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GÉRALDINE SACHAU-CARCEL

FROM FIELD RECORDING OF PLURAL BURIALS TO 3D MODELLING. EVIDENCE FROM THE CATACOMB OF STS. PETER AND MARCELLINUS, ITALY

ABSTRACT: An original methodological analysis of burials is performed using new IT technology which leads to three-dimensional (3D) modelling of architecture and individuals based on field documentation. The 3D modelling is of two plural burials that are part of the catacomb of Sts. Peter and Marcellinus in Rome (Italy). We proposed creating a 3D model of the position of each bone and each subject from field recordings using the drawings and photographs. Our research deals with the acquisition and restitution process of all human remains, funerary treatment and funerary space. The collected data permit an analysis of the relationships between skeletal remains and taphonomic events within the deposits in order to suggest chronological patterns. The possibility of visualising either a skeleton or a body from different angles informs the discussion on how the grave functioned. The simultaneity of some deposits is thus confirmed and the existence of phases probably related to several mortality crises as well. The elaboration of a process adapted to plural burials allows us to define a record protocol and restitution that constitutes an original approach in the study of funerary deposits.

KEY WORDS: Archaeothanatology – 3D modelling – Multiple burials – 3D numerical model – Roman period

INTRODUCTION

The main aim of this study is to understand the function of graves and to appreciate how the three-dimensional (3D) tools can help in determining the chronology in a complex burial. Such a determination of chronological patterns allows the differentiation of multiple and collective burials. Indeed, it is essential to visualise several levels of details, bone by bone, skeleton by skeleton, and to capture all the interactions in the tombs. Built on the example of the three-dimensional refund in the field of archaeology, it seems appropriate to apply it to anthropology in the case of complex burials. With the example of the central sector of the catacomb of Sts.

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Peter and Marcellinus, we discuss the methodological constraints of a 3D restitution and the contributions of this new technical approach to archaeothanatology.

The catacomb of Sts. Peter and Marcellinus is in southeast Rome (Italy), along the *via Casilina*, formerly *via Labicana*. The catacomb has an area of three hectares and contains 20,000 to 25,000 individuals (Castex *et al.* 2011: 275). The burials are principally single ones or grouping of individual burials. The "central sector" was totally unknown before its discovery in 2004 (*Figure 1*). Before the work to secure the site could be carried out, the remains (skeletal funerary apparatus) were studied and sampled for preservation. An Italian team, under the direction of R. Giuliani (chief inspector of the Roman catacombs) and M. Ricciardi (pontifical archaeologist), undertook the initial excavation. They were followed by a French team, under the direction of D. Castex and Ph. Blanchard. There were four operations of preventive excavation in 2005, 2006, 2008, and 2010.

The central sector contains several cavities with many individuals, completely different in its organisation from other parts of the catacomb. The central sector is dated to the 1st to 3rd century AD.

The funerary practices are unusual and most of the individuals are covered with textile and plaster, accompanied by amber, which give them the appearance of mummies (Blanchard *et al.* 2007: 990). This funeral practice makes it difficult to study the different subjects and their relationship and therefore to understand the organisation of the deposit (*Figure 2*). Previous studies were conducted in order to know which people were buried in this particular sector, to characterise the funerary material and finally to discuss how such a large number of individuals were buried in a short time in this particular sector of the catacomb. The large number of skeletal remains suggests a major epidemic event or a succession of mortality crises spread over time (Castex *et al.* 2011; for additional information see Castex *et al.* 2014).

The characterisation of each individual deposit and that of all deposits as a whole is essential to the discussion of these burials. Given the unusual character

FIGURE 1. Map of the catacomb of Sts. Peter and Marcellinus and the central sector. Map by M. Ricciardi, PCAS.

of the deposits linked to the great number of individuals within each grave, it was extremely important to understand how these graves functioned. That is why it was particularly interesting to restore these burials in three dimensions. A project (with the sponsorship of Maison des Sciences de l'Homme d'Aquitaine (Bordeaux, France) directed by D. Castex, Senior researcher, CNRS UMR 5199 PACEA-A3P and I. Cartron, Professor of University of Bordeaux 3, UMR 5607 AUSONIUS) initiated in 2003 proposed to restore the burials – from architecture to the individual – and the 3D modelling of the burials was then undertaken.

FIGURE 2. The first level of deposit of one burial study with funerary apparatus. Mission 2006 photography.

METHODS

During the last twenty years, the development of IT tools permits the testing, exploration, and use new software, and to apply new techniques to archaeology and anthropology. The use of 3D tools in archaeology was developed at first by private sponsorship for exceptional sites like Thebes in Egypt (IBM) or Cluny in France (EDF) (Vergnieux 1999).

