lie beneath, the first of which (unit 24) also covers patch 5. The lowermost is a separate unit.
- Patch 5 is located just southwest of patch four. On the first layer, a brickwork cellar, pile and some loose brickwork units are present. The cellar and pile cut through the upper soil layer (unit 13). The second soil layer is the aforementioned unit 24 with below it a separate unit.
- Patch 6 is the southeastern patch, bordered in the east by the city wall. The upper layer consists of a collection of wallpieces in the north, underneath which a complete brick cellar is present. Another brickwork cellar is present in the southwest. The first soil deposit is represented by the aforementioned unit 13. Below this, a soil layer is present (unit 26) which also covers the neighboring patch 7. On the third level, three separate chunks of floor are present, followed by a stack of three soil deposit units.

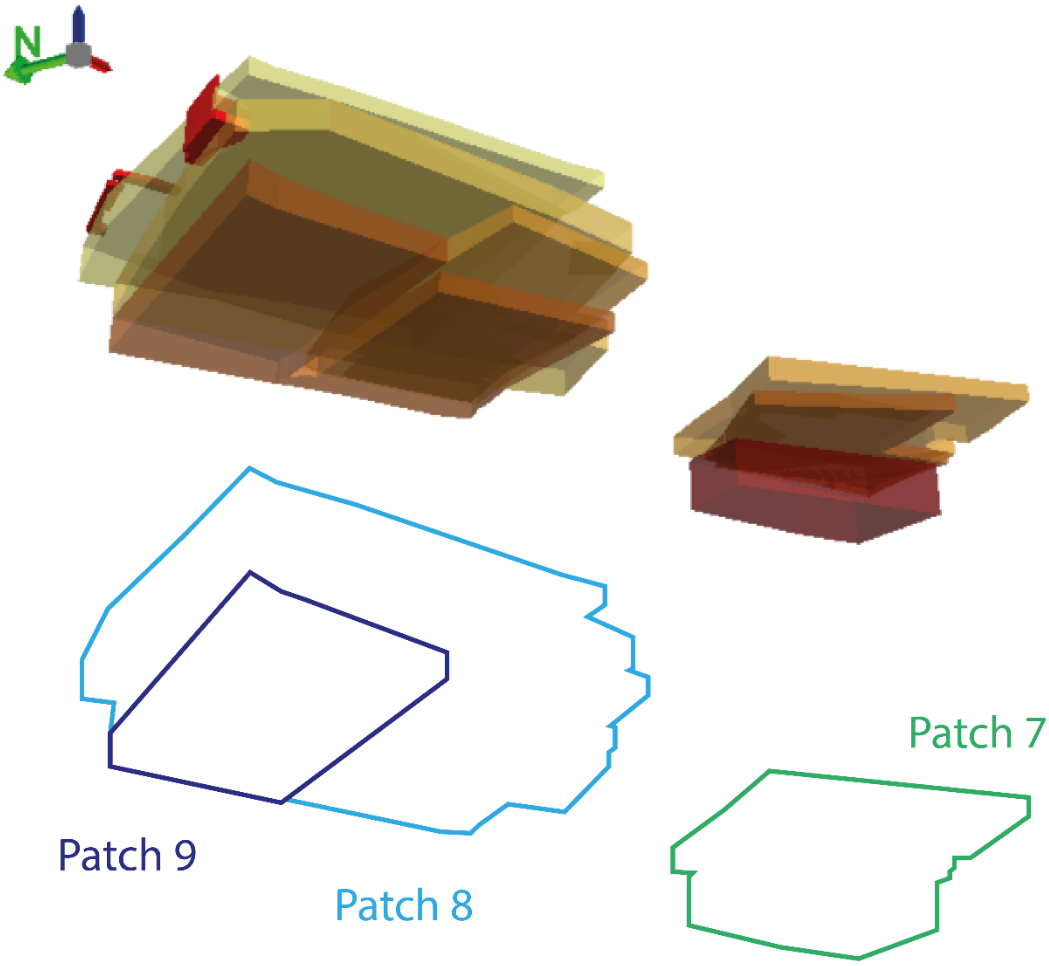

Figure 4.11: Modelling result GROL2 of patches 7-9 as seen from below. Deposit layer units are colored after archaeological level. Patches 4-6 are highlighted. Brickwork units are displayed in red. No scale.

- Patch 7 is located to the west of patch 6 and is represented on the first two levels by respectively the aforementioned units 13 and 26. Below this, three additional soil units represent the rest of this patch.
- Patch 8 is located close to the southwestern corner of the GROL2 plot. The upper two soil layers (respectively unit 18 and 28) also cover plot 9 to the west. Below, two additional deposit units are present.
- Patch 9 is located in the southwestern corner and is represented on the first two levels by the aforementioned units 18 and 28. For the third level, no GIS documentation was available and therefore this deposit unit is missing. The fourth level is represented by deposit unit 49.

5. Volumetric analysis.

This chapter addresses the volumetric analysis carried out on the 3D-GIS models of Grave-Oliestraat. First, an elaborate description of the analyzed material categories as well as the applied methodology is given. Next, the analysis results are presented using a collection of 3D visualisations.

5.1. Methodology

5.1.1. Find categories

In chapter 3.3 a number of material categories have been identified which may be regarded as indicators of leatherworking activity. The extent to which these material groups can be used in the current analysis is dependent on how the material is represented within the site. Not all material groups are treated equally during the excavation research. Not all properties of the material was relevant to the research and some material specialist analyses were not finished as of writing this thesis. Also, not all material groups are equally relevant. This will be discussed in paragraph 6.2.2. Each material group was assessed in the excavation database and available documentation and reports, giving the following output:

Table 5.1: Different material groups along with their relavancy to the research and to what extend their properties are documented. X: completely, /: partially, -: N/A.

Material	Relevance	Amount	Weight	Determination
Leather	X	X	-	-
Bone	/	X	X	/
Wood	/	X	-	/
Metal	/	X	X	/
Stone	/	X	X	X
Ecological	/	/	-	X

Table 5.1 indicates the extent to which material groups have been treated at the time of writing this thesis. Leather artefacts are only administered by amounts and have not been determined. Faunal remains are disclosed by amounts and weights. However, determination of the bone fragments has not been completed yet as of writing this thesis. Wooden finds were administered by amount and only determined partially. Metal is counted, weighed and partially determined. Stone has been counted, weighed and determined based on stone type. Ecological samples have been analyzed and counted. Next, a description will be given on how – and whether – each material group was used in this research, and why.

Leather finds were only counted during find processing. Because leather is relevant to this research, the administered amounts will be included in the analysis. Bone is very relevant to the current research, especially if a distinction can be made between species or even body part. However, because the bone analysis was not complete at the time of this research, only the amounts and weights of faunal remains in general can be incorporated in the results. Wood was not incorporated in the research, because the determination of this material group was not done structurally and wood analysis mainly focused on dendrochronology of the cess- and waterpits. Metal finds were initially incorporated into the research, as an abundance of (non-ferro) knifes were found (van Kampen, 2021a). These were partially identified a restoration specialists (Wijnans, 2021) and partially identified by the author based on pictures taken for restauration. However, the metal finds turned out to be distributed exclusively outside the modeled areas and therefore excluded from the analysis. Stone is left out of the analysis because its relevance to leather working is considered to be too uncertain. Stone is a very broad material category and only plays a limited role in the leather working process.

Lastly, the ecological samples require some elaboration. Archaeobotanical samples were taken on multiple occasions during the excavation, often with specific research aims towards specific contexts. For example, many samples are taken in cesspits or layer which contained a significant amount of archaeobotanical remains. Only a limited number of samples were taken (N=52) from a limited number of feature contexts (N=43). Because ecological material forms a large component of the archaeological indicators for leather working however, it was decided to incorporate these samples regardless of these reservations. Relevant material types which were detected include bone, hair, wood and branches, but also fleas and beetles. These indicators were detected in macrobotanical samples under the 'other' category, counted by means of classification: 0 (-), 1-10 (+), 10-100 (++) and >100 (+++) (van Beurden, Lange, & van der Linden, 2022). In order to quantify this data for the current research, each class that is considered as an indicator for leather working is counted as a value of one. For example: A macrobotanical sample containing + hair, ++ wood and +++ leather is quantified as a value of (1 + 2 + 3 =) 6 for the sake of this analysis.

5.1.2. GIS

The analyses are executed per archaeological material group. Because the two modeled parts of the excavation are spatially separated, the 3D find distribution was also executed separately for both models. To visualize the distribution of finds a sequence of steps were taken. First, all finds of the desired material group was queried in the database, including the find number (VN), amount, weight (if available). The query was subsequently saved and imported into the 3D GIS environment. To locate each find, a join was made between the find measurement from the field data, retrieving the x-y-z coordinates and subsequently plotted in that location. Next, for each identified find number the corresponding deposit unit was determined using the *Near 3D* tool from the 3D Analyst Toolbox, determining the closest 3D object. This will generally determine which 3D unit encompasses the find, or gives the closest. Occasionally a find is plotted outside the reach of a 3D unit, caused by possible flaws in the model. Using the tool *Summary Statistics* from the Analysis toolbox, a statistical summary is made on the combined sum of the amount and weight of finds per modeled 3D unit. This is subsequently joined to the respective 3D-GIS model. Next, two rows are added to the attribute table in which the relative amount and weight per volume (m3) is stored. Using the field calculator, the amounts and weights were divided by the calculated volume. Finally, the results are visualized, using a color gradient based on the (relative) amount/weight of the respective artefacts.

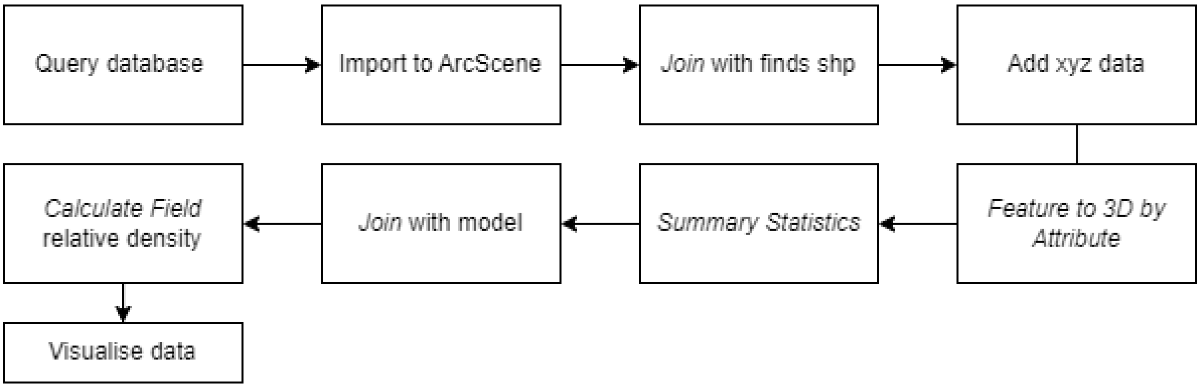

Figure 5.1: schematic representation of the GIS analysis workflow

5.2. Analysis results

Next, the results of the analysis are presented. To understand patterns in the find distribution, the density of the complete find assemblage is presented first. Afterwards, a more detailed description of the distributions of leatherworking artefacts is given per analyzed material group and modeled location.

5.2.1. General find distribution

The find distribution can be analyzed in both absolute or relative terms. Absolute is the summed amount or weight of artefacts within a deposit unit. Relative is the amount or weight of artefacts relative to the volume of the modeled layer, expressed in amount per m^3 or grams per m^3. The general find distributions are visualized in Figure 5.2-Figure 5.5.

The PLOT6 models Figure 5.2/Figure 5.3 show that most material is present within the yard. Within the cellar, finds seem to be more equally distributed with a trend towards the lower layers. The weight model displays a majority in the lower layer of the yard and an equal density distribution of finds in the cellar part. The relative models display a tendency in artefact density measured by both weights and amounts towards the lower layers of the cellar part. The yard part shows a tendency towards either the top or bottom layer in find density, depending on whether amounts or weights are considered respectively. Based on the absolute distribution of finds in GROL2, most finds seem to be located in the upper layers measured by both amounts and weight. Looking at the relative models, artefact density seem to be more equally distributed among layer units. This is especially apparent in the weights model. Especially layer unit 47 is well-represented in the artefact distribution, despite having a modest volume (24.98 finds/m^3-1.48 kg/m^3).

Generally, the density models of PLOT 6 are more erratic than that of GROL2, likely due to the fact that there are less 3D-GIS units available here. Still, both models give a basic idea of the find distribution to which the distribution of find categories can be compared. The models show that within each modeled part a different distribution may be expected. In GROL2, the relative find density is equally distributed among layers with a small bias towards the upper levels and some specific layers. PLOT6 exhibits a tendency in relative find density towards lower levels in the cellar part. Density in the yard of PLOT6 is dependent on whether weights or amounts are considered.

