CASTLE3D - A COMPUTER AIDED SYSTEM FOR LABELLING ARCHAEOLOGICAL EXCAVATIONS IN 3D

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ABSTRACT:

Documentation of archaeological excavation sites with conventional methods and tools such as hand drawings, measuring tape and archaeological notes is time consuming. This process is prone to human errors and the quality of the documentation depends on the qualification of the archaeologist on site. Use of modern technology and methods in 3D surveying and 3D robotics facilitate and improve this process. Computer-aided systems and databases improve the documentation quality and increase the speed of data acquisition. 3D laser scanning is the state of the art in modelling archaeological excavation sites, historical sites and even entire cities or landscapes. Modern laser scanners are capable of data acquisition of up to 1 million points per second. This provides a very detailed 3D point cloud of the environment. 3D point clouds and 3D models of an excavation site provide a better representation of the environment for the archaeologist and for documentation. The point cloud can be used both for further studies on the excavation and for the presentation of results. This paper introduces a Computer aided system for labelling archaeological excavations in 3D (CASTLE3D). Consisting of a set of tools for recording and georeferencing the 3D data from an excavation site, CASTLE3D is a novel documentation approach in industrial archaeology. It provides a 2D and 3D visualisation of the data and an easy-to-use interface that enables the archaeologist to select regions of interest and to interact with the data in both representations. The 2D visualisation and a 3D orthogonal view of the data provide cuts of the environment that resemble the traditional hand drawings. The 3D perspective view gives a realistic view of the environment. CASTLE3D is designed as an easy-to-use on-site semantic mapping tool for archaeologists. Each project contains a predefined set of semantic information that can be used to label findings in the data. Multiple regions of interest can be joined under one label. Further information such as color, orientation and archaeological notes are added to the label to improve the documentation. The available 3D information allows for easy measurements in the data. The full 3D information of a region of interest can be segmented from the entire data. By joining this data from different georeferenced views the full 3D shape of findings is stored. All the generated documentation in CASTLE3D is exported to an XML format and serves as input for other systems and databases. Apart from presenting the functionalities of CASTLE3D we evaluate its documentation process in a sample project. For this purpose we export the data to the Adiuvabit database (http://adiuvabit.de) where more information is added for further analysis. The documentation process is compared to traditional documentation methods and it is shown how the automated system helps in accelerating the documentation process and decreases errors to a minimum.

1. INTRODUCTION

Archaeology is the study of history and the human activity in the past, through the analysis and recovery of their legacies and environmental data that they have left behind such as artefacts, architecture, cultural landscapes, art, etc. In Germany every large scale construction project is prefaced by a series of inspections. These are performed to determine the possible existence of artefacts or other remains of cultural or historical significance. Archaeologist accompany the building projects to prevent the destruction of archaeological sites. It is desirable to excavate efficiently to minimize the time and cost for the client. Therefore development of a framework such as our project comes into effect: an easy-to-use hardware and software system allows the digitisation of the excavation site with 3D laser scanner and generation of digital documentation of the excavation process. This will help archaeological activities to be carried out more efficiently leading to cost saving results. After the completion of the excavation, collected data and documentation of the potential findings will be evaluated and after analysis and post processing a report will be made available to the authorities.

Conventional methods of documentation for archaeological features are based on manual drawings on graph paper and archaeological notes. These sketches provide levels, colors and numbers for findings with a connection to a detailed catalogue. Findings are also photographically recorded within these catalogues. Archaeologist try to document the excavation site meticulously during the excavation process (Fig. 1). These documents are generated to record the findings as precisely as possible and to describe them in three dimensions based on their chronological sequence. Documents are evaluated after completion of the excavation. The findings provide insights on early culture, religion, handcraft, daily life and social process on both local and national levels. However lack of access to the original findings on the excavation and dependency of the documentation on the knowledge and understanding of the onsite archaeologist make the documentation biased. Technological achievements in the last 10 years enable higher accuracies in the documentation process. Moreover they could accelerate this process with regard to economic

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Figure 1: Top: An excavation site located at "Haus Kump", a building from the 16th century, which is the oldest storage building in Münster, Germany. Bottom: Findings on a graph paper that were meticulously sketched by an archaeologist on site.