3D restitution has to be considered from two objectives. First, records of existing remains or vestiges may possibly disappear. Second, excavation is invasive by definition. The 3D restitution of a site from field records informs a hypotheses which can be validated by a scientific research group (Vergnieux 2010: 181). The tools and techniques depend on the objectives. The use of 3D visualisation or restitution is indeed not new for archaeologists or anthropologists. However, in most cases architecture and skeletal remains are not represented together, as the plural burial is visualised through Bodies 3D (Richard Wright) or Crossbones (Isaksen *et al.* 2008) software. In the last ten years, new applications have provided 3D visualisation of one or more individuals, but again the funerary space was merely indicated. Frequently, Laserscan is used to restore the burial, more or less accurately, and it is not possible to appreciate the thickness of deposits, the organisation below and the first level of deposits as well. Moreover, this technique is difficult to use in a complicated stratigraphic context where the remains are superimposed over several layers. In addition, hypothetical (unrecorded) remains are not represented. The 3D restitution permits the control of scientific information well beyond the visual representation. The 3D restitution applied to monumental archaeology shows interest in all these tools.

3D studies offer many possibilities, hypotheses of construction, use, destruction of these buildings can be discussed; which is why there is so much interest in applying this approach to burials. The 3D modelling has been never applied to plural or multiple burials, funerary space, funeral apparatus, skeletal remains and bodies. It was therefore essential before all restitutions to select burials that permit the restoration and to create a protocol that considers all useful remains. Furthermore, it is important to discuss which application of these new tools can be done and which results can be useful as major contributions to archaeothanatology.

With regard to the catacomb of Sts. Peter and Marcellinus, we selected two burials that were totally excavated over two campaigns in 2005 and 2006 and where complete information about the biology of the individuals and the archaeological context are available. These burials contain approximately 80 individuals each. By the time of the discovery, the depth of the skeletal remains was 60 to 80 centimetres. The depth is not very high for such a large number of individuals, the skeletal remains had suffered significant damage, it is a most unusual phenomenon. Indeed, the conservation of skeletal remains is varied, some of the remains are in good condition, and some others are poorly conserved or have completely disappeared. The presence of some individuals is visible only in the traces left by the funerary equipment such as the plaster. The interlocking of skeletal remains is particularly important, so it was a serious constraint for excavations and studies.

The grave is organised in levels of deposit separated by a level of sediment. The number of individuals by level of deposit is variable, for instance in the first grave the number of individuals deposited in the same level varies from 4 to 8. For the other grave, the third level contains 20 individuals. It was not possible to determine for each grave the time elapsed between each level of deposit, but only the overall chronology of the period of use. The organisation within each burial was particularly difficult to define.

To produce a 3D representation, it is important to know which element is necessary to study and thus to the model, and which element must be restored in terms of the archaeo-anthropological issues. However, here all elements are important because the site contains a unique example of plural graves excavated in Rome for this period and in a catacomb. The type of burial is most complicated than plural or multiple or collective, so to facilitate the discussion, we have decided to use the terms of burial or plural burial as the definition of a burial with many individuals.

The necessary documentation

The aim is to go from 2D representations – records, photography, etc., into a 3D restitution. To achieve this, it is necessary to replace each bone, each element of funerary treatment and the funerary space with a three dimensional referential (Sachau-Carcel 2012, Sachau *et al.* 2010). The archaeological and anthropological records of excavation are examined to determine what information is available and can be used for 3D modelling.

The field essential documentation consists of the drawings, because each detail observed in the grave is recorded. The field records include the bones and elements of funerary treatment. It allows us to obtain spatial coordinates, but this is not sufficient for the