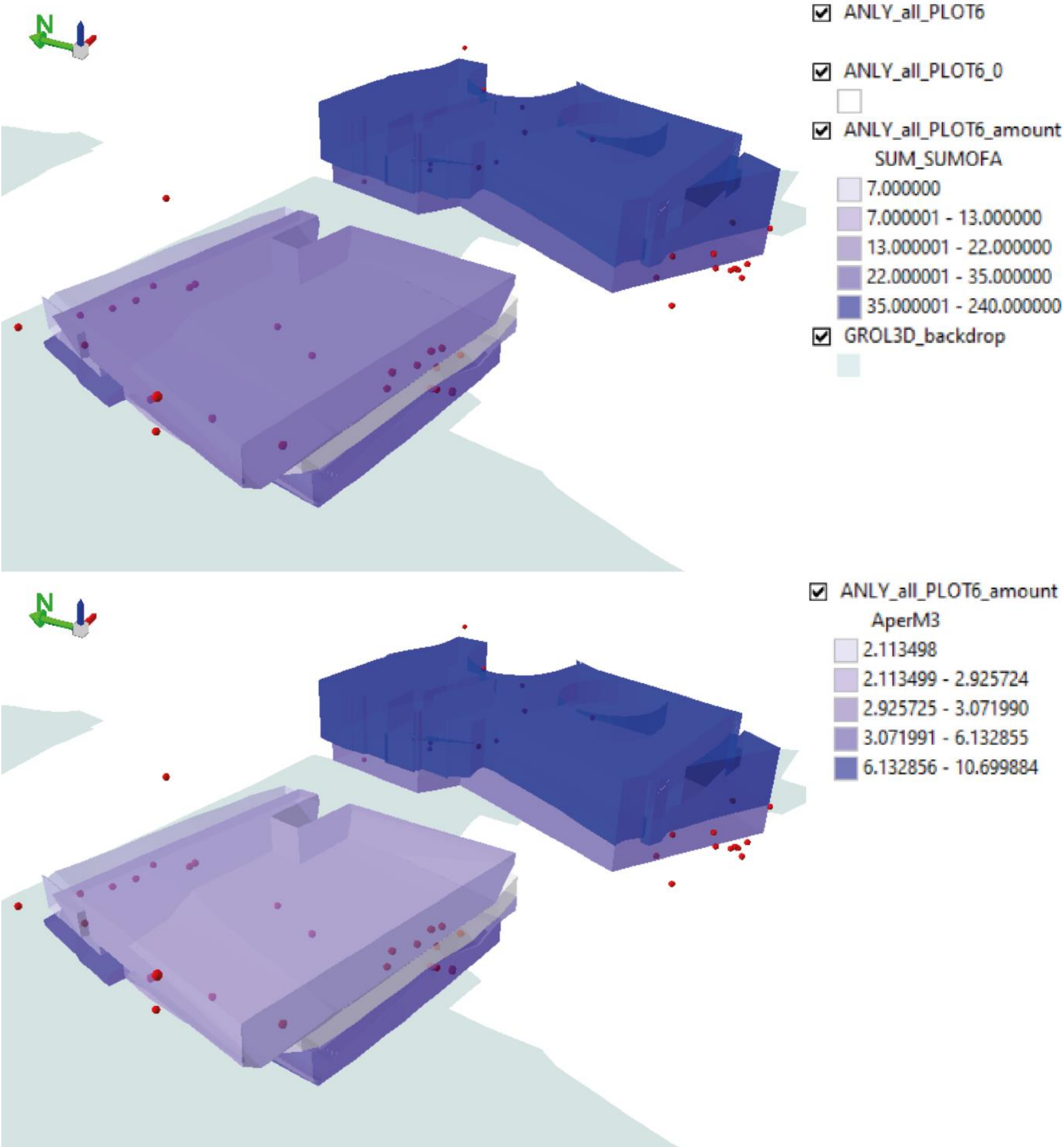

Figure 5.2: General find distribution of the complete assemblage for PLOT6. Absolute and relative amounts. No scale.

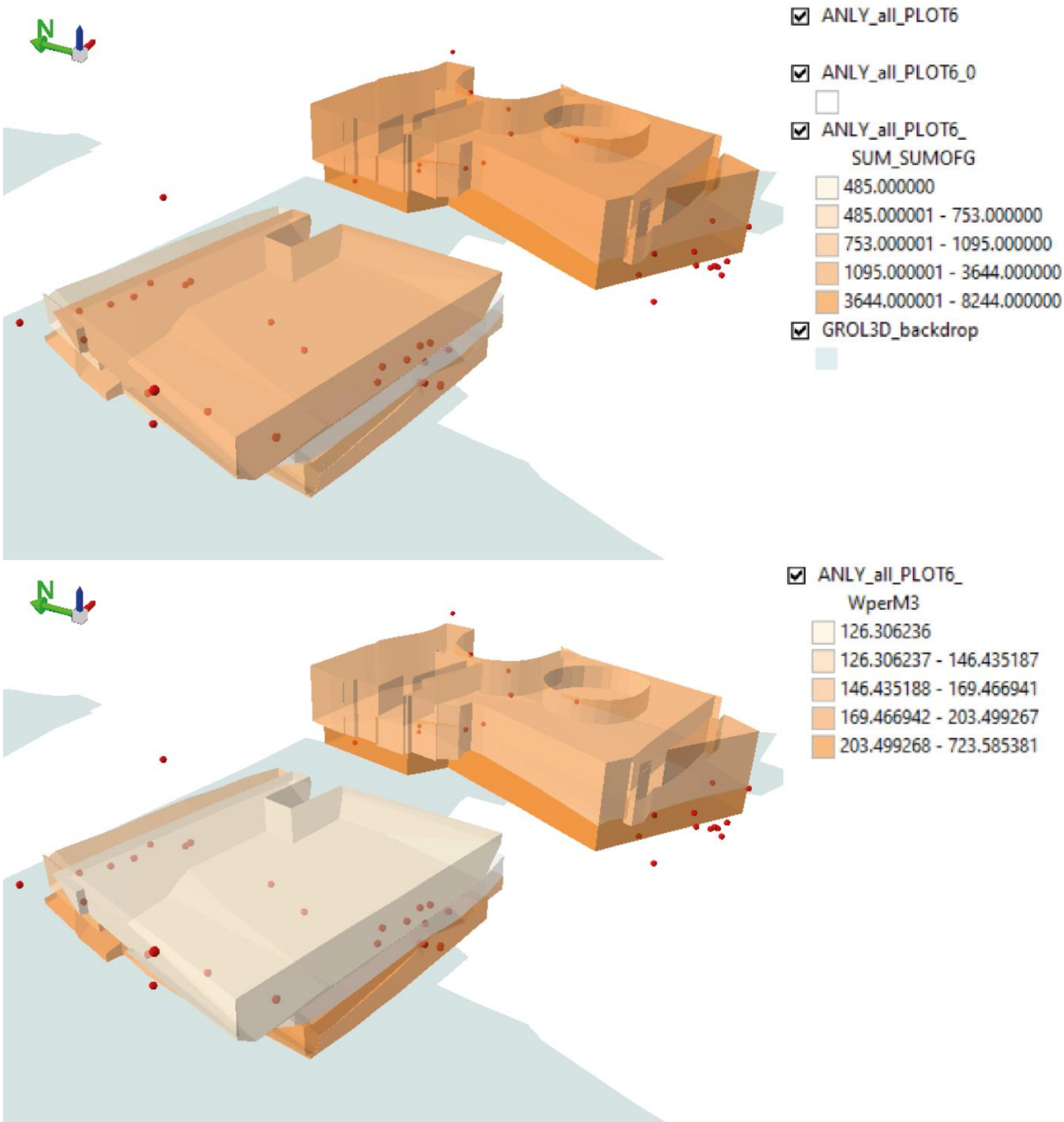

Figure 5.3: General find distribution of the complete assemblage for PLOT6. Absolute and relative weights. No scale.

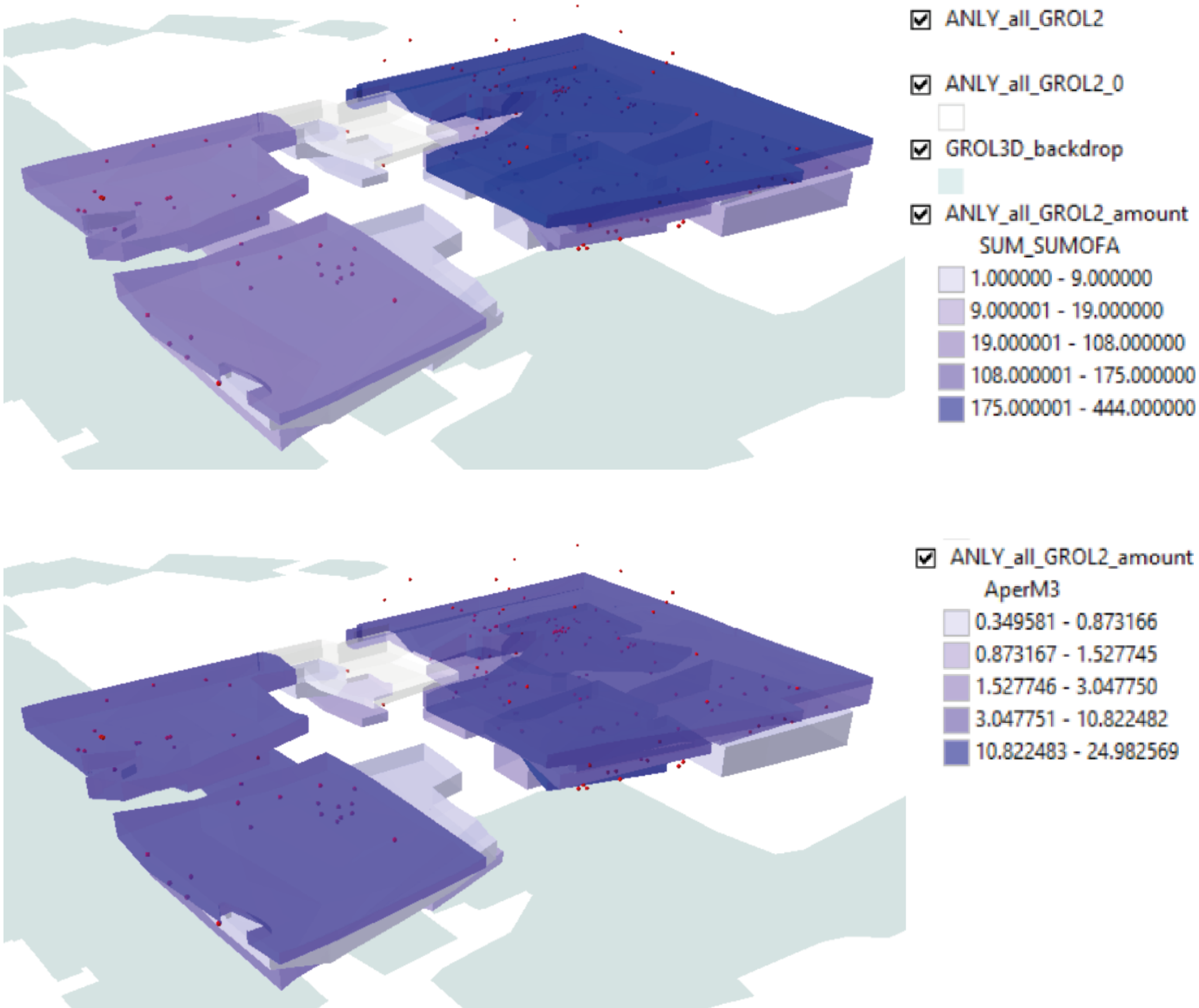

Figure 5.4: Absolute and relative distribution of all artefacts within GROL2 based on amounts.

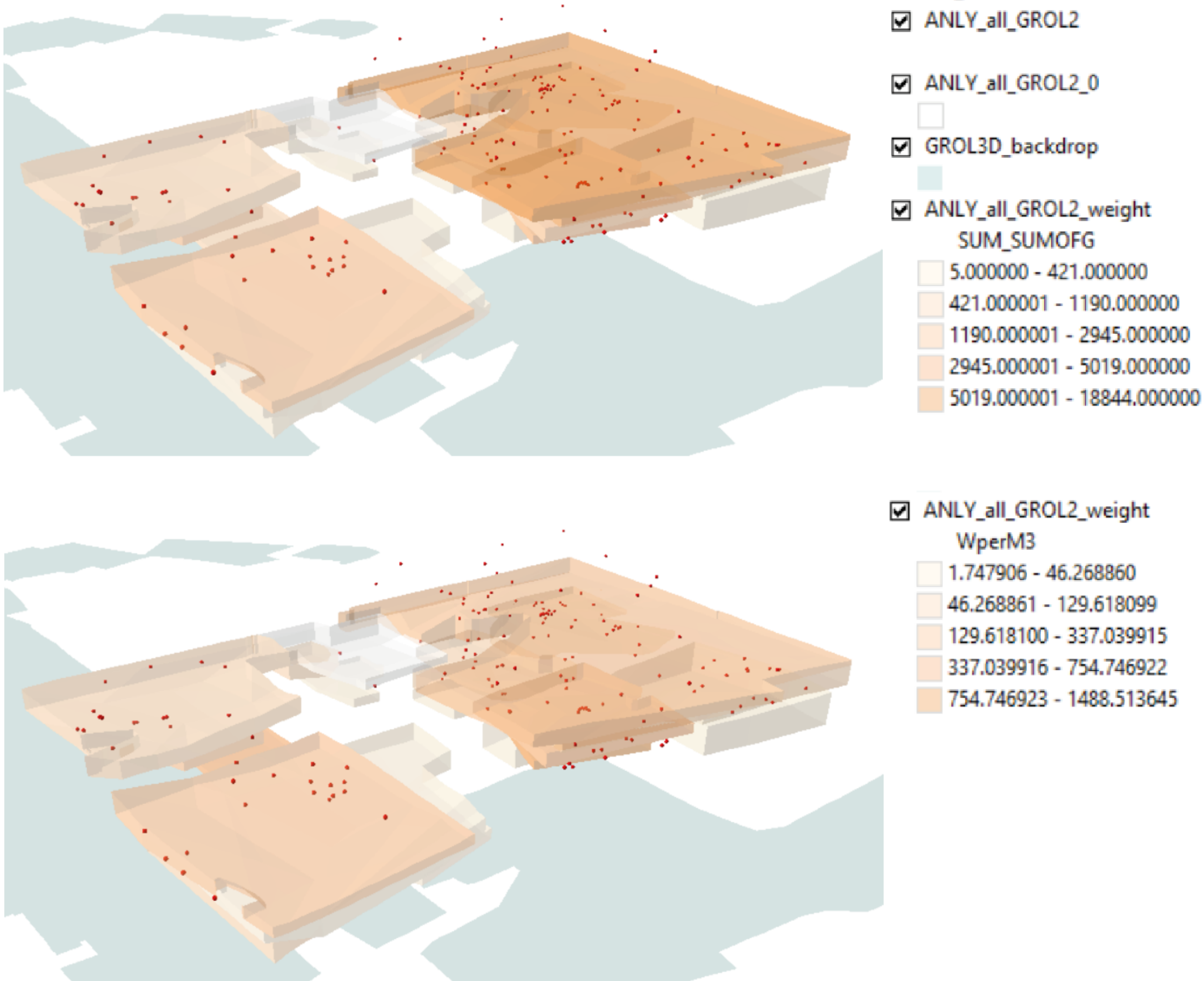

Figure 5.5: Absolute and relative distribution of all artefacts within GROL2 based on weights.