constraints. But, they create at the same time a large amount of data that is no longer subject to the evaluation judgment of the archaeologist. Automatic acquisition of data occurs even without interaction of the archaeologist. Photogrammetry, 3D laser scanners and electronic measuring devices are used in archaeology. However the data captured with cameras and 3D laser scanners from the excavation sites often only serve as a snapshots as as-build documentation and reference. (Campana and Remondino, 2007) remark in their publication that use of 3D digital documentation and representation in terms of scientific investigation is disappointing and that the use of such technologies is typically oriented to suggest final reconstructions and not to contribute to the scientific interpretation. 3D representations of environments, especially excavation sites are becoming the standard for archaeologist. 3D laser scanners are the standard instrument in the field of optical metrology. They measure the distance to a point on a surface around the scanner by sending a focused laser beam in that direction. The distance is calculated by measuring the time difference of the emitted and reflected signals. Two different types of laser scanning technology have established themselves in this field. Pulsed laser range finders send a short pulse of light and directly measure the amount of time it takes for the laser pulse to travel from the scanner to the object and back to the scanner. The distance is then calculated via the speed of light. Since the speed of light is almost 300000 km/s, tools with picoseconds (10^{-12} s) resolution need to be used in order to calculate the distance with an accuracy of 10 mm. Other than pulsed systems there are laser scanners that continuously emit modulated laser light. The change of the phase between the emitted light and the received signal determines the light travel time. Since the phase shift in only one interval between 0 and 2π is non ambiguous, the maximum range of these devices is inherently limited. Current phase-based laser scanners achieve a range of about 80-120 m whereas pulse-based laser scanners can measure distances up to several kilometers. However, since phase-based laser scanners emit light continuously they can operate at a higher measurement speed than pulsed systems. Besides the distance to objects, laser scanners determine the intensity of the reflected light. This yields information about the reflectivity of the scanned surface. Further combination of the Light Detection and Ranging (LiDAR) systems with color cameras is possible.

This paper presents a framework with a set of software tools for archaeologist to digitise excavation sites and generate documentation on site. It is built based on *The 3D Toolkit (3DTK)*. 3D laser scans obtained by frequently scanning the archaeological site are georeferenced and efficiently visualised to the archaeologist on a tablet computer. Findings are marked on-site with a closed polygon and measurements are available for the digitised environment. These localised information and archaeological notes are send to an archaeological database for documentation and reasoning. CAD (Computer Aided Design) models of the findings are available by exporting the polygon vertices of the findings. Post processing of the generated documentation on the database provides the Harris Matrix for constraint checking. Thus generated documentation is suitable for publication. The paper is structured as follows. Section 2. reports on the state of the art in modern archaeology and the tools to assist archaeologist during excavation, documentation, study and analysis of excavation sites. Section 3. presents our framework to asset the archaeological team from excavation to publication of the documentation. It contains our Computer Aided System for Labelling Archaeological Excavations in 3D (CASTLE3D). Section 4. presents CASTLE3D in detail including tools to import the captured data to the software and the visualisation tool in 2D and 3D. The software focusses on semantic mapping of the excavation. Section 5. presents a workflow of our framework on an excavation site in Germany and section 6. contains the concluding remarks.

2. RELATED WORK

Archeological artefacts and historical sites have an inestimable value. However, often they have only been recognised after they are damaged or destroyed. An archaeological excavation usually leads to the discovery and understanding of the archaeological remains. In most cases it also leads to the destruction of the context and integrity of those remains. With the use of technology and 3D modelling techniques it is possible to reconstruct such cultural heritage objects. (Katsianis et al., 2008) discuss a formal data model and a complete digital workflow for the documentation of excavation sites in 3D by using GIS. (Apollonio et al., 2012) propose a framework that uses 3D digital models as a restitution of the real object and as metaphor for navigation through the data. They describe the procedures, techniques and pipeline used for creating the framework. Their ultimate goal is to use the framework to generate the base elements needed to develop a 3D GIS of a large archaeological site. (Wüst et al., 2004) propose applying the 3D GIS project DILAS (Digital Landscape Server) to archaeology and cultural heritage projects. The original aim of DILAS was the efficient generation, management and visualisation of large 3D landscapes and city models. (Rua and Alvito, 2011) propose the creation of a series of methods and tools for testing and analysing theories and hypotheses for historical scenarios through the use of 3D modelling tools and virtual reality engines. (Cosmas et al., 2001) introduce the "3D Measurement and Virtual Reconstruction of Ancient Lost World of Europe" system (3D MURALE). This system consists of a set of tools for recording, reconstructing, encoding, visualising and database searching or querying. These tools are linked together by a common database. The database serves several purposes. It contains information about the pieces. It also serves as a repository for archaeologist to help them to classify findings, to prepare restoration and to keep track of statistics. The database is a major gateway to the wider public and to other archaeologists. (Grabczewski et al., 2001) describe the 3D MURALE multimedia database system architecture. The goal of this system is to digitally record, store, restore and visualise archaeological findings. (Reu et al., 2014) suggest the use of image-based 3D modelling methods for the recording, documentation and visualisation of the excavated archaeologic heritage. It offers great possibilities for increasing the quality of the achieved archaeological excavation record. (Gilboa et al., 2013) report the development of a computerised automatic system to illustrate complex archaeological objects based on 3D scans of the artefacts. 3D models can be automatically translated into 2D or 3D line drawings, into coloured images and to images to enhance the visualisation of the artefact. These methods are tended to replace traditional hand drawings which are very expensive to produce and not accurate enough. Their system uses 3D scans of archaeological artefacts in order to produce images that visualise them better than the 3D model themselves. (Kuzminsky and Gardiner, 2012) propose the use of 3D laser scanning which offers a sophisticated method of documenting and studying prehistoric human skeletons. A major benefit of laser scanners is that they offer a cost-effective method of creating a digital record of skeletal collections for museum archives. The 3D imaging methods are enabling scientists to expand and improve their research. They present how advanced but affordable 3D scanners can be used for new research and aid in the documentation and preservation of the fragile skeletal material. (Karmacharya et al., 2008) suggest the use of a web platform based on knowledge management and semantic web technologies. It is used to store the data during the excavation process and to manage the knowledge acquired during the identification process of findings. Since different technologies are being used during the excavation, different patterns of data are generated. One of the sources of data are the 3D point clouds obtained through the terrestrial laser scanning process. Point clouds, floor plans, images and archaeological notes are collected during the project for the creation of 3D object models. Non-academic archaeology generates a huge amount of data in a very short period of time. Thus, the collected data is stored in a repository. Once the data is stored, the process of identification of findings is carried out.