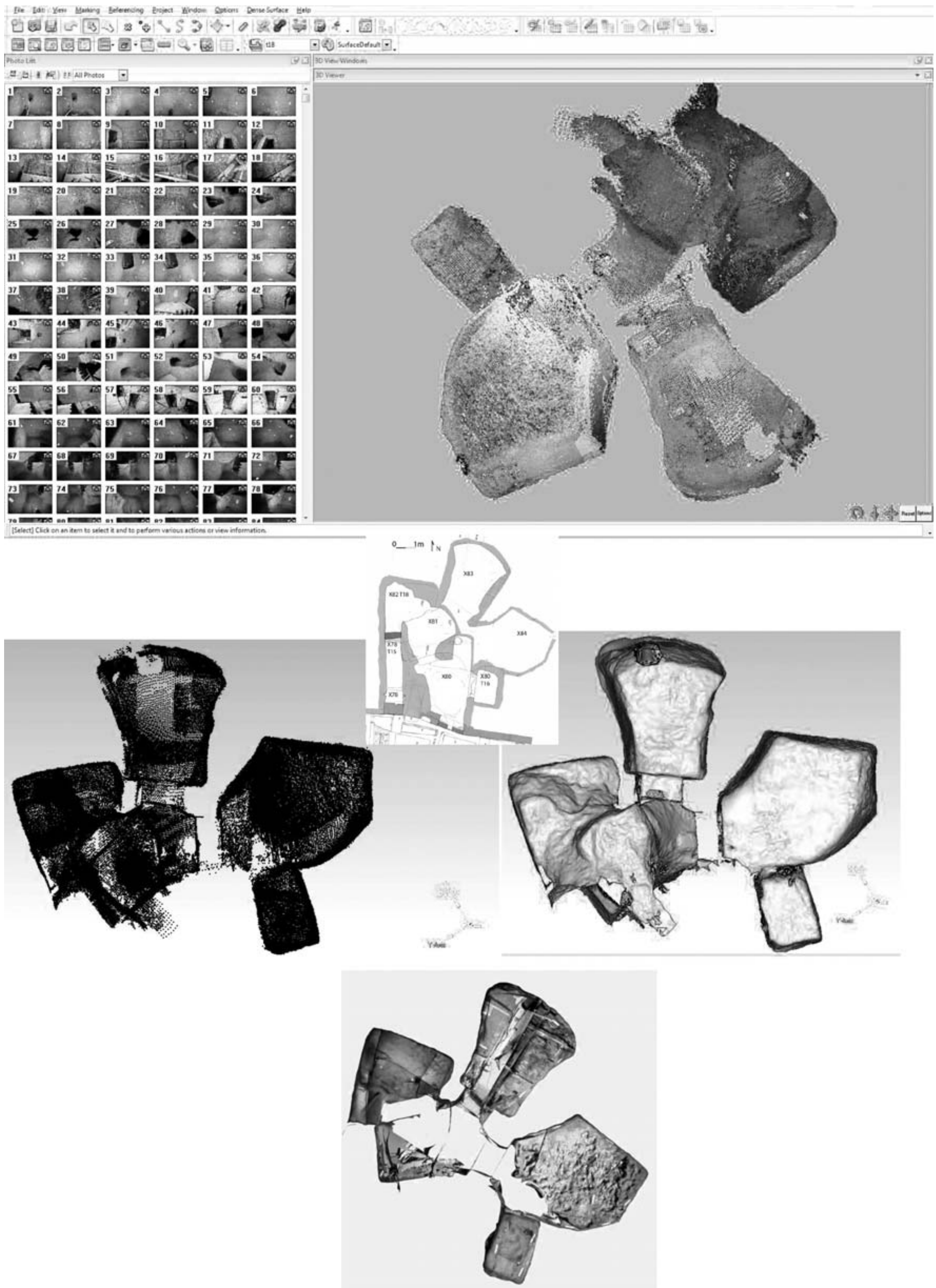

FIGURE 3. Modelling of the central sector, the funerary space. Model by G. Sachau from P. Mora.

restoration of an "original picture of the past" (Duday 2008: 49–54). For this reason, the construction of a database which is as complete as possible is a major step, every piece of information is as important as the missing one. For that, all field information is essential, such as the observable face of the bones, conservation and representation of the skeleton, and relationships between individuals.

The choice of 3D models for skeletons and bodies

It is essential to research how to represent skeletons and bodies, i.e. which 3D models will be used. For the skeleton, an open and free 3D model was chosen. This model adheres to the anatomical proportion although this is not a scientific 3D model of a skeleton. Indeed, prior to this project, no complete scientific 3D model of a skeleton was available, based upon a reference collection and free of pathology. Besides, the skeletal remains stemming from the central sector have too poor conservation to be scanned and used.

For the bodies, the 3D model was made with the *MakeHuman*™ software. The 3D individual is entirely configurable and size, weight, or gender can be selected. The configuration of the 3D model is clear and accurate. This software is particularly adapted for reconstructing corpses in 3D and can be applied to individuals measuring over 1.10 metres in stature.

The process selected to restore the funerary space

The funerary space needs a particular treatment because it is always preserved and the dimensions, the morphology of each grave determines deposit conditions in many cases. This is the reason why another method of 3D reconstitution was used for the grave, restored with photogrammetric records. The photogrammetry seemed better adapted than laser scan because the central sector of the catacomb is composed of small and wet cavities, with variable lighting and access to the basement is particularly difficult.

The photogrammetric recording in the entire central sector was done in 2010 by the team of Archeotransfert using UPS SHS 3D (n°3551, CNRS) and lasted one week. The treatment of photography, the elaboration and correction of a wireframe model and the texturing of the two burials we studied was done afterwards, taking one week for each (*Figure 3*).

To sum up the modelling processes of these burials, all remains found are depicted and missing elements are positioned in the grave where possible. The modelling of burials is done in three steps: first, acquisition of 3D spatial coordinates; second, modelling of each element (bone, funerary treatment, space funerary), and third, all elements modelled are assembled in a one file, called a 3D scene.

The modelling is not carried out only on the skeletal remains but also on the bodies. This step with body volume enables us to visualise the corpse as it was deposited. This hypothesis of work is extremely important to the study of individuals as they were deposited in these graves, and to capture the manipulation of the corpse, so as to understand the functioning of the burials and the funerary treatment.

PROCESS OF 3D RECONSTRUCTION

The body deposits are modelled in wireframe, 3D skeleton and volume bodies (*Figure 4*). Each step allows visualising in 3D the interactions between each individual, between funerary treatment and funerary space.

3D skeletal model

The 3D coordinates for all remains are obtained from the archaeological records and with the use of vector drawing software after scaling. All the drawn remains are modelled, but the problem is for the fragmentary remains, too small or with poor conservation to allow recording, so they were not modelled precisely. However, it was possible to approximately replace them because the information was available thanks to the anthropological observations or in photography. The points used to place the skeletal remains in a spatial referential are the same as those that are used to draw the skeletal remains and they are defined in accordance with the archaeo-anthropological team and already defined and used for other plural burials (Blanchard *et al.* 2011).