5.2.2. Traces of leatherworking in Cellar 6

Leather

Within PLOT6, two find contexts contained leather artefacts. One find number contained five pieces of leather and the other contained one. Figure 5.6 shows the density of leather artefacts relative to layer volume. The analysis shows that the density is relatively equal among both units. Unit 9001 within the cellar has slightly higher find density (0.223/m3) as opposed to unit 9004 within the yard (0.225/m3) due to its smaller volume.

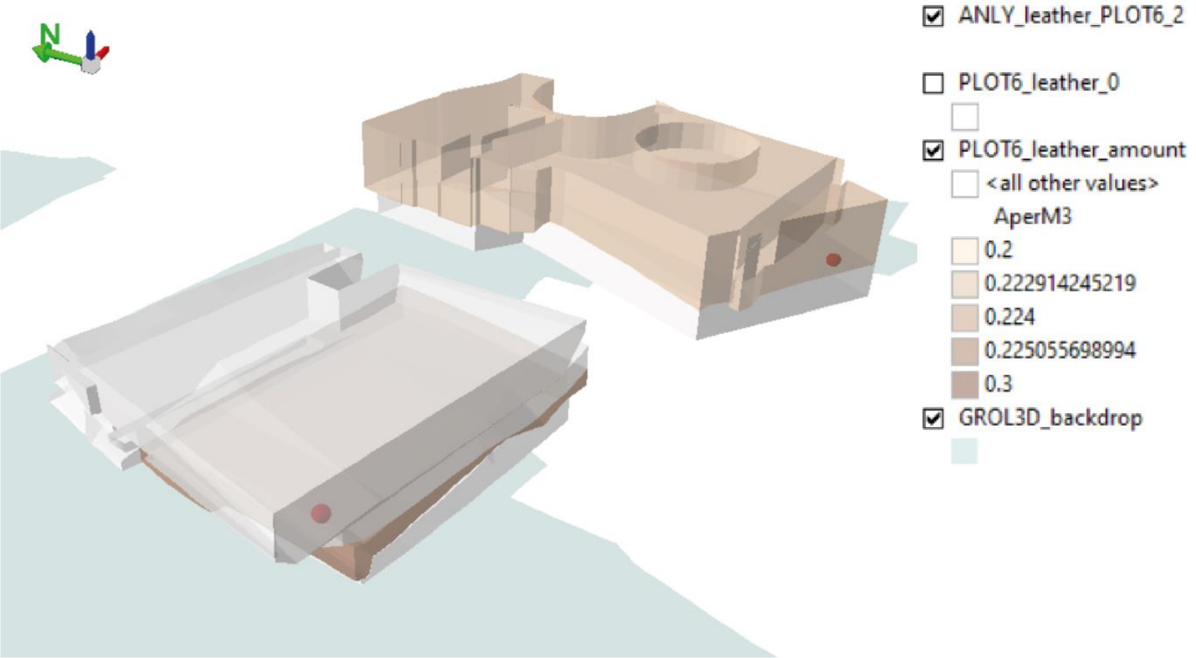

Figure 5.6: Volumetric analysis results. Artefact density of amounts (top) and weights (bottom) of leather artefacts per m³ within the PLOT6 3D-GIS model. No scale.

Animal remains

52 find numbers containing animal remains were located within the PLOT6 model, containing a total of 350 individual artefacts, weighing over 15 kg. The find density of archaeological layers relative to volume is displayed in Figure 5.7. The volumetric analysis shows that the lower layers within the cellar part of the 3D-GIS model have the highest artefact density. The yard has a considerable density of faunal remains. Here, the upper layer contained the majority faunal remains relative to volume when counted by amount. The lower layer of the yard contained the most faunal remains when counted by weight. A similar pattern as seen in the general find density (paragraph General find distribution5.2.1).

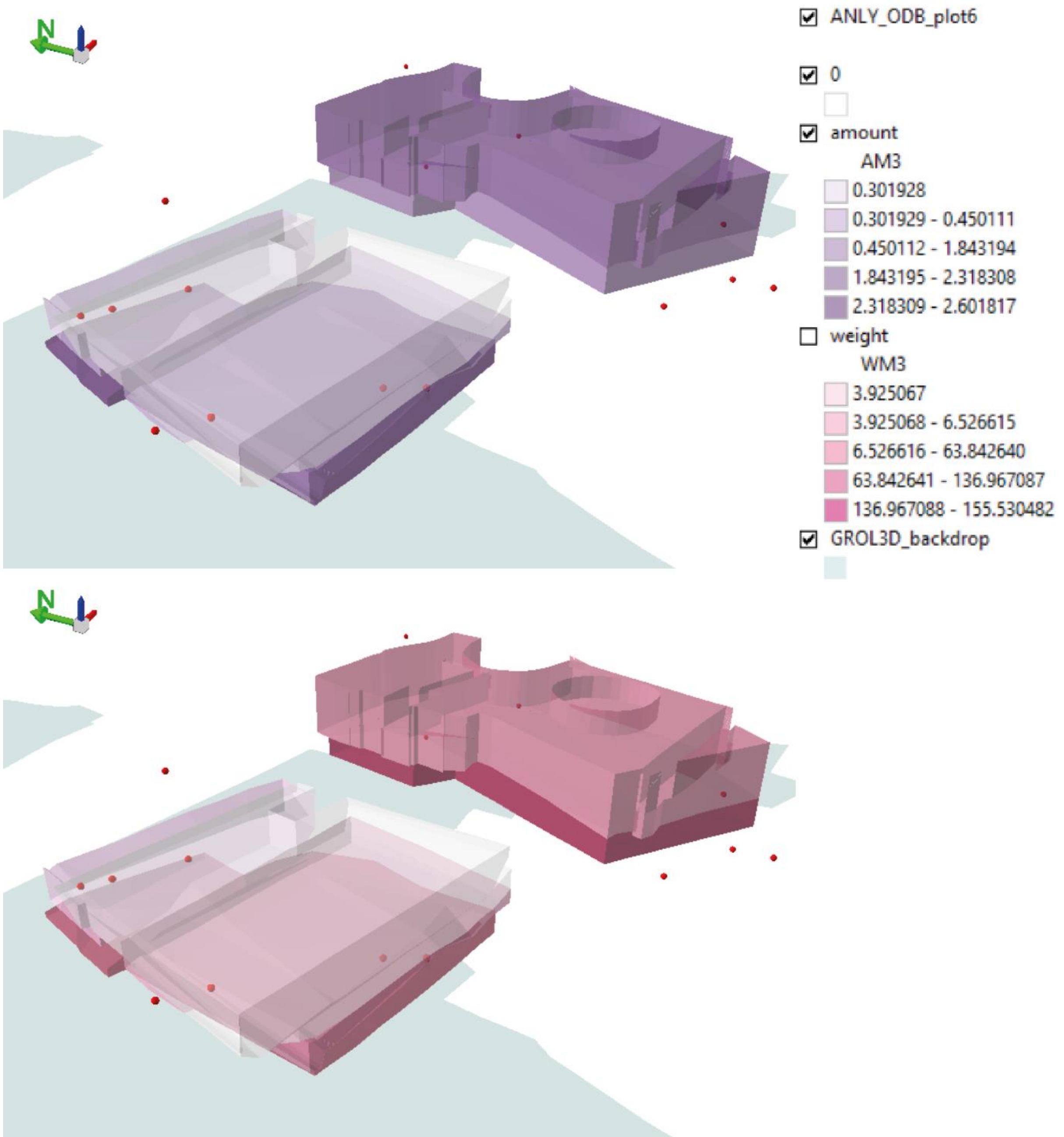

Figure 5.7: Volumetric analysis results. Artefact density of amounts (top) and weights (bottom) of faunal remains per m³ within the PLOT6 3D-GIS model. No scale.

<u>Ecological</u>

Whitin PLOT6, two ecological samples were taken which contained macrobotanical remains. The indicators add up to a total rate of 15 for ecological indicators of leatherworking. The distribution of macrobotanical indicators for leather working is displayed in Figure 5.8. Both macrobotanical samples originate from the lower unit of the cellar. Important to note is that this is the only unit sampled for macrobotanical remains within PLOT6.

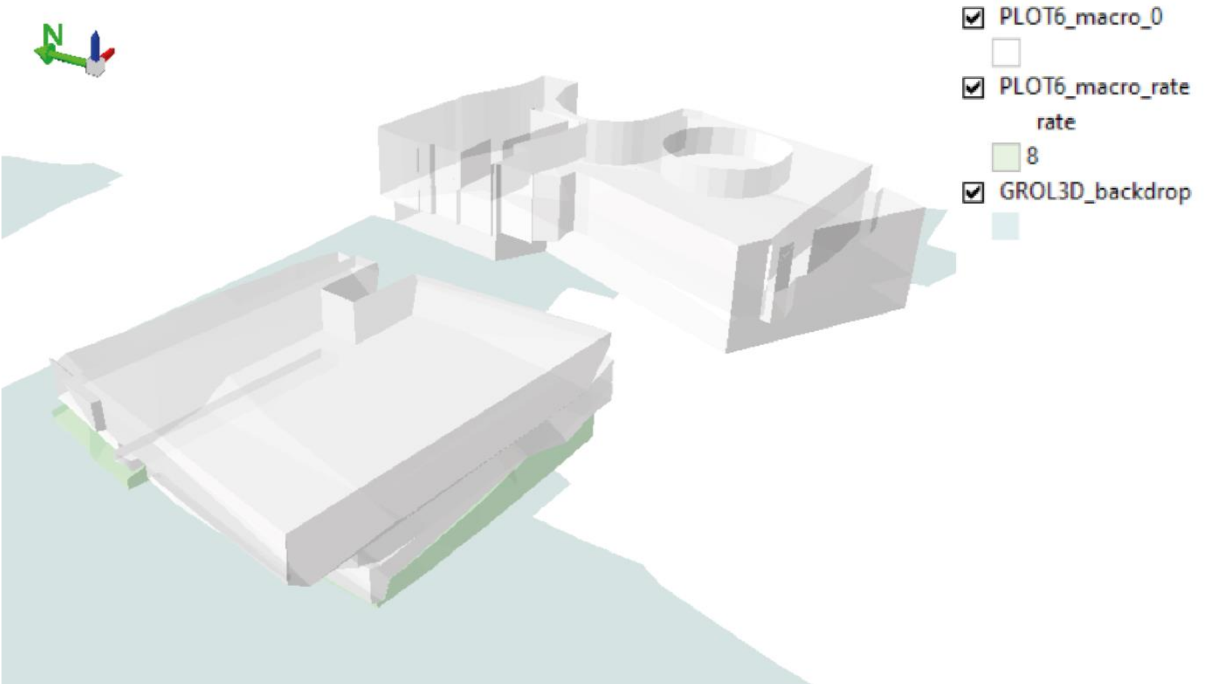

Figure 5.8: Volumetric analysis results. Rate of ecological indicators for leatherworking in macrobotanical samples per layer unit within the PLOT6 3D-GIS model. No scale.

Summary and interpretation results PLOT6

Volumetric analysis shows that material groups related to leather working generally occur in the highest density around the lower levels of the cellar area. Specifically, units 9002 and 9001 often contain the most artefacts related to leatherworking in weight and amount relative to their volume. The yard part (units 9004 and 9005) is also well represented in both the find material and artefact density. For two analyses limited contexts were available to base distributions on, meaning the dataset for these analyses is rather small. The top layers of the cellar, units 1350 and 9003 contained no find material related to leather working.

Based on the analysis results it may be stated traces of leatherworking are encountered throughout PLOT6, both within the cellar part and the yard. The empty layers within the upper cellar part of the model indicate that no leatherworking has taken place after construction of the cellar. Possibly, more traces of leatherworking have been present here historically, but will are disturbed during construction of the cellar. Significant reservations have to be given along with this interpretation considering the small sample size the data of PLOT6 offers.

5.2.3. Leatherworking GROL2

Leather

Five contexts within GROL2 contained leather artefacts, adding up to a total of 82 individual pieces. Figure 5.9 displays the find density among the layer units of GROL2. Most leather artefacts were distributed in the mid-southern and southwestern part of the excavation. Especially unit 18 contained a significantly high amount of leather (9.08/m3). This is where find number 62 is collected from, which contained a significant amount of leather strips (N=73). Unit 47 also contained a considerable amount of leather (2.61/m3), as well as the two units below, albeit in lesser amounts (respectively 0.18/m3 and 0.15/m3).