A lot of work has been done to use computer-aided systems to facilitate archaeological excavation processes. 3D laser scans are used in several projects for data representation as an snapshot of the excavation. 3D models are generated to present the findings for museums. However, to the best of our knowledge no tools have been presented yet that allow archaeologists to use 3D laser scanners as main tool for documentation and to achieve more precise results in the same form as conventional methods in shorter time. In this paper we present an easy-to-use framework that combines several tools to assist the excavation process. We propose the use of 3D scans for documentation and semantic mapping of the excavation. To generate objective data for archaeological teams for further studies and analysis. Our framework presents a workflow that combines different systems such as a 3D laser scanner, a tool for marking and labelling findings, a database and provides an infrastructure for other tools to be included in the framework.

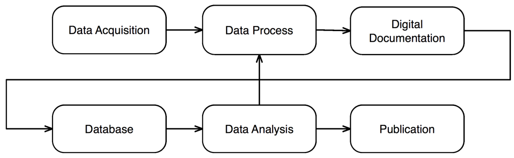

Figure 2: Framework Overview

3. FRAMEWORK

The advance in new technologies provides tools and methods to asset the archaeologist during the excavation process and to generate an objective documentation of the excavation. Our goal is to present a framework that uses several components to achieve online semantic mapping of the excavation and to produce digital data and documentation from excavation sites (Fig 2). This data is used for further studies and analysis of the archaeological sites. The aim of this framework is to provide computer aided systems to substitute the conventional methods of the archaeological documentation and analysis process. The documentation of an excavation is a very important and time consuming task that requires an archaeologist on the excavation site. Conventional methods of documentation include hand drawings of findings and manual measurements of the objects with comprehensive archaeological notes. The quality of the gathered data depends to a great degree on the skills and expertise of the archaeologist on the site. Therefore these documents are prone to human error. Furthermore managing and studying this inadequate data is a very difficult process. Due to the essence of the excavation, providing new information and extending or modifying the documentation based on conventional methods are demanding tasks. New technologies such as photogrammetry, 3D imaging and 3D laser scanning are vastly used in modern excavations to provide a snapshot of the excavation for publication purposes. However, the captured data has hardly been used for the documentation or analysis process. Computer systems are used in modern archaeology, but mostly for saving the captured data and the generated documentation in the database. In this framework we present a toolchain to help archaeologists to capture, generate, process, save, study and analyse the excavation site. This framework presents new ways of semantically mapping the excavation site. Moreover, it creates objective data and provides means for archaeologists to study and analyse an excavation based on their own knowledge. This will reduce the human inaccuracies and increase the efficiency and speed of the excavation. The framework presents the combination of several tools and incorporates the idea of using computer aided systems in archaeology through a standard workflow. Figure 2 shows the entire processing pipeline that is undertaken for an excavation. It starts with the data acquisition at the excavation site, goes through the processing and analysis and ends with the publication of the results. The individual components are explained in more detail in the following. The idea of our framework is to create a standard for computer-aided archaeological documentation. Each tool in the chain is exchangeable to comply with the archaeologist's needs and the available infrastructure.