The bones that are not recorded raise the same problem. Indeed, some bones are not drawn because they were not preserved but it was essential to restore them. We used several conditions and objective criteria to reposition them: the free place for this bone, joint continuity and symmetry among others things, if it is possible. The bones are depicted in opaque shape if the bone is recorded and transparent, if the location of the bone is estimated. The position in which each bone appears is important to understand the real position of the individual. This information is not in the drawing but kept in the anthropological or archaeological observations or in photography. That is why it is important to transfer all data on a single individual to a complete database. To position each bone we used the

3D coordinates for each end of the bones, to have the dip and the length except the skull and the pelvis and the observable face of the bones.

Gender and individual age at death are additional information that help to visualise if a spatial positioning exists according to such parameters or to body size.

During the 3D modelling of skeletons, we wondered how to restore the real volume of the skeleton if we have only a measurement. The height of the remains is taken only in the upper part, so we do not have information on the depth of the remains. Indeed, the field records did not take into account the thickness of bones, as it was impossible to measure them properly, due to their state of conservation. It is an important parameter because the position of the 3D skeleton must consider this. The remains have suffered significant damage, the thickness of remains is slight in comparison to the real thickness of bones. Therefore, we have decided to place the 3D skeleton bones in the middle relative to the measurement and this for all skeletal remains. An average thickness was determined depending on the samples.

Another difficulty consists in the non-anatomical interlocking. Any individual without connection in appearance becomes in contact or interlocked. To correct this type of error, we studied all the field documentation in order to understand perfectly the position of each bone of each subject to look for a mention of a relation between two or more subjects concerned. If nothing was observed, we calculated the relative position of each bone from the spatial coordinates that determine the bone positions.