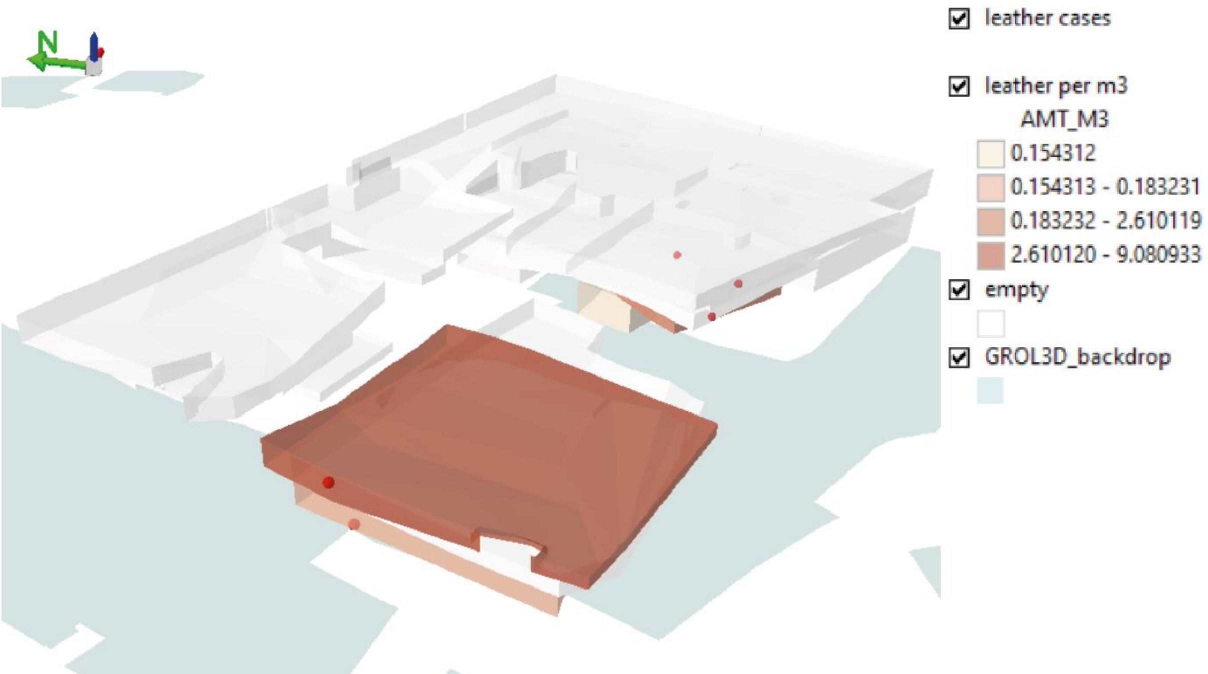

Figure 5.9: Artefact density of leather artefacts per m³ within the GROL2 part of the model. No scale.

Animal remains

51 contexts containing animal remains were collected within GROL2. A total of 248 individual pieces of animal remains were collected, weighing a total of 7150 grams. The find density of animal remains in amounts and weights are displayed in Figure 5.10. Relative to volume, most animal remains were located in the eastern and mid-southern units, as well as some within the northwestern corner of GROL2. Especially the mid-southern units 37 and 47 contain a significantly high amount of animal remains, respectively 5.07 and 6.71 per m^3 (or 44.2 g/m3 and 272.2 g/m3).

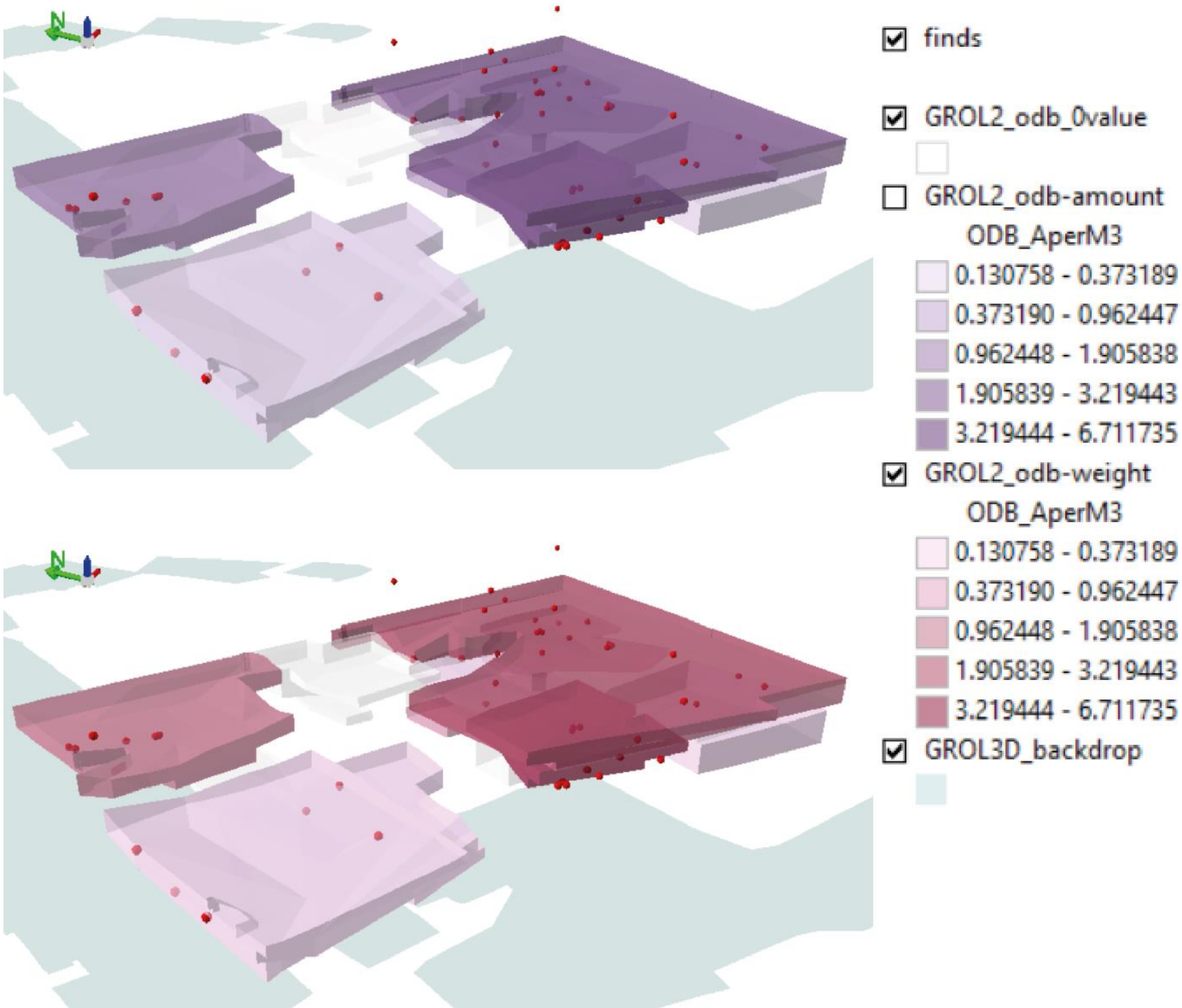

Figure 5.10: Volumetric analysis results. Artefact density amounts (top) and weights (bottom) of artefacts per m³ within the GROL2 part of the model. No scale.

<u>Ecological indicators</u>

Within the boundaries of GROL2, six macrobotanical samples, contained indicators for leatherworking ranging from rates of 2 to 8. Three samples originated from cesspits, two from (water)pits and one from soil deposits. Indicators for leatherworking in the samples predominantly originate from southwestern and mid-southern units. The find density is displayed in Figure 5.11. Especially the upper unit in the southwestern corner (unit 18) contained a significant amount of indicators (N=8) for leatherworking, notably in the form of a high amount of leather strips in a macrobotanical sample. Additionally, units 37 and 47, located in the mid-southern part of the model contain respectively 5 and 7 indicators for leatherworking.

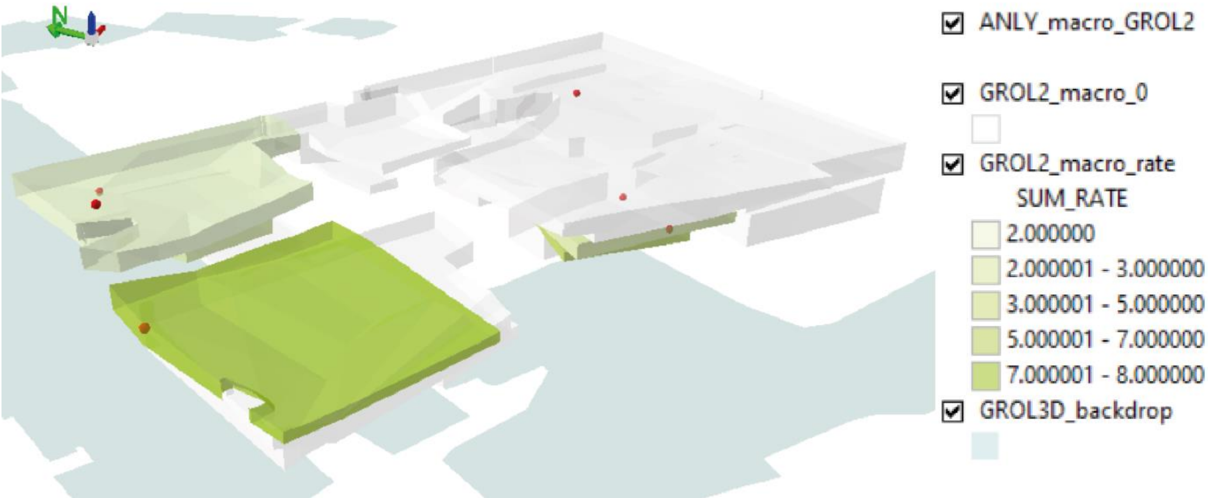

Figure 5.11: Analysis results - ecological indicators GROL2

<u>Summary results GROL2</u>

The volumetric analysis of GROL2 shows that material groups related to leather working occur in the highest density around the southwestern and mid-southern patches. Specifically, unit 18 contains a high amount of indicators of leatherworking, expressed by the density of leather finds and macrobotanical indicators. Additionally, material groups tend to be relatively more present in units 37 and 47, which are also significantly represented by the volumetric analysis of faunal remains. To a lesser extent units in the northwestern part of the model and unit 13 - which covers the eastern top of the model – contain a high amount of indicators for leatherworking.

Based on the analysis results it may be stated that traces of leatherworking predominantly occur in the southwestern and mid-southern patches. The distribution of artefacts related to leatherworking is similar to that of the general find distribution (paragraph 5.2.1).

6. Discussion

The current research consists of a 3D-GIS model of the site Grave-Oliestraat, on which a volumetric analysis has been carried out investigating the material indicators for leatherworking. In this chapter, both the 3D-GIS model and methodology, as well as the subsequent volumetric analysis and methodology will be critically reviewed in order to assess the significance of the results and interpretation thereof which was given in the previous chapter. First, the 3D-GIS model will be reflected upon, after which the volumetric analysis is addressed.

6.1. Modelling reflection

6.1.1. Correlation 3D-GIS model and documentation

The current modeling strategy involves a combination of methods to model respectively archaeological brickwork, archaeological surfaces and layer deposits. Modelling brickwork involves extruding the archaeological plan drawing between top and bottom height measurements. Layer modelling involves extruding GIS plan drawings between TIN surface representations of the archaeological levels. This is assumed to provide an accurate – albeit simplified - representation of the stratigraphy within the site. Although profile drawings were generally not included in the modelling strategy, they can be used to review the accuracy of the model with respect to the documented reality. Profile drawings can be added to the ArcScene workspace using the Generate Cross Section tool, developed by Riccardo Rocca, which allows plotting 2D raster files as textured 3D objects (Rocca, nd). In the northwestern corner of the PLOT6 model, two profiles were documented which allow comparing the modeled units to the archaeological documentation retrospectively, providing insight into the accuracy of the 3D-GIS model (Figure 6.1).

Considering Figure 6.1 a deviation seems to exist between the 3D-GIS model and the documented situation. Modeled brickwork features correspond relatively well to the documentation, as were these are often based on the profile drawings to begin with. The floor levels are not documented on the profile drawings and therefore do not allow for comparison. However, especially the Southview (P93) displays a rather unrealistic surface gradient. The top surface of layer unit 9001 is not specifically documented in profile P92, but corresponds to a transition between two archaeological levels. However, this transition is documented 20 cm lower in profile 93, which might be due to the profile being positioned away from the model. The lower deposit, S9002 is not represented in the profile drawings and seems to end in the middle of a feature level.

This comparison exhibits one of the limitations of the modelling strategy. Individual ground features on plan- and profile drawings are neglected during the 3D-GIS modelling. Rather, a 3D-modeled layer units represent an abstraction of the field methodology, specifically the space between each archaeological surface. Nevertheless, because archaeological surfaces are located on the transition between archaeological deposits, the modeled layer units should represent distinct collections deposits, albeit a significantly simplified version of it. However, comparison to the profile drawing shows that this is not necessarily the case and the layer models deviate significantly from the effectively documented stratigraphy.