3.1 Data Acquisition

One of the main limitations for industrial excavations is the amount of time available for the excavation. Data acquisition in conventional archaeological methods includes hand drawings of the findings and sometimes the whole excavation area. This requires an

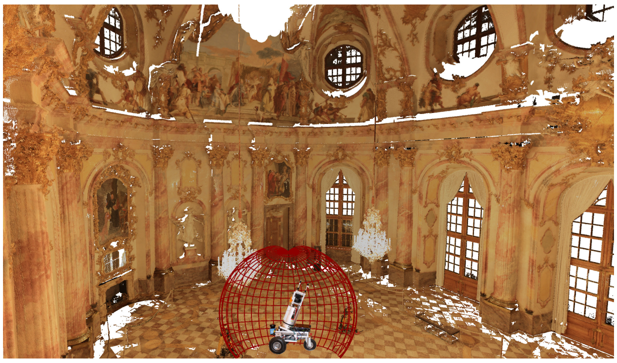

Figure 3: llustration of a 3D scan reconstruction of the imperial Hall of the Würzburg Residence. Data is captured by Irma3D with VZ-400 laser scanner by RIEGL Measurement GmbH. Attached to the top of the scanner is a Canon 1000D DSLR camera. After a 3D scan has been acquired the camera is used to acquire color information for the point cloud.

expert to manually measure the findings and draw a scaled version of the finding on a paper. Advances in 3D laser scanning systems reduce the required time for capturing the data from an excavation site. 3D scans withdraw the human inaccuracies in drawings and provide realistic representation of the findings and the excavation site. Modern laser scanners are capable of capturing up to 1 million points per second. This provides a very detailed 3D point cloud of the environment. 3D points clouds and 3D models of an excavation site provide a better representation of the environment for the archaeologist and for documentation. 3D point clouds represent the environment in a spherical coordinate system. Measured points are represented by the polar coordinates and the measured range of the point. Modern scanners provide the reflected energy of the surface of the measured point. Combination of 3D point clouds with color images will provide a colourful scans (Fig. 3). Using 3D scanners and cameras will provide more detailed information than the conventional hand drawings. Furthermore, utilizing these technologies will save time and cost by creating objective data from the excavation site.

3.2 Data Process

All the captured data in the form of the images and 3D point clouds are processed and categorised in different projects. Many scan formats from different laser scanners and different images can be combined into one project to provide more detailed information of the excavation. Captured data can be modified, e.g., by removing unnecessary parts of the 3D point cloud. This makes processing the data of a project easier and faster for adding documentation and further studies. As shown in Figure 2 after data analysis, archaeologist are able to access the raw data to check the analysis or to modify the project for further study based on the new entry of data.

3.3 Digital Documentation

Rapid growth of technology makes it possible to produce huge amounts of data in a short period of time. The primary motivation of computer aided systems for archaeology is to produce new ways of recording, cataloging, encoding and visualising archaeological artefacts and monuments. 3D technologies have produced portable and fast systems to record large amounts of precise 3D data efficiently. These systems are used to visualise the data that has been acquired from excavation sites. Captured data from the excavation site are used for digital documentation of the excavation. This is used to substitute the conventional methods of documentation. Computer aided systems will provide tools for archaeologist to visualise the captured data in 3D on site. They provide simple tools for measurement, region of interest selection, adding labels, adding notes and georeferencing. In this paper we propose the use of CASTLE3D (Computer aided system for labelling archaeological excavations in 3D) for on site semantic mapping and gathering digital documentation of the excavation sites. This system will improve the documentation process with the possibility of accessing the original data at all times. Archaeologist are able to add or modify the documentation based on their knowledge and understanding of the excavation. Digital documentation increases the speed of the documentation process. This provides the possibility for sharing and collaboration between archaeologists.

3.4 Database

Huge amounts of data are produced in a short period of time on excavation sites. Therefore management of data has become problematic with conventional methods. The conventional methods of data storage and cataloguing simply cannot coupe with the amount and speed of data generation. Data management is widely used in archaeological projects to store and retrieve generated information during and after an excavation. In this framework we use the database Adiuvabit (denkmalDaten Winkler KG, 2008) as back end of the framework. The aim of the framework is to provide seamless connection between the digital documentation process and the database. The use of a standard XML schema to transfer the data from the documentation process to the database makes the framework modular. Therefore it is possible to substitute the database with the existing database of any archaeological project.