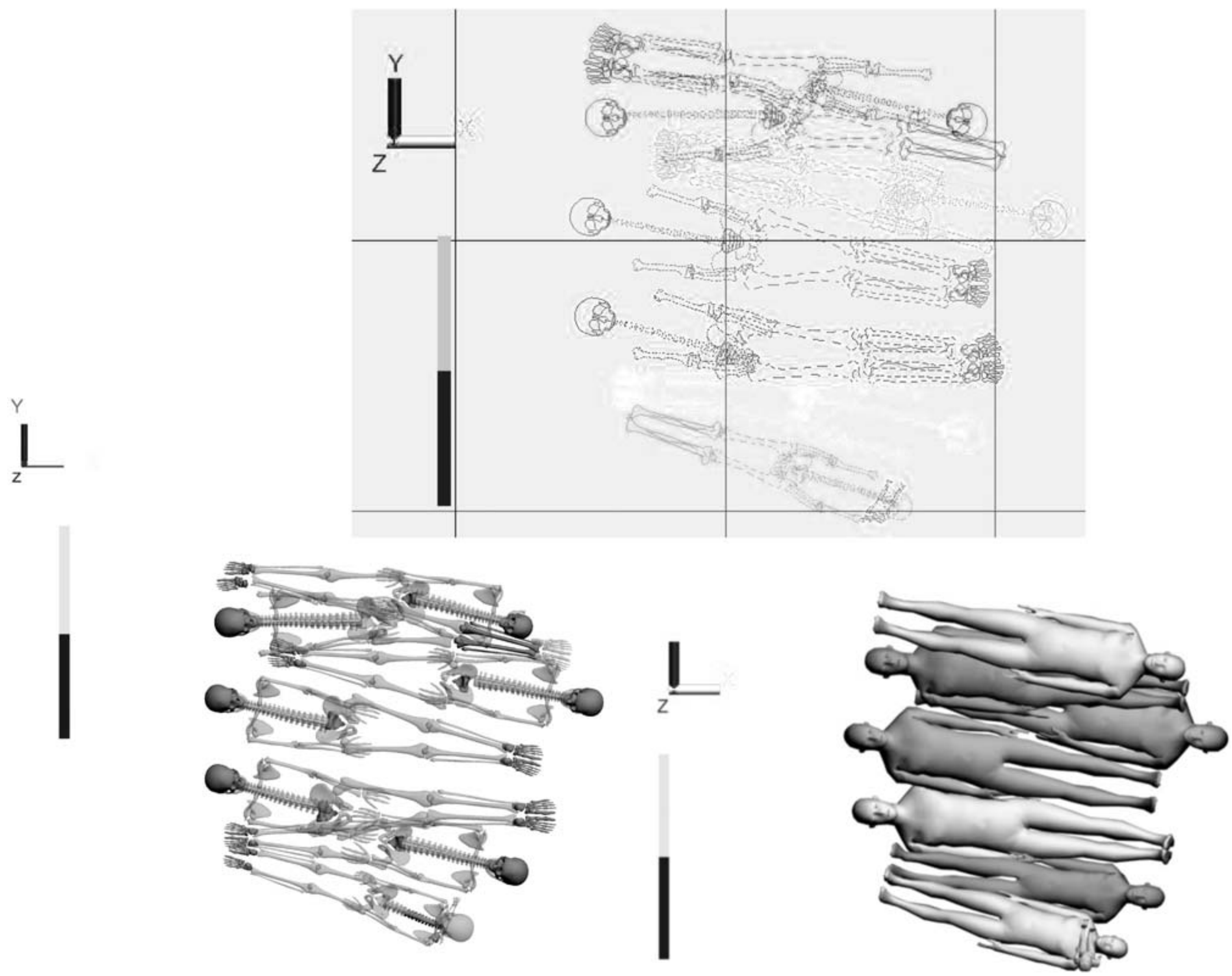

FIGURE 4. Three types of 3D modelling for one level of deposits. Model by G. Sachau.

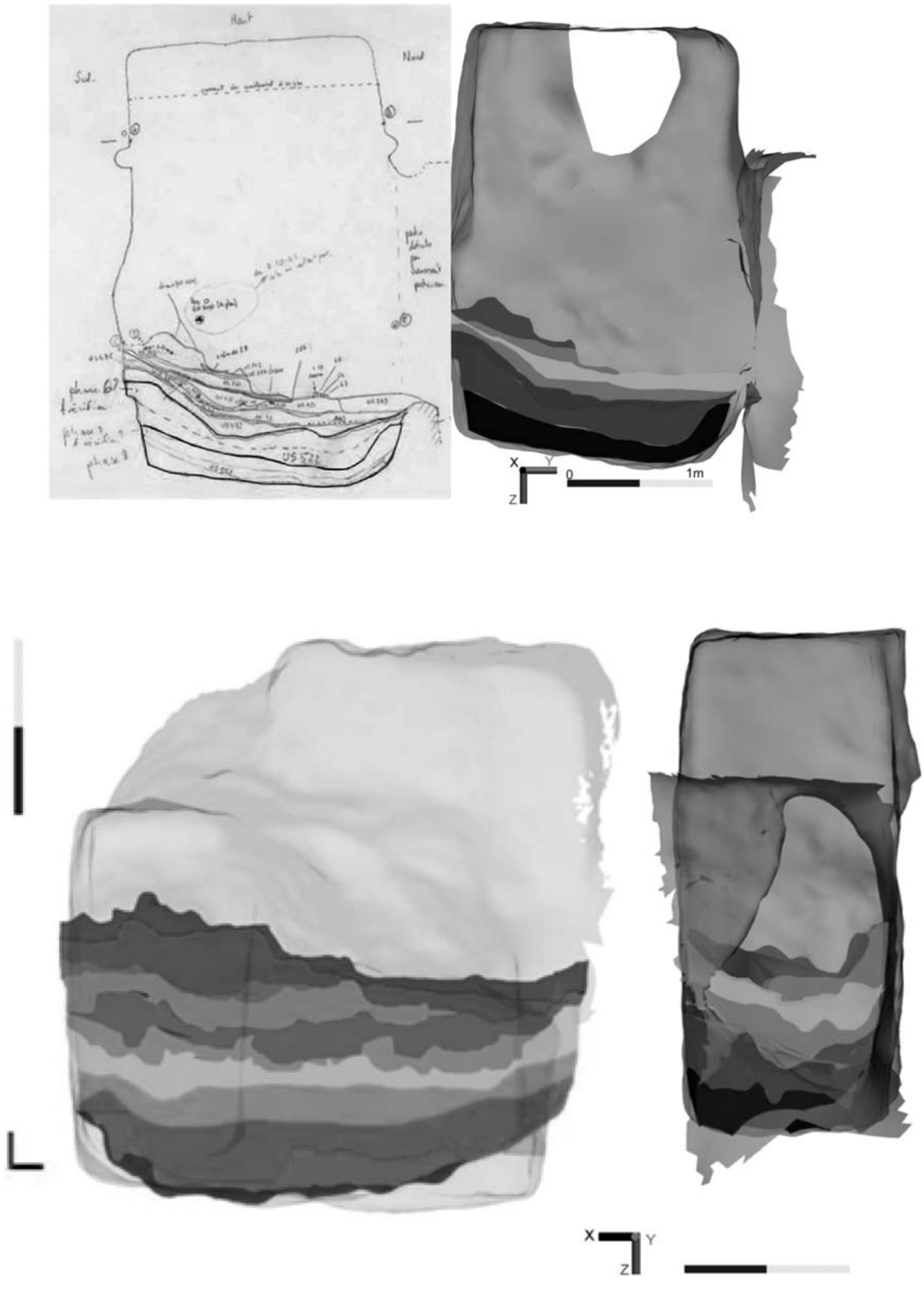

FIGURE 5. View of levels of sediment in the two burials. Model by G. Sachau.

3D bodies

For the reconstruction of body volume, the problem was different as we choose to restore the bodies entirely, and not just as the subjects were conserved. It was necessary to estimate the stature of each individual to adapt the size of the body model and that for each individual, mature and immature. We have used when possible the *in situ* measurement of femur or the estimated measurement with femur coordinates (Cleuvenot, Houët 1993: 245–255). When the femur was not available, we used comparisons and made estimations from other bones. However, the interlocking between bodies is more significant than the skeletal remains, so we proposed two possible visualisation of bodies in volume, with interlocking and without interlocking as deposited with funerary treatment.