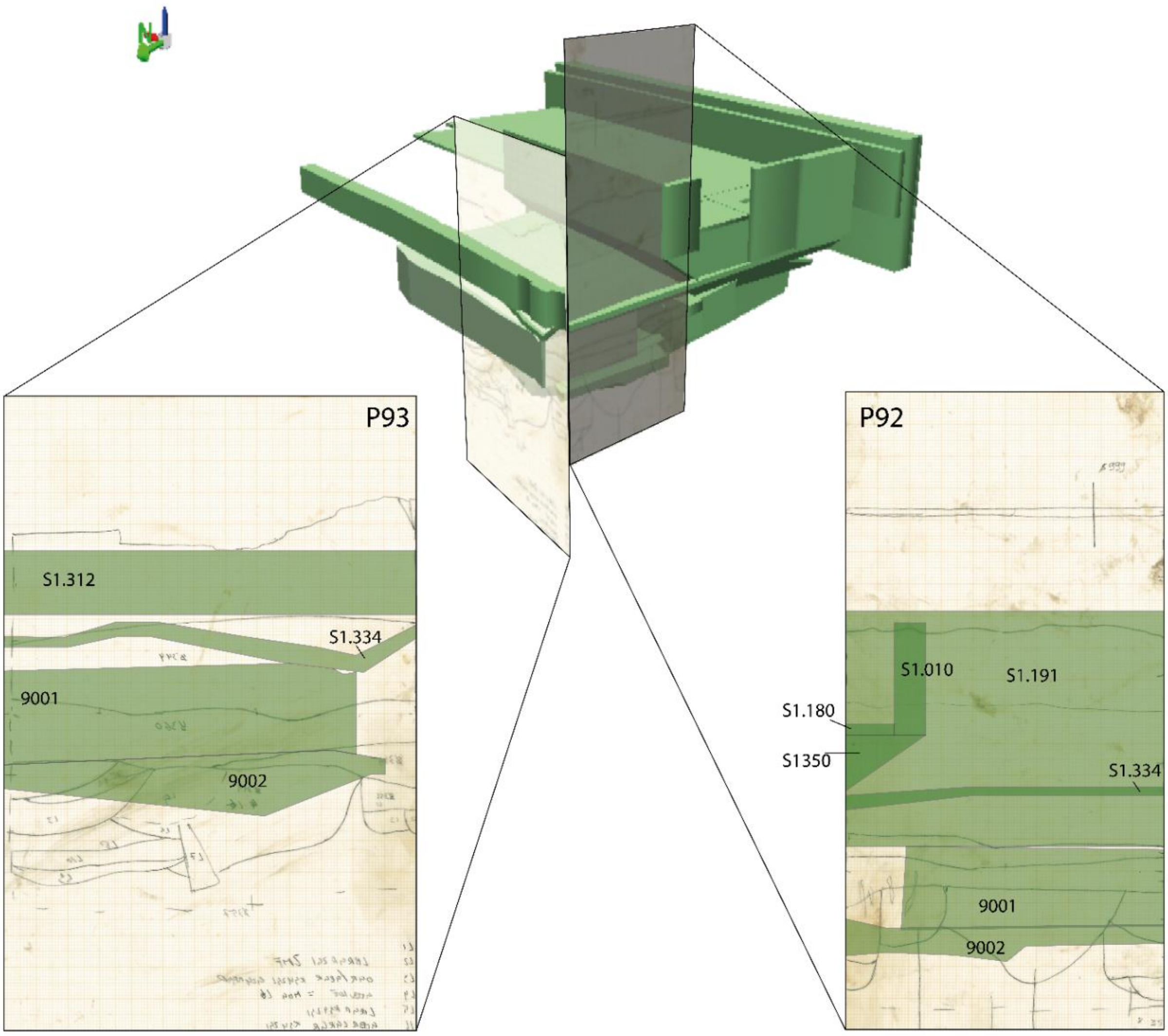

Figure 6.1: Profile drawings with the (approximate) location of the 3D modeled units relative to their position in 3D. Back wall S1.191 was left out of the 3D view for visualization purposes. No scale.

6.1.2. The impact of brickwork

During this project a lot of time and effort was put into the modelling of brickwork features. Brickwork occurs in the documentation of the upper three archaeological levels and was assumed to have a significant impact on the underlying soil deposits and by extend the volumetric analysis. During the modelling process however, it became apparent that the archaeological layers only occasionally intersected with anthropogenic layers. It may therefore be challenged whether brickwork features impact layer units in a significant amount. Using the *Inside 3D* Tool from the 3D Analyst toolset, an inquiry was made on the amount of brickwork features that intersect with layer units, along with their respective impact on the calculated volume. The results are expressed in Table 6.1. It seems that Within GROL2, 74 out of 129 brickwork features intersect with or are completely encompassed by eight out of 25 layer models. 17 layer units remain unaffected by brickwork.

Table 6.1: Attribute table of GROL2 layer units affected by brickwork. Volume before and after subtraction, volume difference and percentage of the whole is included. Units 13, 24 and 26 could not be calculated because the subtracted units were not closed.

FID	shape	vlak	patch	IsClosed	M^3 before	M^3 after	difference	percentage
1	MultiPatch M	1	8	Yes	8.156784	8.038822	-0.11796	1.446183
2	MultiPatch M	1	1	Yes	16.16771	15.83257	-0.33513	2.072854
3	*MultiPatch M*	*1*	*3*	*No*	*55.91029*	*0*	*-55.9103*	-
6	*MultiPatch M*	*2*	*4*	*No*	*10.96577*	*0*	*-10.9658*	-
7	*MultiPatch M*	*2*	*6*	*No*	*22.22817*	*0*	*-22.2282*	-
8	MultiPatch M	2	8	Yes	15.32514	15.29541	-0.02973	0.193995
10	MultiPatch M	3	6	Yes	2.927873	2.860566	-0.06731	2.298836
19	MultiPatch M	4	4	Yes	3.082675	2.937876	-0.1448	4.697187

Comparing the layer volumes before and after subtraction, neither exceed 5% of the original volume. Three layer units were unable to be assessed because it was impossible to obtain a closed multipatch object after subtracting the brickwork features. Importantly, these are the very layer units which are most impacted by brickwork features. Nevertheless, the assessment indicates that subtracting brickwork features from layer units generally has a limited impact on the volumetric analysis. Although most impacted layers are located on the two uppermost archaeological levels, the heaviest influenced unit is the model within path 4 on the fourth archaeological level. 4.6% of its total volume removed by subtracting brickwork features. Based on the above, a future continuation of the current research within this specific site may benefit from neglecting brickwork features. Although it would decrease the accuracy of the layer models, especially on higher archaeological top levels, time and effort saved would allow for a larger portion of the site to be analyzed. Contrarily, the remaining portion is of more similar to PLOT6, in which the brickwork played a larger role in the modelling process.

6.1.3. Outside the 3D-GIS models

As mentioned, the original intent was to model the entire sequence of cellars along the street *Oliestraat*. However, due to the modelling process taking more time than expected, the focus shifted to GROL2. This shift of focus was initiated based on the distribution of find material related to leatherworking. After carrying out the analyses for PLOT6 and GROL2, other interesting zones may be suggested for 3D-GIS modelling and volumetric analysis in the future, continuing the current research.

Figure 6.2 provides insight in the find distribution of the material groups that were considered for the current research. The zone around aforementioned profile in the north of the site appears to contain many of the analyzed material groups and therefore seems to be significant for analysis. However, modeling this part of the excavation may require an entirely different modeling strategy, as this involves modeling a large channel that was found at the site. A similar method to Maas/Vissers (2011) can be envisioned, interpolating a channel between multiple profile drawings. However, the channel profile for Grave-Oliestraat lacks counterparts between which the layers of the channel can be interpolated (personal communication Johan van Kampen, 20-3-2023).

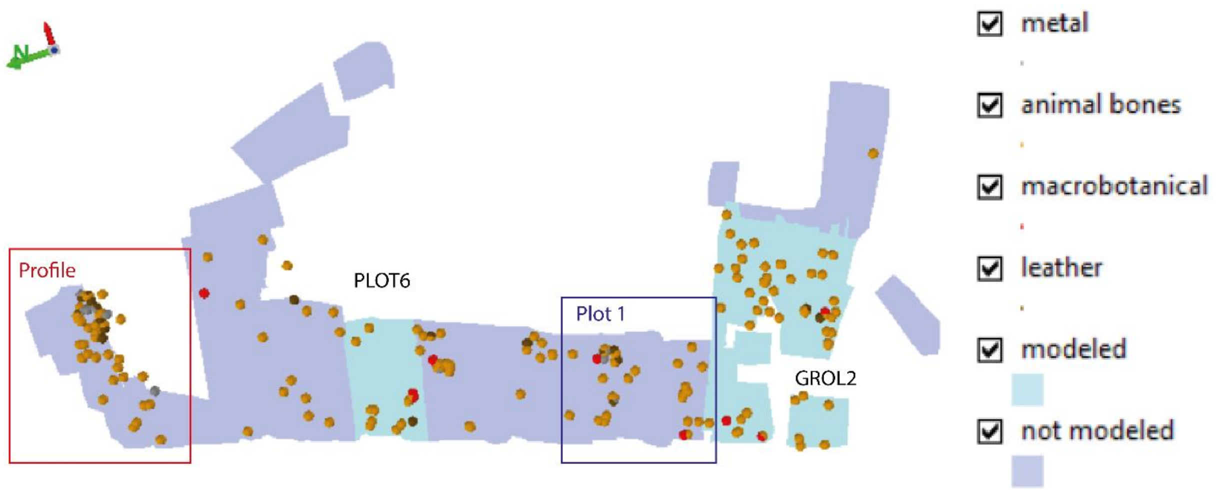

Figure 6.2: Distribution of material groups included in the current analysis relative to the rest of the site and the modeled areal. Zones mentioned in text indicated. No scale.

Alternatively, a zone in the northwestern corner of plot 1 seems to hold much of the analyzed material. Extending model GROL2 northwards, or ideally connecting the two current models, modeling the intermediate cellars might provide more insight into the distribution of finds related to leatherworking over the site as a whole. It may be questioned however how much additional insight extending the current analysis would provide, considering the limitations of the research methods which are discussed in this chapter. In general it can be recommended to determine a modeling area based on the lateral distribution of the desired material groups for research. Additionally, modeling adjacent areas would allow for assessing the 3D-GIS model as a whole, rather than as two separate parts, as was done for the current analysis.

6.2. Analysis.

6.2.1. Distinguishing the process of leatherworking

This thesis focuses on the remains of leatherworking within an urban archaeological context. A description of the leatherworking process was included in chapter 3.3, addressing the three stages the material goes through to from hides to leather; preparation, tanning and processing. In the eventual analysis however, no such distinction is explicitly made. The volumetric analysis distinguishes solely on material categories. Especially the analysis of macrobotanical samples in does not distinguish indicators related to the preparation of tanning phase, which often coincide. On the other hand, the remaining two material categories do indicate a specific phase in the leatherworking process. Horn pits - in the analysis treated as general faunal remains - are associated with tanning. Leather strips - in the analysis treated as the general material category of leather - are associated with processing.

It is however not warranted that each leatherworking activity, be it the preparation, tanning or processing, takes place all in the same location. The location for leather tanneries in a city is often away from the city center with close access to water (Demiddele, 2014, p. 15). Both are true for the site of Grave-Oliestraat. Because the modeled area is limited, the potential to (spatially) distinguish these different phases of the leatherworking process is limited. Generally, each analysis indicates similar layer units to contain material groups related to leatherworking. However, GROL2 shows a tendency towards the southwestern corner for leather and macrobotanical indicators, whereas the amount of faunal remains are relatively low there. Faunal remains rather occur in high density in the mid-southern deposits - also well represented the other two categories. An observation could be that tanning occurred in the mid-southern zone of GROL2, and the preparation and processing occurred within the southwest. However, without considering the actual context the finds are discarded in and subsequently archaeologically retrieved from it remains challenging and perhaps reprehensible to draw such conclusions, especially considering the limited data available. Additionally, because the general excavation report is not available as of writing this thesis, the specific feature contexts can currently not be included in the interpretation.

6.2.2. Material categories

Three material categories were researched by volumetric analysis: leather, faunal remains and macrobotanical samples. Important to keep in mind is that the material may not represent leatherworking exclusively. Artefacts of each category may be deposited through a different manner. This is also highly dependent on the type of artefact as opposed to merely the material properties of an artefact. Leather, being the specific material which is being processed in leatherworking, may be considered the foremost indicator for leatherworking in the find assemblage. However, at the time of executing this research, no specialist analysis was yet executed on the leather assemblage. Therefore, every artefact indicated as leather during find processing was included in the volumetric analysis, regardless of the type of artefact. No distinction is made between a hide, mere leather strips or usage objects. This also ties in to the previous paragraph, disallowing for distinction between the phase in the leatherworking process which is represented by the material.

Next, faunal remains are considered one of the main material remnants of tanneries (Blonk, 2016, p. 101), perhaps also due to their preservatory characteristics. Not every animal bone can be considered being related to leatherworking however. Alternatively, bones might be remains of animal butchery or food related household activities. The literature indicates that specifically horn pits, parts of the foot and tailbones are left behind by the tanner (Blonk, 2016, p. 101), since hides were delivered with said parts of the skeleton attached (Zeiler, 2000, p. 7). At the time of carrying out the volumetric analysis, specialist analysis of the faunal remains from Grave-Oliestraat was only partially finished. Therefore, a distinction based on body part or even species could not be made. Faunal remains are in this research treated only by the general category assigned during find processing: bone. Table 6.2 assesses the amount of faunal remains per species in the specialist data that was available at the time of this research. About 60% (623/1062) of the total assemblage was analyzed by the zooarchaeology specialist at the time of writing this thesis. It seems that the majority of faunal remains are bovine and in lesser amounts pig or sheep/goat. Focusing on the bovine remains, it seems that about 80 out of 237 (33-41%) of the bovine finds represent bones from the head or feet. Tailbones were not yet identified. A total of nine zoological remains were identified as specifically being a horn pit. Based on this assessment it seems that roughly 12% of the total bone assemblage from Grave-Oliestraat represents material that may indicate leatherworking. When interpreting the analysis results it should be considered that only a minor proportion of faunal remains possibly represent leatherworking.

Table 6.2: numbers faunal remains. N=623. Bovine finds (R) from different bodyparts.

	amount	weight	type	bodypart	amount	weight
Bovine	237	11176	R	Achterpoot	41	2235
Vpig	75	1725	R	Kop	38	3138
Sheep/goat	43	742	R	Torso	82	2457
Chicken	10	23	R	Voet	42	1499
Dog/cat	85	80	R	Voorpoot	34	1847
Other	150					

Macrobotanical samples were included in the analysis as they may provide insight into the ecological remains left behind during the leatherworking process. The specialist analysis of the macrobotanical samples was completed prior to the volumetric analysis, which means these results could be incorporated in the research. Although portions of the identified macrobotanical remains correspond to ecological indicators of leatherworking, there is again no guarantee that these actually represent it. Additionally, the ecological remains treated as indicator within this research are based on Blonk (2016). A more specific list of ecological indicators, especially plant remains is available in Demiddele (2014), but this was taken note of only after the analysis was already executed and therefore not included in the current research. Finally, tannin substances were not included in the analysis because they were either not found or not mentioned as such in the specialist report (van Beurden et al., 2022).

It remains challenging to identify how the aforementioned reservations on the material categories impact the analysis results. However it is important to be aware of the research limitations when interpreting and considering the analysis results.