3.5 Data Analysis

An essential task after the excavation is to analyse and study the captured data. This will produce knowledge about the environment and the era of the excavation site. Computer Aided Models are used to study the stratigraphy of the excavation. CAD models are used to generate 3D models of the excavation sites. These models represent the excavated findings and sites in their original structure. These can reveal the purpose and functionality of the findings. Moreover, regular, e.g., daily scans of the excavation site enable the compilation of the Harris matrix. This matrix can be generated automatically or semi-automatically with the help of an archaeologist. Our framework provides a tool for the compilation of the matrix as it uses the database Adiuvabit (denkmalDaten Winkler KG, 2008) as back end. Moreover, the matrix can be generated after the excavation from the original data. This improves the objectivity of the analysis of the findings. Excavation sites can be studied by the archaeology community and they can compile a new Harris matrix based on their understanding from the original scans.

3.6 Publication

The last step of any archaeological activity is to publish the findings. Computer aided systems and all the captured data in the form of 3D point cloud, images, archaeological notes, semantic mappings and all added documentation in the database provide a huge amount of data for the archaeologist to publish their findings. Furthermore, availability of the original data creates a possibility for other archaeologist for further study and comparison of their analysis. Computer systems make the publication, analysis, comparison and modification of the data very simple and this will improve the quality and the quantity of the publication in archaeology.

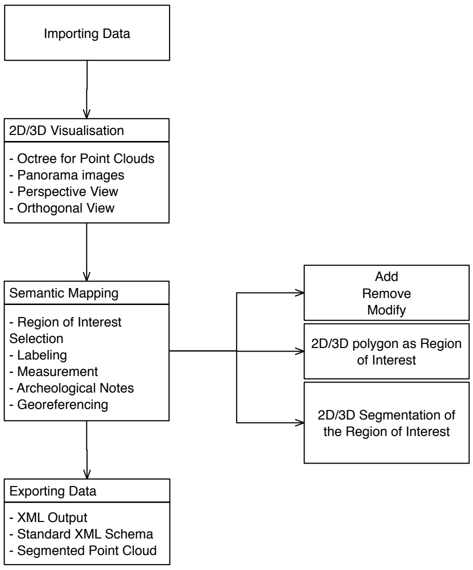

Figure 4: CASTLE3D Overview

4. CASTLE3D

The primary motivation of computer aided systems in archaeology is to produce new ways of recording, cataloging, encoding and visualising archaeological artefacts and monuments. 3D technologies have produced portable and fast systems to record large amounts of precise 3D data efficiently. Digital documentation is the most important part within the proposed framework for which no satisfactory solution has been presented yet. For this purpose we developed the CASTLE3D (Computer aided system for labelling archaeological excavations in 3D) software to create digital documentation of the excavation site. Figure 4 presents an overview of the CASTLE3D. The software provides an easy to use set of tools for archaeologists to import the captured data from an excavation directly from the scanner to the software. The visualisation tool provides different views of the point cloud. The on site semantic mapping is available to archaeologist to generate documentation of the excavation on site. All the generated data in the CASTLE3D can be exported for further study and analysis.

4.1 Importing Data

CASTLE3D provides a tool to import point clouds. It uses the internal data structure for visualisation. Therefore, different formats of point clouds are converted into the internal data structure by the system. Scanners have different methods to represent the reflected value from the measured points. CASTLE3D provides different normalisation methods for generic visualisation of different scan formats. It supports many different scan formats, amongst them the file formats from known laser scanner producers such as Riegl (rxp) and Faro (fls), or standard ASCII file formats (xyz). This tool supports scans with reflectance and color information with different scales. Normalisation, scan scale and the point values are selected during the import process and the scan information is saved in the project. Imported scans are available for visualisation and semantic mapping.

4.2 Visualisation

Recently (Elseberg et al., 2013) introduced a data structure to improve the visualisation of point clouds with millions of point.