FIGURE 6. View of the two burials with all of skeletal remains. Model by G. Sachau.

Funerary treatment, level of sediment, and funerary space

The funerary material is represented by a geometrical form with the same thickness because it was not precisely delimited on the drawings, it is represented like an area when it is present. The colour determines the type of materials, either plaster, tissue, or resins.

Another important point for the model was the thickness of sediment that separates two levels of individual deposits. The field recording was incomplete because the stratigraphic section shows sediment levels with one angle of view and we cannot appreciate the distribution of sediment. So, in the first case the distribution of the sediment was thought to be uniform and just delimited by the walls of the grave.

For the other grave, we had two perpendicular stratigraphic sections so, we estimated that the distribution between sections was uniform (*Figure 5*). The modelling of sediment levels was particularly interesting to attribute individuals in a level of deposits when it was not possible with only field observations.

The 3D modelling was tested first on one grave, because the individuals did not superpose on the same level of deposit and then the application was conducted on the second grave (*Figure 6*). For modelling the grave, which contained 76 skeletons, we needed two weeks for all remains and one week for the funerary space. Ultimately, with the use of 3D tools, we produced a restitution of two graves from the central sector, individuals and funerary treatment, levels of sediment and restitution of funerary space of several cavities.

ARCHAEOLOGICAL AND ANTHROPOLOGICAL RESULTS IN THE UNDERSTANDING OF GRAVES

The analysis of the 3D scene demonstrates pertinent elements to understand the functioning of the selected Sts. Peter and Marcellinus graves. It also brings new information about these burials, with several levels of details, from single bone to burial understanding. The results presented here do not constitute an exhaustive framework but they are the most significant ones obtained through this procedure.

At the individual level, the major observation is the visualisation of close relationships that permits the study of the way in which two or more individuals interlock. The interlocking is an argument to demonstrate the simultaneous deposit of individuals and to characterise the burial type. The most evident example is represented by an immature individual located between the lower limbs of an adult. The adult is on the back, none funerary treatment is observed. The young individual is below the right lower limb and on top of the left lower limb of the adult. No funerary treatment is observed for this subject. Such observations confirm a simultaneous deposit with the maintenance of anatomical connection for the child (*Figure 7*). In the smaller burial, the number of individuals deposited is the same, however the width is smaller so, the interlockings are more numerous.

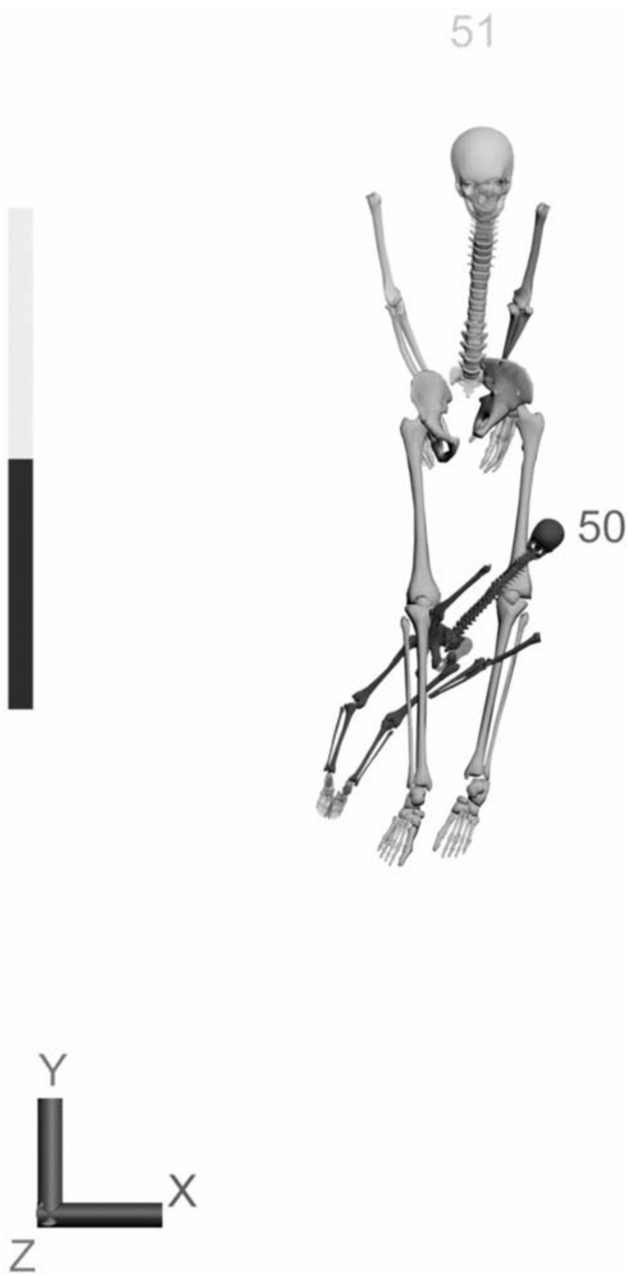

FIGURE 7. Interlocking between two individuals, an adult on light grey, number 51 and an immature on grey, number 50. Model by G. Sachau.