6.2.3. Context and date

As described in paragraph 6.1.1, layer units in the 3D-GIS model of Grave-Oliestraat represent the space between excavated archaeological surfaces. This means that volumetric analysis on the 3D-GIS model disregards the original context of the find material. In reality, the find assemblage originates from a range of different archaeological contexts such as pits, postholes and cess- and waterpits. In the 3D-GIS model, all features are merged together and no distinction is made between artefacts from deposits or manually dug and filled-up archaeological features. This also disallows for taking into account potential features specifically related to leather working, such as tanning pits or waterworks. Additionally, although soil features that occur on one archaeological surface may date differently to the archaeological layers which the features were dug into, the model will regard them as the same context. Table 6.3 assesses the context of finds analyzed for this research project. The majority of finds are gathered from anthropogenic deposits. However, significant amounts originate from ground features and cess- and waterpits. Especially susceptible to this issue are macrobotanical samples, which contexts are fairly even distributed.

Table 6.3: Origin of find analysed material in Grave-Oliestraat.

	Leather	Bone	Sample	Total
Cess-/waterpit	25	331	16	372
Pit/posthole/ditch	7	383	13	403
Brickwork	0	177	0	177
Layers	126	639	13	778
Other	0	24	0	24
Total	158	1554	42	

Acknowledging these issues, all artefacts and macrobotanical samples are still included in the analysis. Material from other contexts besides anthropogenic deposit layers could have been left out. This may especially have been significant for cess- and waterpits, as these features are often made out of brick and therefore specifically modeled separately. In some instances the volume of said cesspits were subtracted from the layer units, like in the yard of PLOT6 because the cesspits have a stone mantle. Additionally, their contents are expected to outdate anthropogenic layers and may represent household activities from a later date, rather than earlier craft activity. However, artefacts originating from those cesspits were still included in the analysis. This may have caused a discrepancy between the artefacts assigned to layer units and its calculated volume, causing a higher artefact density. In general, the model represents a simplification of the archaeological archive at the site. The 3D distribution of artefact densities may therefore only be regarded as an indication that particular zones of the site are of interest for traces of leatherworking, rather than highlighting specific deposit units. Interpreting the analysis results should be done with this in mind and should consider the actual archaeological features that were uncovered at a particular location. Because the current research is carried out prior to the definitive publication of the archaeological results, such an interpretation is not included.

7. Conclusion

In this chapter the thesis is concluded, answering the research questions which are posed in paragraph 1.3.

Over the last decade, 3D-GIS has mostly been applied in academic setting covering topics such as stratigraphy, distribution and artefact density. 3D-GIS can be defined as a digital tool that complies with the principles of GIS, while maintaining the ability edit in all three spatial dimensions. 3D-GIS applied was to analyze the occurrence of leatherworking within the site *Oliestraat* in Grave, a historical city on the bank of the river Meuse which became a urbanized settlement during the Medieval times. From the 16th century onwards, leatherworking gained a more systematic approach, located on the edge of towns and cities in close proximity to water. The excavation of Grave-Oliestraat mainly facilitated volumetric analysis of leatherworking activities based on the assemblage of leather discharge, faunal remains and ecological indicators.

A 3D-GIS model of Grave-Oliestraat can be constructed based on preexisting archaeological documentation. Modelling an urban site such as Grave-Oliestraat includes modeling brickwork, archaeological surfaces and archaeological soil deposits. Although the field methodology and the output documentation generally allowed for a 3D-GIS model, within each modeling phase additional steps had to be taken retrospectively to supplement the body of documentation. Creating a 3D-GIS model for volumetric analysis that is more true to the complexity of the site and more scientifically accurate would require more extensive documentation. Specifically, more depth data and ensuring continuous documentation on both the lateral and vertical axis are crucial.

Within the site, most archaeological artefacts are located on the upper archaeological levels. Calculated per cubic meter, the artefact density is more equally distributed. Using volumetric analysis, the current research indicated specific model units with a relatively high artefact density related to leatherworking. Specifically, the southwestern and mid-southern patches of the model GROL2 contain a relative high amount of finds related to leatherworking. A distinction leatherworking phase may be possible based on the nature of the artefacts. However, due to limited input data and the context of the find material being excluded in the analysis disallows for such interpretation.

Volumetric analysis based on a 3D-GIS model provides insight in find distributions relative to the context volume artefacts were retrieved from. Through this it provides a more objective approach for researching artefact distribution when the stratigraphy is complex. However, an urban archaeological site such as Grave-Oliestraat is in reality significantly more complex than 3D-GIS modelling can reliably achieve. Although more detailed modelling is possible, it would take significant amounts of time and effort and preferably requires more elaborate and structured documentation.

8. Abstract

This paper entails a scientific reflection on the creation of a 3D-GIS model of the archaeological excavation Grave-Oliestraat and a subsequently executed volumetric analysis on the occurrence of leatherworking therein. Following developments in computer soft- and hardware, the use of both GIS and 3D applications in archaeology has increased over the past decades. One branch of this development is 3D-GIS, distinguishing itself from other 3D methods by connection 3D spatial data to a database system and abiding to the principles of 3D-GIS. This allows for multiple types of spatial analyses. One of which is volumetric analysis, which calculates artefact density base on the volume of an artefact context, rather than its distribution in (2D) space. For this thesis, the site Grave-Oliestraat was analyzed by means of volumetric analysis, focusing on material traces of leatherworking. From the 16th century onwards, leatherworking became more systematic, giving rise to tannery workshops which were usually located on the edge of towns. Tanneries leave behind traces in the archaeological archive, including leather discharge, faunal remains ecological remains. During the fieldwork of Grave-Oliestraat an abundance of leather discharge and horn pits were found, indicating the occurrence of leatherworking in the Late Medieval period. The complexity of the site as well as the interest of the author made the site ideal for 3D-GIS modelling. Two parts of the site have been modeled using the ArcScene 3D-GIS application, referred to as PLOT6 and GROL2. Both areas were modeled following workflow charts developed based on the same modelling process. The modelling entailed modelling brickwork, archaeological surfaces and anthropogenic deposits and gave significant insight into the possibilities but also the limitations of 3D-GIS modelling based on documentation gathered by standard archaeological field methodology. Subsequently, a volumetric analysis was carried out on the modeled layer units. This provided insight in the distribution of finds related to leatherworking within the site and allowed for inquiring the value and viability of such a research method. The research shows that the field methodology applied at Grave-Oliestraat only partially allowed for viable 3D-GIS reconstruction of the site. Although a model is possible, additional and more consistent depth information such height measurements and profile documentation is necessary to model more effectively and realistically. Volumetric analysis provided insight into the distribution of finds related to leatherworking, pointing out specific deposit units which contain relatively many finds. However, results seem to correspond to general find densities, questioning the need for this expensive research method. Additionally, because the 3D-GIS model realistically remains a simplification of reality, the interpretation provide limited disclosure.

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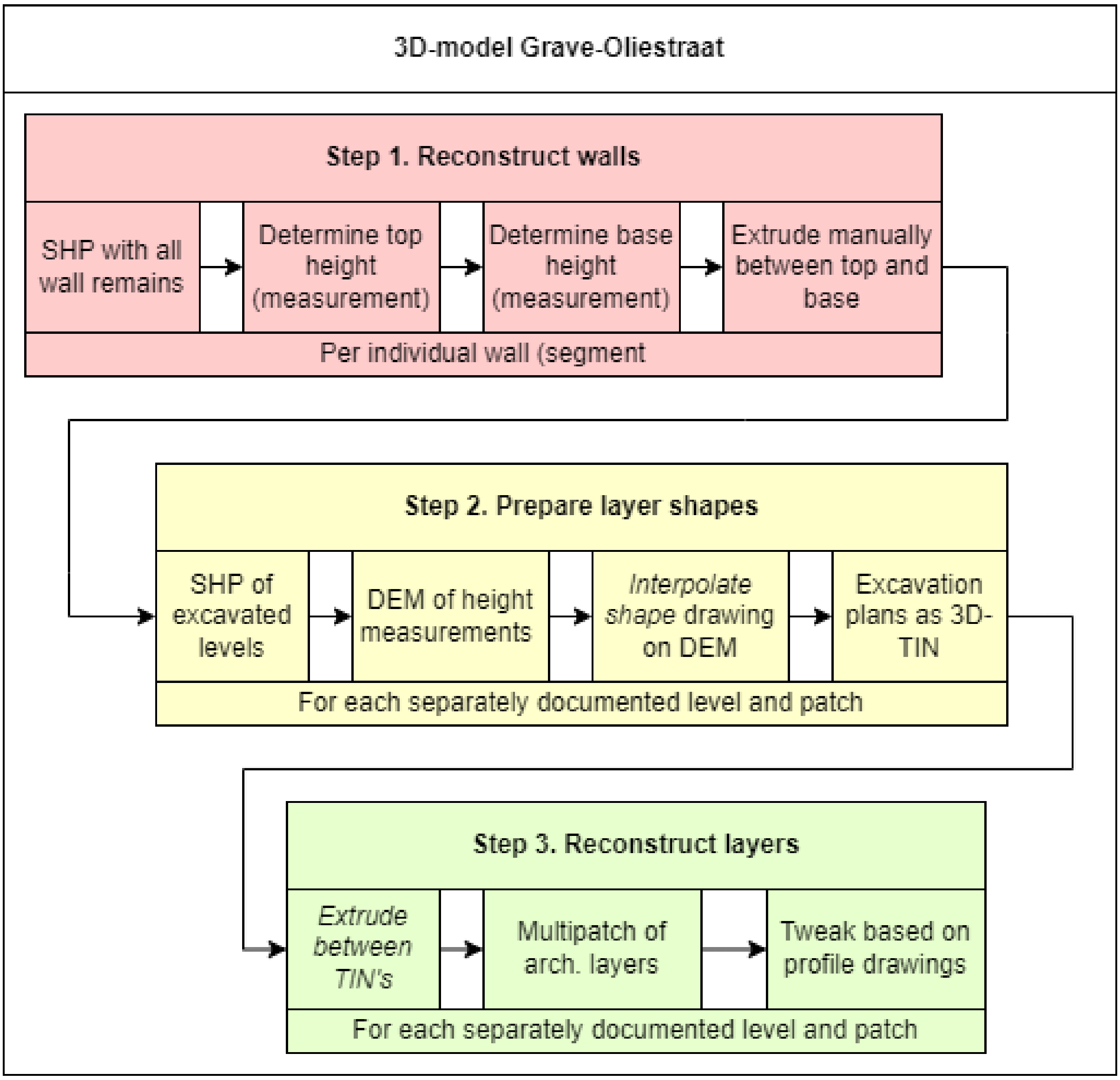
Appendices

Appendix 1.

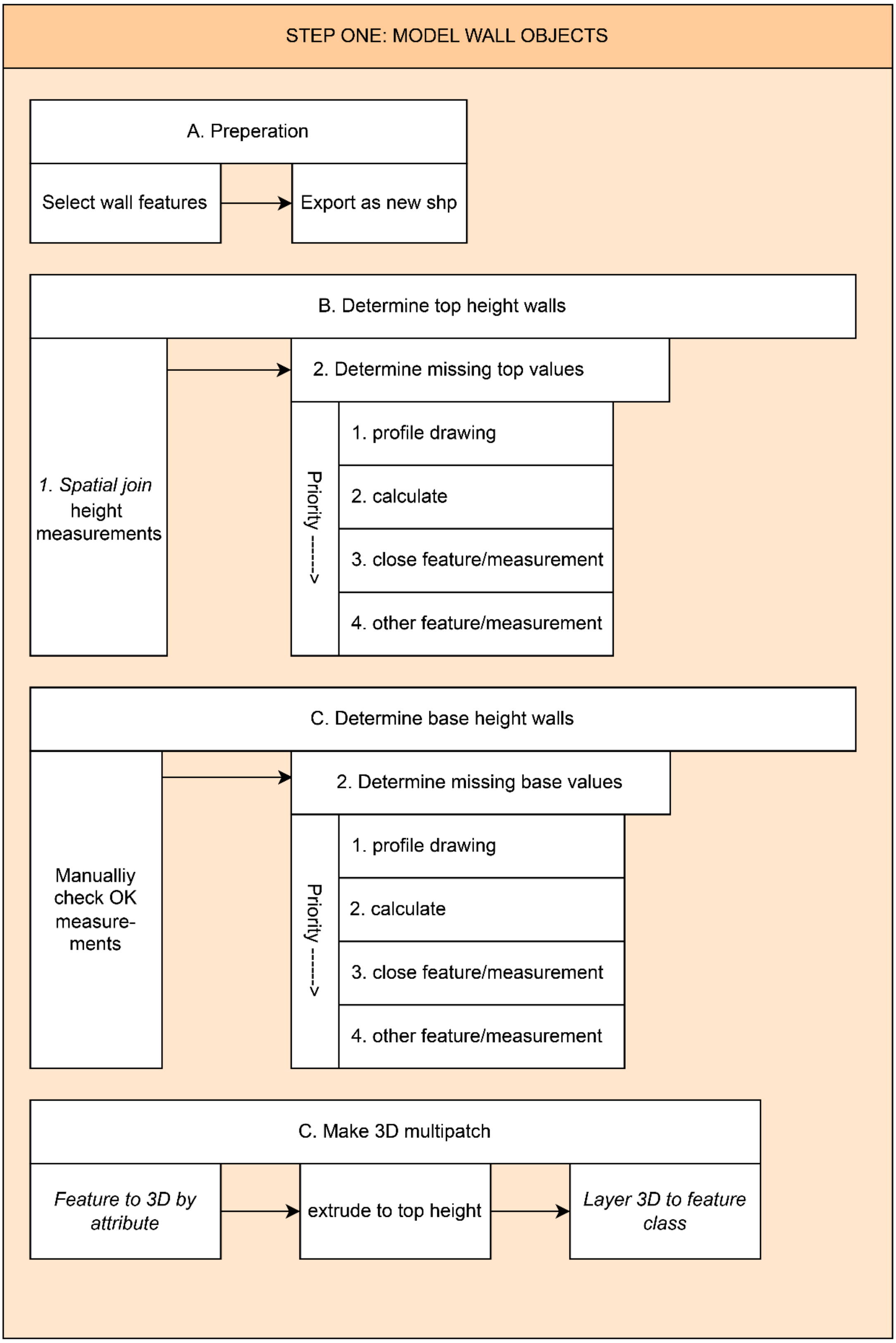
Preliminary 3D-GIS modelling workflow. (Pasteels, 2023)