Figure 5: Visualisation of a 3D point cloud

A fast and easy to use visualisation tool is integrated into the software to visualise these point clouds in a matter of milliseconds (Figure 5). The visualisation tool has improved the interaction of archaeologist with the recorded data of an excavation site. Nonacademic archaeology sites are often only available for a very short period of time. Therefore, the excavation process has to happen quickly. Recording data with 3D with laser scanners will provide detailed data of the site. Reconstruction and visualisation of the data after the actual excavation assists archaeologist in studying the site more precisely. It also produces an infrastructure for other archaeologists to study the excavation sites based on their own knowledge. Modern terrestrial scan systems acquire data at an impressive rate. To load and process large point clouds in the main memory on a standard system we use two efficient data structures for 3D point clouds: an octree and a panorama image array. (Elseberg et al., 2013) describe a spatial data structure called octree with a low memory consumption. An octree is a tree data structure that is used to index 3D data. Each node of the octree represents the volume formed by a rectangular cuboid. An octree node has up to eight children. Each child corresponds to one octant of the cube. A node without a child implies that for the corresponding volume no further subdivision is necessary and the volume can be uniformly represented. When storing a point cloud, they defined a stopping rule for occupied volumes. The stopping criteria is defined as both maximal depth and minimal number of points. This criteria is applied to volumes without points, such that child nodes are created only for volumes that contain points. All nodes without children are considered as empty space. As laser scanners sample the surface of objects, the acquired 3D point clouds are not fully volumetric. Since most space in point clouds is not occupied, most octree nodes will only have few children. The octree data structure is therefore ideally suited for 3D laser scanner data. Most modern laser scanners provide color and reflectance information in addition to range information. This information has been used by numerous applications to produce images. The 2D representation of a 3D point cloud permits the use of conventional 2D algorithms for acquired 3D data. We use the range information to produce panorama images of scans (cf. Fig. 6). Several projections are available to generate the panorama images from the point clouds. All pixels of the image contain color, intensity and a list of 3D points, that fall into the array element. A panorama image offers a full view of the excavation site in one image and provides a better understanding of the environment. The visualisation of point clouds provides a detailed representation of the excavation site. This is a realistic presentation of the excavation. In comparison to conventional methods, where hand drawings of the findings are used for further study, the 3D point cloud is an extremely accurate and precise model of the actual excavation.

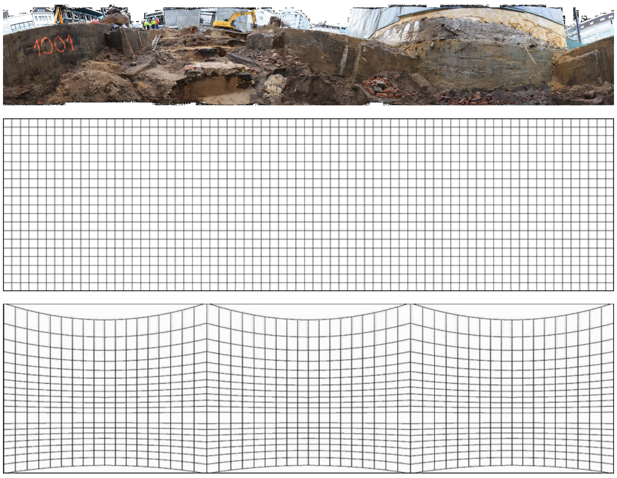

Figure 6: Top: Panorama image of an excavation site. Middle: Panorama image in eqirectangular prjection. Bottom: Panorama image composed of 3 Pannini projections.

4.3 Semantic Mapping

Currently, archaeological observations are recorded on-site using conventional methods (cf. Fig. 7). The outlines of findings are drawn on graph paper with detailed information based on subjective understanding of the findings. Images, floor plans and other data such as archaeological notes are collected during the project. These data are of great value in the analysis of archaeological findings in any project. 3D data acquisition and computer aided systems will facilitate this process and they are less prone to human error. In CASTLE3D a series of labelling tools assists

Figure 7: Conventional methods to record excavation sites include, hand drawings, manual measurement and archaeological notes.

archaeologists in documenting their findings on-site for further inspections. These tools facilitate the creation of several labels on visualised data by selecting regions of interest. Afterwards, selected regions are available as polygons in both 2D and 3D representations of the scan (see Figure 8).

A series of predefined categories are available for semantic mapping of the label. These categories are included in each project during the creation process as an XML file. The categories are modified for each project to contain the required level of information for the excavation. Additionally, these regions of interest can be segmented from the rest of the point cloud. The segmented region will represent findings, such as monuments, buildings, stones, and other structures. Figure 6 (top) illustrates a panorama image with a marked region of interest presented in the 2D viewer

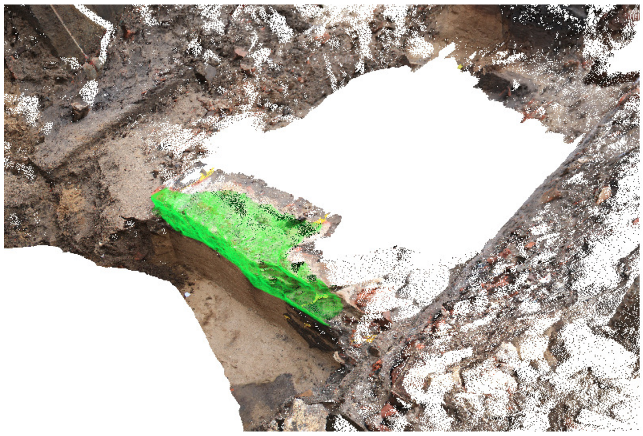

Figure 8: 3D presentation of a selected region of interest in a point cloud.