With 3D visualisation, we were able to discuss all cases of simultaneous deposits and in which level they are observed, or where they are absent. The combination of all arguments enables us to determine that for the two burials studied, the individuals are deposited simultaneously and successively. This is particularly interesting for discussion of the funerary treatment and to characterise the burial.

Another contribution of the 3D visualisation of the position of skeletal remains is the recognition of deformation induced by the weight of bodies that means the modification of position occurring during a body's decomposition, which is related to the pressure exerted by other bodies. It is an additional argument for simultaneous decomposition. Identification of joint decomposition results from the posture of any skeleton which presents a higher position of extremities, skull and foots relative to the pelvis. These effects are detectable whatever is the position of the individual, either on his back or on his abdomen. In the first case, the pressure is so great that the knees are not in their anatomical position, in hyperextension or sometimes disconnected.

This information allows us to identify chronological patterns, as illustrated by one of the graves for level six and also in the other grave for level one to seven. It is an indication of simultaneous decomposition in some levels. The visualisation in 3D of each bone allows us to study precisely the placement of the individuals, their relationships and thereby inform us about the funerary practices.

The combination of studies on each individual and the relationships between them completes the overall knowledge of how the grave functioned.

For the grave

In contrast with the 2D approach, 3D modelling provides information on the estimation of the volume occupied by the bodies, skeletons in the grave, as it permits to test the free place available after each deposit and when the grave is full, in order to place chronological patterns of the grave usage. With the restitution of non-nested 3D skeletons, deposits rose up to the ceiling height, but with the volume bodies, the ceiling height is exceeded (*Figure 8*).

For the first grave studied, only five consecutive levels can be deposited. To deposit the last three levels (up to eleven), the previous levels must be in decomposition or totally decomposed. For the grave (*Figure 8*), the height of the ceiling is reached after six levels of deposit and the entrance of the grave after five levels. The last three levels (seven to nine) were made when the six previous ones had decomposed. Obviously, not all the bodies were deposited at the same time. Understanding the use of the grave is based in part on arguments of simultaneity that allows us to understand the operation of the grave during mortality crises. Cases of simultaneous decomposition between a few individuals within certain levels were thus detected.

The 3D representation also allows us to study circulation spaces, distribution by sex, age, and to comprehend the logical management of body deposits. A relative chronology was proposed for each burial although it was not possible to precisely date each level of deposit either by conventional methods (radiocarbon dating) or by analysis of the model.

Analyses of the 3D burials show that their usage is quite complicated, with periods of simultaneity deposits, periods of successive deposits and periods of waiting between deposits. This is a collective grave with multiple deposits. We are able to show that the bodies were prepared before being placed in the tomb, and there was likely a selection according to stature (based on the estimation of the stature for each individual and statistical tests).

IMPLICATIONS OF 3D RESTITUTION IN COMPARISON WITH A CLASSICAL STUDY

Building 3D scenes allows us to create not only one 3D picture but an infinite number of pictures and to visualise multiple burials under every angle. In comparison with a classical study, 3D modelling permits not only a visualisation of all individuals, but leads to recognition of interlocking between one and several subjects.