Appendix 2. Modelling workflows

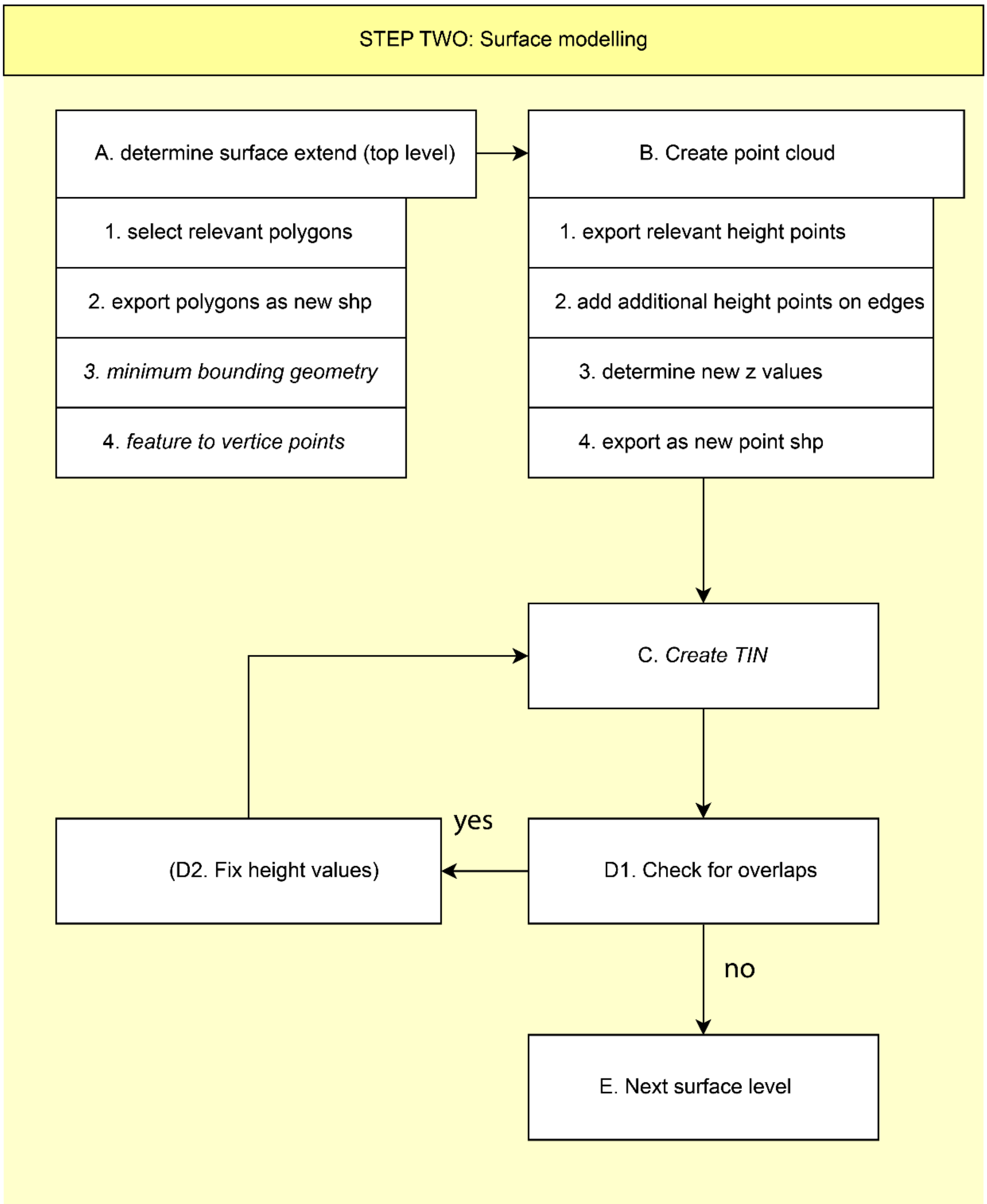
Appendix 2.1.

Brickwork 3D-GIS modelling workflow



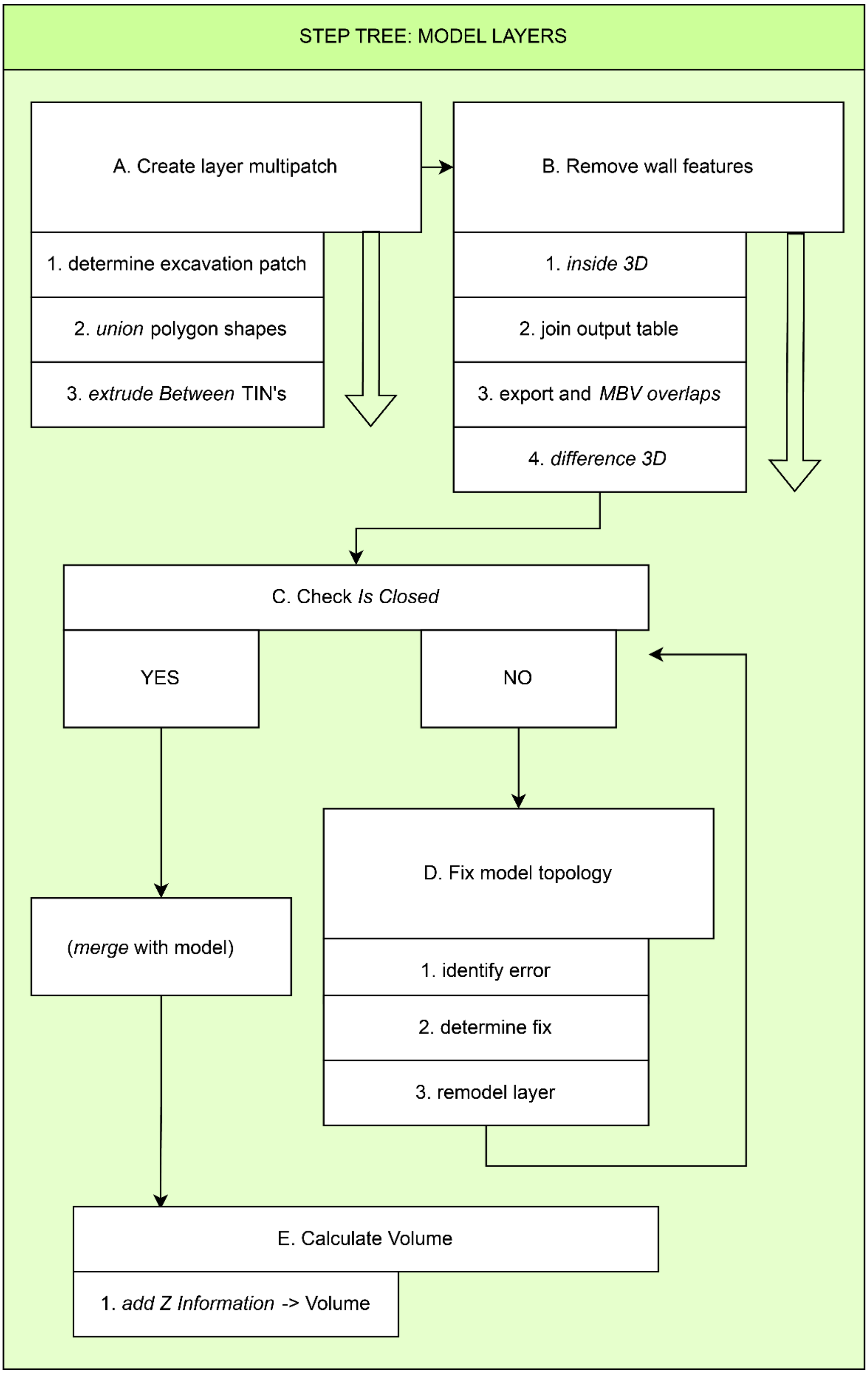
Appendix 2.2.

Archaeological surface modelling workflow



Appendix 2.3.

Archaeological deposit layer 3D-GIS modelling workflow.



Appendix 3. Attribute tables PLOT6

Appendix 3.1.

Attribute table PLOT6_brickwork_DEF

FID	Shape	FD_SPOORDE	FD_FEATURE	Volume	WPSN	TOP_dm	BASE_dm	TOP_cv	BASE_cv	FEATURE_cv	IsClosed
0	MultiPatch M	vloer	brickwork	0.019587	1334	interpolation zvlak	OK close	2	3	3	Yes
1	MultiPatch M	vloer	brickwork	0.009736	1334	interpolation zvlak	OK close	2	3	3	Yes
2	MultiPatch M	vloer	brickwork	0.010702	1334	interpolation zvlak	OK close	2	3	3	Yes
3	MultiPatch M	muurwerk	brickwork	1.501501	1191	single zvlak	profile drawing	1	1	1	Yes
4	MultiPatch M	muurwerk	brickwork	0.641812	1010	maximum zvlak	OK measurement	1	1	1	Yes
5	MultiPatch M	muurwerk	brickwork	0.647611	1312	single zvlak	profile drawing	1	1	1	Yes
6	MultiPatch M	beerput	brickwork	0.001147	1335	base_z + brick height	closest zvlak	2	3	3	Yes
7	MultiPatch M	muurwerk	brickwork	0.954083	1010	maximum zvlak s1.192	OK corresponding	3	3	2	Yes
8	MultiPatch M	muurwerk	brickwork	0.804199	1571	maximum zvlak	top-layers*bricks	1	2	2	Yes
9	MultiPatch M	muurwerk	brickwork	0.028259	1572	maximum zvlak	top-layers*bricks	1	2	2	Yes
10	MultiPatch M	muurwerk	brickwork	0.093075	1579	zvlak s1.584	bottom s1.584	4	4	4	Yes
11	MultiPatch M	beerput	brickwork	0.994894	1547	zvlak l1	OK mesurement	3	1	3	Yes

12	MultiPatch M	beerput	brickwork	1.681317	1547	single zvlak	Bottom measurement	1	1	1	Yes
13	MultiPatch M	beerput	brickwork	0.293263	1578	zvlak s1.578	profile drawing	3	1	3	Yes
14	MultiPatch M	beerput	brickwork	0.02337	1578	zvlak s1.578	corresponding segment	3	3	2	Yes
15	MultiPatch M	muurwerk	brickwork	0.044027	1577	single zvlak	profile drawing	1	1	1	Yes
16	MultiPatch M	beerput	brickwork	0.792281	1578	zvlak s1.578	profile drawing maximum	3	1	3	Yes
17	MultiPatch M	beerput	brickwork	0.859644	1578	single zvlak	profile drawing	1	1	1	Yes
18	MultiPatch M	muurwerk	brickwork	0.070705	1585	maximum zvlak	top-layers*bricks	1	2	2	Yes
19	MultiPatch M	muurwerk	brickwork	0.054834	1585	corresponding segment	corresponding segment	3	3	2	Yes
20	MultiPatch M	muurwerk	brickwork	0.319454	1544	s1.542 and pic	s1.542 and pic	3	3	2	Yes
21	MultiPatch M	muurwerk	brickwork	0.886389	1543	maximum zvlak	top_z-layers*brick height	1	2	2	Yes
22	MultiPatch M	muurwerk	brickwork	0.073667	1584	single zvlak	top-layers*brics pic	1	2	2	Yes
23	MultiPatch M	muurwerk	brickwork	0.111431	1579	zvlak s1.584	bottom s1.584	4	4	4	Yes
24	MultiPatch M	stiep/poer	brickwork	0.023258	1542	base_z+layers*bric k height	s1.542 and pic	2	3	3	Yes
25	MultiPatch M	stiep/poer	brickwork	0.100094	1542	base_z+layers*bric k height	s1.542 and pic	2	3	3	Yes
26	MultiPatch M	stiep/poer	brickwork	0.034727	1542	base_z+layers*bric k height	s1.542 and pic	2	3	3	Yes
27	MultiPatch M	muurwerk	brickwork	0.291855	1237	single zvlak	average s1.10 s1.191	1	4	4	Yes

28	MultiPatch M	muurwerk	brickwork	0.005037	1543	corresponding feature, pic	corresponding feature, pic	3	3	2	Yes
29	MultiPatch M	muurwerk	brickwork	0.003216	1193	closest zvlak high	closest zvlak low	2	3	2	Yes
30	MultiPatch M	muurwerk	brickwork	0.426416	1574	maximum zvlak	top s1.572	1	3	2	Yes
31	MultiPatch M	beerput	brickwork	0.001145	1335	base_z + brick height	closest zvlak	2	3	3	Yes
32	MultiPatch M	muurwerk	brickwork	0.030882	1575	single zvlak	top-layers*bricks	1	2	2	Yes
33	MultiPatch M	muurwerk	brickwork	0.018365	1573	single zvlak	top-layers*bricks	1	2	2	Yes
34	MultiPatch M	vloer	brickwork	0.057903	1180	single zvlak	top-layers*bricks	1	2	2	Yes
35	MultiPatch M	vloer	brickwork	1.108886	1180	maximum zvlak	top-layers*bricks	1	2	2	Yes
36	MultiPatch M	vloer	brickwork	0.076729	1180	single zvlak	top-layers*bricks	1	2	2	Yes
37	MultiPatch M	vloer	brickwork	0.483221	1349	TIN zvlak3	TIN zvlak3-brickheight	2	2	3	Yes
38	MultiPatch M	muur	brickwork	0.097438	1346	avg close zvlak	top-layers*brickheight	3	2	3	Yes
39	MultiPatch M	vloer	brickwork	1.156493	1334	TIN zvlak2	TIN zvlak2-brickheight	2	2	3	Yes
40	MultiPatch M	muurwerk	brickwork	0.518238	1336	base_z s1.80	TIN zvlak3	3	2	3	Yes
41	MultiPatch M	muurwerk	brickwork	4.194371	1192	max zvlak	profile s191	1	3	3	Yes
42	MultiPatch M	muurwerk	brickwork	1.026762	1192	max zvlak	profile s191	1	3	3	Yes

Appendix 3.2.