of the CASTLE3D software. Moreover, the measurement tool is used to add more data for each label. This is more precise than the conventional methods of adding manual measurements of the findings to archaeological notes. Additional notes can be added to each label. The orientation of the findings provides more information for each label. Georeferencing methods are available to transform the point cloud into the global coordinate system. This computer system facilitates the identification process of the findings on-site. It also provides feasible tools to study and observe the excavation site and findings both for the archaeologist on the site and for the public.

4.4 Exporting Data

Documentation is essential to archaeological analysis. Therefore, it is crucial to have a proper amount of documentation for each finding. This data is based on the archaeologists understanding and experience. Since the data has been acquired by terrestrial laser scanners and represented by computer aided systems, they can be studied in the archaeology community. The data can be used for further studies, catalogues, archaeological databases, and archaeological data management systems. We offer an Extensible Markup Language (XML) file format to export the data and documentation of findings. This is essential for multi-platform communication. The XML file can be easily imported into other softwares. In our framework we transfer the data to an Adiuvabit database. Further documentation is included in the database for each finding. Analysis and publication of data is carried out based on the database. In addition to the XML file for transferring the documentation, georeferencing information, selected region of interest and measurement information, segmentation of findings are available. This produces small point clouds containing only the findings.

5. EXPERIMENTS AND RESULTS

In this paper we present a workflow of our framework on an excavation site in Ganderkesee, Germany. Figure 9 shows an aerial view of the excavation site. After the deduction of the level of the topsoil to the relevant layer by an excavator potential records are flagged by an archaeologist. The flagged regions are cleaned by an excavation team consisting of a minimum of two people. This reduces the level to the first planum presenting the potential findings clean and free of crumbs. The excavation specialist documents the archaeological relevant findings. The potential findings are sequentially numbered. The numbered findings are photographed immediately after surface cleaning with the accompanying photo panel, scale and north arrow (Fig. 10). 3D scans

Figure 9: Aerial view of the excavation site in Ganderkesse, Germany.

Figure 10: Numbered potential finding are cleaned for further inspection.

Figure 11: Profile view of a potential finding on Ganderkesse excavation site in Germany.

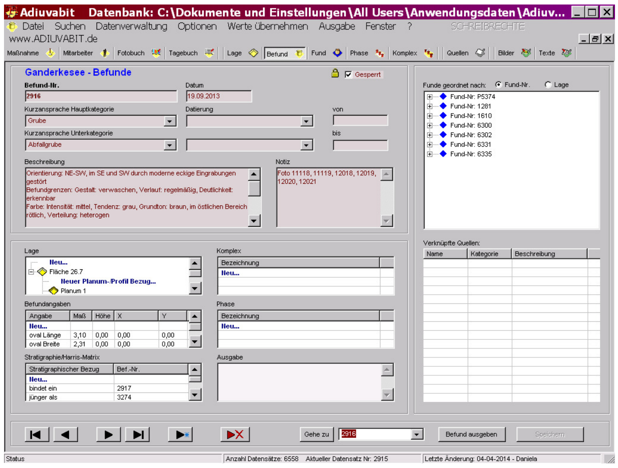

Figure 12: Generated record for a finding in Adiuvabit database.

are captured for visualisation purposes. Afterwards the cutting direction of the profile is determined with at least two nails and the limits of the findings are marked. A database record with an initial description is generated. The marked limits and cutting directions are measured with a tachymeter or a GPS. The profile is created on the measured records by removing a vertical box of soil in longitudinal direction of the marked cutting nails. Afterwards the front half of the profile is removed to salvage the findings (Fig. 11). Profiles with archaeological artefacts are prepared for further documentation by an archaeologist. The conventional documentation of the profile consist of image acquisition from the numbered profiles, scaled hand drawings, manual measurements and archaeological notes. Some archaeological projects contain a database and the excavation team transfers all the documentation from the site to the database. However, this process is insufficient and time consuming. It takes days for archaeologist to combine all the gathered data and to transfer it to the database. With the use of our framework this could be reduced to hours of work. Our framework provides tools and computer aided systems to improve and accelerate this process. In our framework the excavation process continues to salvage the rest of the profile and prepare findings for 3D scan acquisition. After the data acquisition process scans are imported into suitable projects. Visualised scans form the basis for interactive tools for archaeologist to mark the findings simply by selecting a polygon containing the finding. The selected regions of interest are labeled and additional documentation, orientation and accurate measurements are included in the CASTLE3D project (Fig. 13). The archaeologist exports the generated data from CASTLE3D into the existing Adiuvabit database for the project. Database records are generated or merged automatically for the marked findings (Fig. 12). Profile views of the selected regions of interest are generated from the database. Our framework provides a comparable view to the conventional hand drawings of the findings (cf. Fig. 14). Additionally, 3D point clouds, 2D images, segmented findings and all the extra documentation provide higher quality of the representation of the excavation. This will improve the documentation and reduces the required time for data generation and organisation. The available multimodal representation of the data in our framework facilitates the analysis of the findings. Further studies are carried out on the gathered documentation and results are published. The digital nature of our framework makes the analysis and the original data available instantly to other archaeologist for further study.