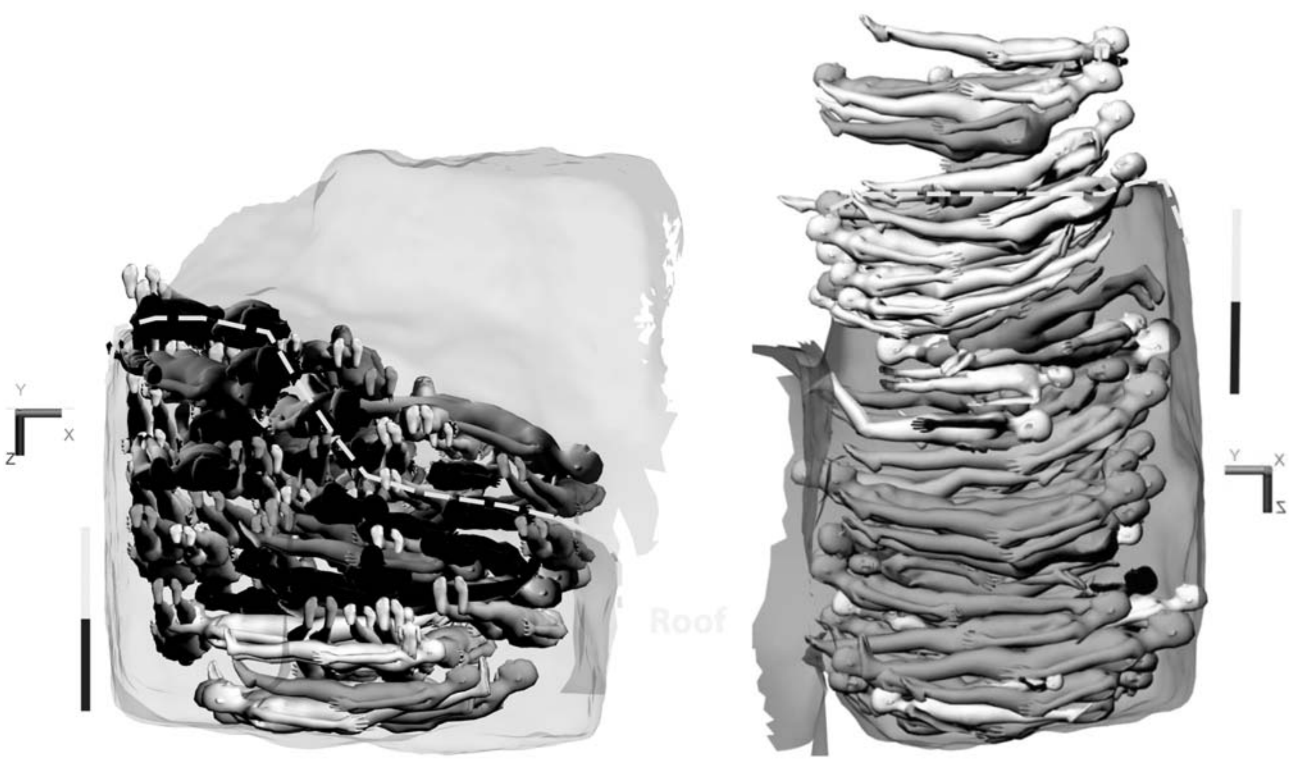

FIGURE 8. 3D modelling of volume of bodies in a grave. Model by G. Sachau.

Indeed, the 3D scene based on the field documentation leads to an exhaustive representation, which conserves data reliability and provides new insights into the discussion. The use of 3D models provides data backup, reproducibility of the analysis and reading of the structured data. These 3D models are evolving and can greatly improve with new hypotheses and new discoveries. In this way, the use of 3D models allows us to have more pertinent results than a 2D representation.

In fact, scholars working on the central sector of the catacomb of Sts. Peter and Marcellinus benefitted from the same available representation. The 3D visualisation avoids calculating altitude for each bone or anatomical segment. The interlocking between individuals are observed and confirmed, like the circulation space.

Mainly, indications about chronological patterns is certainly the most important piece of information gained through the 3D modelling, with the visualisation of each individual, all deposits, funerary treatment, and levels of sediment. This is the great advantage of the 3D reconstitution of these graves, we can choose to visualise exactly what we need to study such as the distribution of plaster or of prone individuals.

New insights for other archaeo-anthropological studies

Other tombs of the central sector are still being excavated and comparative operations between tombs may be particularly interesting to understand the global functioning of this sector in the first centuries AD in Rome. The catacomb will perhaps never be open to public visitors, thus the 3D modelling of funerary spaces in the central sector of the catacomb, besides an illustration of the variety and richness of the funerary complex, gives access to a virtual reconstruction which can be shown.

This type of representation is particularly suited to the study of multiple human remains and a complex stratification. This project allow us to develop a protocol and a method suited to the restitution of plural burials and identifying essential data modelling to apply to other sites. However, our protocol has yet to be tested for modelling plural burials, simultaneous or collective burials, unpublished or on-going excavations and at a larger scale, in order to quantify measurement errors and to identify more precisely the chain of inaccuracies, dependent on the tools used, but also the context of the research.

The prospects of the application of the modelling protocol are also good with possible extension to other burials, either single, multiple, or collective. Indeed, single burial modelling could help to address the visualisation and test archaeological assumptions in the case of decomposed contents.

For collective burials, the ability to model every skeletal remain would assist in the recognition of items in anatomical connection or in relative proximity anatomy. Visualisation of the distribution of the various parts of an individual bone would also facilitate and open up new avenues of reflection for the handling of bodies and bone re-organisation.

CONCLUSION

Three dimensional modelling applied to plural graves allows us to understand, test, and develop new lines of enquiry. The analysis of the 3D digital scene brings a set of results that contribute to the understanding of the graves. Such results complement the data already collected for a particular sector of the Sts. Peter and Marcellinus catacomb, and provide new insights in the discussion of archaeological or anthropological hypotheses. Developing this reconstruction protocol, we were able to propose a new form of recording in order to synthesise the biological and archaeological data (Sachau-Carcel 2012). In-situ recording permits field studies of individual position and the relationship between individuals in order to improve the comprehension of a plural burial with simultaneous and successive deposits. 3D modelling offers a new method for the representation and visualisation of plural burials, which contributes to new research perspectives. Finally, the use of digital scene in the analysis of various burials represents a useful tool for understanding the mortuary practises and funeral behaviour of the living population.

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Géraldine Sachau-Carcel
UMR 5199 – PACEA
Anthropologie des populations passées et présentes
University of Bordeaux
Allée Geoffroy St. Hilaire
CS 50023
33615 Pessac Cedex
France
E-mail: g.sachau@wanadoo.fr