Attribute table PLOT6_layers_DEF

FID	Shape *	GROL3D_plo	FD_SPOORDE	FD_FEATURE	Volume	IsClosed
0	MultiPatch M	1350	puinlaag	layer	7.687665	Yes
1	MultiPatch M	9002	layer	layer	5.380855	Yes
2	MultiPatch M	9001	layer	layer	4.443344	Yes
3	MultiPatch M	9003	layer	layer	2.678421	Yes
4	MultiPatch M	9004	layer	layer	22.43015	Yes
5	MultiPatch M	9005	layer	layer	11.39327	Yes
6	MultiPatch M	9006	layer	layer	3.312045	Yes

Appendix 4. Attribute tables GROL2

Appendix 4.1.

Attribute table GROL2_brickwork_DEF

FID	Shape	wpsn	FD_SPOORDE	FD_FEATURE	TOP_DM	BASE_DM	TOP_CV	BASE_CV	FEATURECV	IsClosed
0	MultiPatch M	2014	stiep/poer	brickwork	zvlak	profile	1	1	1	Yes
1	MultiPatch M	2014	stiep/poer	brickwork	zvlak	profile	1	1	1	Yes
2	MultiPatch M	2014	stiep/poer	brickwork	zvlak FID1	profile	3	1	3	Yes
3	MultiPatch M	2014	stiep/poer	brickwork	zvlak FID1-brickheight	profile	3	1	3	Yes
4	MultiPatch M	2018	muurwerk	brickwork	s2013	s2013	4	4	4	Yes
5	MultiPatch M	2126	muur	brickwork	zvlak	OK (s210)	1	1	1	Yes
6	MultiPatch M	2248	beerput	brickwork	zvlak s2248	zvlak s2248-layer*brickheight	3	3	3	Yes
7	MultiPatch M	2248	beerput	brickwork	close zvlak	zvlak s2248-layer*brickheight	3	3	3	Yes
8	MultiPatch M	2249	vloer	brickwork	zvlak	zvlak-layers*brickheight	1	2	2	Yes
9	MultiPatch M	2237	beerput	brickwork	p57	p57	1	1	1	Yes
10	MultiPatch M	2237	beerput	brickwork	zvlak	p57	1	1	1	Yes
11	MultiPatch M	2237	beerput	brickwork	zvlak	p57	1	1	1	Yes
12	MultiPatch M	2237	beerput	brickwork	zvlak	p57	1	1	1	Yes
13	MultiPatch M	2237	beerput	brickwork	zvlak s2237-5	p57	3	1	3	Yes
14	MultiPatch M	2210	muur	brickwork	zvlak	OK (s210)	1	1	1	Yes
15	MultiPatch M	2126	muur	brickwork	zvlak	OK	1	1	1	Yes

16	MultiPatch M	2103	muur	brickwork	zvlak	OK s2126	1	3	3	Yes
17	MultiPatch M	2086	stiep/poer	brickwork	zvlak	base_z S2085	1	3	3	Yes
18	MultiPatch M	2085	muur	brickwork	zvlak	zvlak-5L*brickheight	1	2	2	Yes
19	MultiPatch M	2105	stiep/poer	brickwork	profile	profile	1	1	1	Yes
20	MultiPatch M	2105	stiep/poer	brickwork	profile	profile	1	1	1	Yes
21	MultiPatch M	2105	stiep/poer	brickwork	profile	profile	1	1	1	Yes
22	MultiPatch M	2146	put	brickwork	zvlak	zvlak -1m (photo)	1	2	2	Yes
23	MultiPatch M	2126	muur	brickwork	zvlak	OK	1	1	1	Yes
24	MultiPatch M	2067	beerput	brickwork	zvlak	ok	1	1	1	Yes
25	MultiPatch M	2067	beerput	brickwork	zvlak	ok	1	1	1	Yes
26	MultiPatch M	2067	beerput	brickwork	zvlak	ok	1	1	1	Yes
27	MultiPatch M	2104	beerput	brickwork	base+20cm	zvlak2	3	4	4	Yes
28	MultiPatch M	2158	beerput	brickwork	zvlak	Floor s158-brickheight	1	2	2	Yes
29	MultiPatch M	2067	beerput	brickwork	zvlak	ok	1	1	1	Yes
30	MultiPatch M	2098	stiep/poer	brickwork	zvlak	p13	1	1	1	Yes
31	MultiPatch M	2098	stiep/poer	brickwork	zvlak	p13	1	1	1	Yes
32	MultiPatch M	2098	stiep/poer	brickwork	zvlak	p13	1	1	1	Yes
33	MultiPatch M	2070	muur	brickwork	zvlak	profile	1	1	1	Yes
34	MultiPatch M	2158	beerput	brickwork	close zvlak-brickheight	Floor s158-brickheight	3	2	3	Yes
35	MultiPatch M	2158	beerput	brickwork	zvlak	Floor s158-brickheight	1	2	2	Yes
36	MultiPatch M	2078	muur	brickwork	zvlak	zvlak-2*brickheight	1	2	2	Yes
37	MultiPatch M	2044	muur	brickwork	zvlak	OK s102	1	3	3	Yes

38	MultiPatch M	2074	muur	brickwork	zvlak	OK s102	1	3	3	Yes
39	MultiPatch M	2147	gootje?	brickwork	zvlak	zvlak-brickheight	1	2	2	Yes
40	MultiPatch M	2103	muur	brickwork	zvlak	OK (s126)	1	1	1	Yes
41	MultiPatch M	2044	muur	brickwork	zvlak	OK s102	1	3	3	Yes
42	MultiPatch M	2070	muur	brickwork	zvlak	profile	1	1	1	Yes
43	MultiPatch M	2094	muur	brickwork	zvlak	ok	1	1	1	Yes
44	MultiPatch M	2147	gootje?	brickwork	zvlak	base s2147	1	3	3	Yes
45	MultiPatch M	2053	muur	brickwork	zvlak	zvlak-5L	1	4	4	Yes
46	MultiPatch M	2043	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
47	MultiPatch M	2055	waterkelder	brickwork	zvlak	OK s102	1	3	3	Yes
48	MultiPatch M	2055	waterkelder	brickwork	zvlak s2054+brickheight	OK s102	3	3	3	Yes
49	MultiPatch M	2054	vloer	brickwork	zvlak s2054-brickheight	OK s102	3	3	3	Yes
50	MultiPatch M	2102	muur	brickwork	zvlak	OK	1	1	1	Yes
51	MultiPatch M	2102	muur	brickwork	zvlak	OK	1	1	1	Yes
52	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
53	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
54	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
55	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
56	MultiPatch M	2102	muur	brickwork	zvlak	OK	1	1	1	Yes
57	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
58	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
59	MultiPatch M	2014	stiep/poer	brickwork	zvlak s2014	profile	3	1	3	Yes

60	MultiPatch M	2013	vloer	brickwork	profile	profile	1	4	4	Yes
61	MultiPatch M	2248	beerput	brickwork	zvlak	zvlak s2248-layer*brickheight	1	3	3	Yes
62	MultiPatch M	2248	beerput	brickwork	zvlak s2248	zvlak-layers*brickheight	3	2	3	Yes
63	MultiPatch M	2249	vloer	brickwork	zvlak	zvlak-layers*brickheight	1	2	2	Yes
64	MultiPatch M	2237	beerput	brickwork	p57	p57	1	1	1	Yes
65	MultiPatch M	2146	put	brickwork	base +20cm	base s2146	3	3	3	Yes
66	MultiPatch M	2204	muur	brickwork	close zvlak -2*brickheight	OK	3	1	3	Yes
67	MultiPatch M	2103	muur	brickwork	zvlak	OK s2126	1	3	3	Yes
68	MultiPatch M	2085	muur	brickwork	zvlak	zvlak-5L*brickheight	1	2	2	Yes
69	MultiPatch M	2104	beerput	brickwork	zvlak	zvlak2	1	3	3	Yes
70	MultiPatch M	2101	vloer	brickwork	zvlak	zvlak-brickheight	1	2	2	Yes
71	MultiPatch M	2146	put	brickwork	top s2146 -20cm	base_s2146	3	3	3	Yes
72	MultiPatch M	2158	beerput	brickwork	zvlak	Floor s158-brickheight	1	2	2	Yes
73	MultiPatch M	2108	muur	brickwork	zvlak	5L measurement	1	4	4	Yes
74	MultiPatch M	2067	beerput	brickwork	zvlak	ok	1	1	1	Yes
75	MultiPatch M	2076	vloer	brickwork	zvlak	zvlak-brickheigt	1	2	2	Yes
76	MultiPatch M	2045	muur	brickwork	zvlak	OK s102	1	3	3	Yes
77	MultiPatch M	2064	muur	brickwork	zvlak	OK s102	1	3	3	Yes
78	MultiPatch M	2158	beerput	brickwork	zvlak	Floor s158-brickheight	1	2	2	Yes
79	MultiPatch M	2147	gootje?	brickwork	zvlak	base s2147	1	3	3	Yes
80	MultiPatch M	2103	muur	brickwork	zvlak	OK (s126)	1	1	1	Yes
81	MultiPatch M	2158	beerput	brickwork	close zvlak +brickheight	Floor s158	3	3	3	Yes

82	MultiPatch M	2147	gootje?	brickwork	zvlak	base s2147	1	3	3	Yes
83	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
84	MultiPatch M	2076	vloer	brickwork	zvlak	top s2077	1	3	3	Yes
85	MultiPatch M	2077	vloer	brickwork	zvlak	low zvlak-brickheight	1	2	2	Yes
86	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
87	MultiPatch M	2055	waterkelder	brickwork	zvlak 2055	OK s102	3	3	3	Yes
88	MultiPatch M	2054	vloer	brickwork	zvlak	OK s102	1	3	3	Yes
89	MultiPatch M	21031	muur	brickwork	zvlak	top s203	1	3	3	Yes
90	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
91	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
92	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
93	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
94	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
95	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
96	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
97	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
98	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
99	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
100	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
101	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
102	MultiPatch M	2126	muur	brickwork	base s147	ok	4	1	4	Yes
103	MultiPatch M	2203	stiep/poer	brickwork	p41	p41	1	1	1	Yes

104	MultiPatch M	2203	stiep/poer	brickwork	p41	p41	1	1	1	Yes
105	MultiPatch M	2203	stiep/poer	brickwork	p41	p41	1	1	1	Yes
106	MultiPatch M	2203	stiep/poer	brickwork	p41	p41	1	1	1	Yes
107	MultiPatch M	2092	muur/vloer	brickwork	profile	profile	1	1	1	Yes
108	MultiPatch M	2125	muur	brickwork	zvlak s125+6	ok	2	1	2	Yes
109	MultiPatch M	2125	muur	brickwork	zvlak s125+6	ok	2	1	2	Yes
110	MultiPatch M	2102	muur	brickwork	zvlak	ok	1	1	1	Yes
111	MultiPatch M	2102	muur	brickwork	zvlak	ok	1	1	1	Yes
112	MultiPatch M	2102	muur	brickwork	zvlak	ok	1	1	1	Yes
113	MultiPatch M	2102	muur	brickwork	zvlak	ok	1	1	1	Yes
114	MultiPatch M	2102	muur	brickwork	zvlak	ok	1	1	1	Yes
115	MultiPatch M	2125	muur	brickwork	zvlak	ok	2	1	2	Yes
116	MultiPatch M	2125	muur	brickwork	zvlak s125+6	ok	2	1	2	Yes
117	MultiPatch M	2125	muur	brickwork	zvlak s125+6	ok	2	1	2	Yes
118	MultiPatch M	2125	muur	brickwork	zvlak s125+6	ok	2	1	2	Yes
119	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
120	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
121	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
122	MultiPatch M	2158	beerput	brickwork	p29	p29	1	1	1	Yes
123	MultiPatch M	2158	beerput	brickwork	zvlak	p29	1	1	1	Yes
124	MultiPatch M	2158	beerput	brickwork	8.889	max_z plank	1	2	2	Yes
125	MultiPatch M	2114			zvlak s114	zvlak=brickheight s114	3	3	3	Yes

126	MultiPatch M	2113			zvlak	zvlak-brickheight	1	2	2	Yes
127	MultiPatch M	2112			zvlak	zvlak-brickheight s113	1	3	3	Yes
128	MultiPatch M	2114			zvlak	zvlak-brickheight	1	2	2	Yes

Appendix 4.2.

Attribute table GROL2_layers_DEF

FID	Shape	IsClosed	Volume	vlakpatch
0	MultiPatch M	Yes	8.038822	18
1	MultiPatch M	Yes	15.83257	11
2	MultiPatch M	Yes	6.296442	21
3	MultiPatch M	Yes	15.29541	28
4	MultiPatch M	Yes	6.234107	34
5	MultiPatch M	Yes	6.55971	33
6	MultiPatch M	Yes	6.514819	37
7	MultiPatch M	Yes	4.581915	38
8	MultiPatch M	Yes	5.457604	49
9	MultiPatch M	Yes	21.7599	56
10	MultiPatch M	Yes	2.368793	53
11	MultiPatch M	Yes	2.68187	47
12	MultiPatch M	Yes	55.91029	13
13	MultiPatch M	Yes	10.96577	24
14	MultiPatch M	Yes	22.22817	26
15	MultiPatch M	Yes	4.352785	12
16	MultiPatch M	Yes	1.241887	22
17	MultiPatch M	Yes	2.860566	36
18	MultiPatch M	Yes	0.947721	32
19	MultiPatch M	Yes	2.677719	48
20	MultiPatch M	Yes	3.062147	46
21	MultiPatch M	Yes	5.373382	45
22	MultiPatch M	Yes	2.937876	44
23	MultiPatch M	Yes	4.335814	43
24	MultiPatch M	Yes	6.480392	57
25	MultiPatch M	Yes	1.830042	31