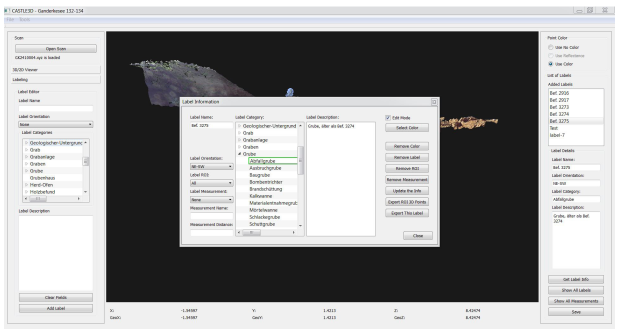

Figure 13: Presentation of CASTLE3D with added labels and selected regions of interests.

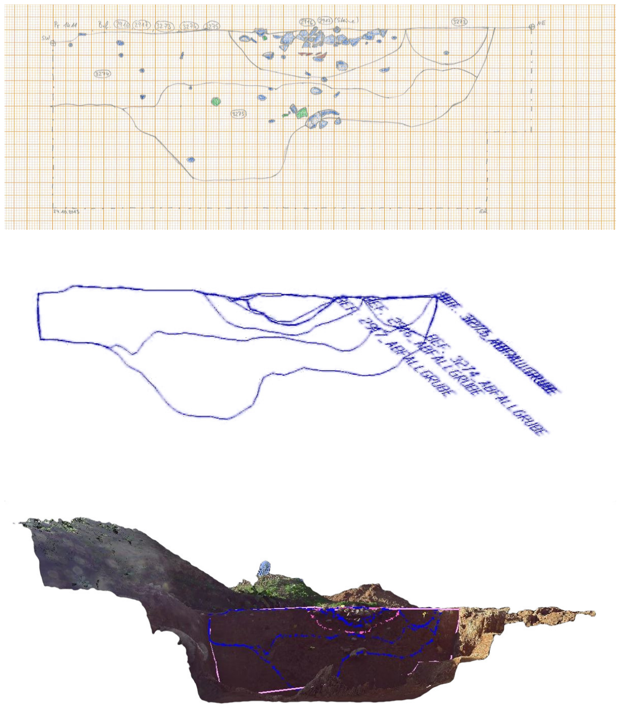

Figure 14: Top: Conventional hand drawing presentation of the excavation. Middle: 2D CAD model of the excavation based on the digital documentation. Bottom: Marked region of interest on a 3D point cloud of an excavation.

6. CONCLUSIONS

In this paper we present a framework to improve the process of archaeological excavation and documentation. The aim of this framework is to assist the archaeologist on excavation and to substitute the conventional methods of documentation. The generated data in this framework combines 2D images, 3D point clouds, archaeological notes and CAD models to present the excavation. A huge amount of data is generated in a very short period of time. We present a set of hardware and software to facilitate the data acquisition of the archaeological excavation. CASTLE3D (A Computer aided system for labelling archaeological excavations in 3D) is a novel tool for digital documentation. In combination with Adiuvabit as the back end database of the framework. It is used to execute the workflow of the framework. The generated data in CASTLE3D is exported with standard XML format to the data base. We show that with this combination in a case study at a sample excavation site we are able to create similar documentation results as with conventional methods but more efficiently and with higher quality. The availability of the original data helps to achieve objective integrity even with destructive methods as new studies and analysis can be carried out over the data. The achievement in technology provides tools from several disciplines such as, surveying, computer science, laser scanning, 3D modelling to assist archaeologists during an excavation. We plan to perform a more extensive study of the presented framework for several excavation sites with varying experts on site for further evaluation of the framework and the presented components.

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