ACTA IMEKO
ISSN: 2221-870X
June 2024, Volume 13, Number 2, 1 - 10

Dynamic 3D model for decoding archaeological complexity of funerary contexts. Phenomena of collapse and fragmentation in an Iron Age burial of Padua (Italy)

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ABSTRACT
Archaeological settings are intrinsically dynamic, undergoing transformations over time that significantly impact the archaeological record. These changes result from both deliberate human interventions and natural degradation processes. Post-depositional phenomena often distort our understanding of ancient contexts, complicating the identification of the original arrangement and hindering the interpretation of archaeological findings. This issue is particularly pronounced in funerary contexts, such as burials, which are susceptible to various natural and human-induced alterations. This study shows the potential of analysing funerary contexts within a processual framework and reconstructing them in a dynamic 3D environment. By employing metrically and morphologically accurate 3D reconstructions, it becomes possible to simulate, isolate, and analyze post-depositional phenomena. The precision of 3D simulation increases significantly when considering factors such as gravity. The goal of this study is to assess changes resulting from transformative phenomena, with a specific focus on creating a sequential representation that elucidates the burial's transformation processes, spanning from deposition to excavation phases.

Section: RESEARCH PAPER

Keywords: 3D modelling; physic simulations; Iron Age; burials; Blender

Citation: F. Adesso, E. Faresin, G. Salemi, Dynamic 3D model for decoding archaeological complexity of funerary contexts. Phenomena of collapse and fragmentation in an Iron Age burial of Padua (Italy), Acta IMEKO, vol. 13 (2024) no. 2, pp. 1-10. DOI: 10.21014/acta_imeko.v13i2.1788

Section Editor: Fabio Leccese, Università Degli Studi Roma Tre, Rome, Italy

Received February 27, 2024; **In final form** May 14, 2024; **Published** June 2024

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1. INTRODUCTION

The methodological premises of this work are based on the fundamental principles of processual archaeology and Virtual Archaeology. Processual archaeology is a theoretical approach that focuses on understanding ancient human societies and cultures through scientific and objective study of their development processes and dynamics. Its objective is to reconstruct the social, economic, and political systems that shaped ancient societies analytically by examining closely behavioural patterns, cultural practices, and material remains with the aim of developing general interpretation models.

Formally, the emergence of the New Archaeology, or processual archaeology, is commonly situated in the 1960s, but as early as 1958, G. Willey and P. Phillips emphasized the importance of applying a processual interpretation [1].

From this premise, a lively debate began, with Lewis R. Binford emerging as a key figure. In 1972, Binford published one of the seminal texts in this theoretical framework [2]. One of the primary paradigms posited by Binford emphasized the archaeologist's attention to processes of change [3]. The author himself highlighted how the only way to decipher the archaeological record and its significance lay in the study of material elements and their arrangement. The greatest challenge faced by Binford, and other scholars was to interpret an apparently static archaeological record, recognizing and comprehending the dynamic processes that engendered it. This process of decoding entailed acknowledging and studying the changes that transpired over time, enabling archaeologists to reconstruct and accurately interpret past dynamics through the analysis of material aspects and their transformations within the archaeological context [4]. Other prominent figures included David L. Clarke [5], Colin Renfrew [6], and Michael Schiffer [7]. For a general overview of the proponents and fundamental principles of the New Archaeology, see the works of Renfrew, Bahn [8]; Guidi [9], and Giannichedda [10].

In the field of archaeology, formative processes encompass a range of natural and cultural dynamics contributing to the development and alteration of archaeological deposit and materials over time. These processes include both natural and anthropic factors. Natural factors refer to geological and environmental factors, such as sedimentation, erosion, and weathering, which are all those changes of exclusively natural origin that can visibly modify archaeological features. Anthropic factors, on the other hand, refer to the outcomes of actions voluntarily carried out by humans, such as construction, use, and abandonment of sites (of production, habitation, cultural, or funerary nature). The analytical study of formative processes plays a fundamental role in understanding how archaeological deposits and artifacts take shape and evolve over time.

Leonardi [11] schematically formalizes how an archaeological stratification forms and changes over time. Three different factors are considered: firstly, the elements that determine changes, referred to as agents, which can be either natural or human. The actions of these agents are the processes that drive changes in the material record. The study of formative processes plays a fundamental role to understand how archaeological sites and artifacts come into being and how they change over time; in this way it is possible to reconstruct the history of the formation of the archaeological deposit and the ancient rituals [12].

The identification of transformative processes within a burial offers enhanced insights into the original arrangement in various ways. Examining the post-depositional phenomena affecting a tomb allows for the identification and isolation of changes occurring over time. Moreover, understanding the sequence of transformative processes sheds light on the cultural practices and rituals linked to the tomb. For instance, the presence of materials differing from the original grave goods initially placed within the tomb could suggest subsequent grave reopening or additional depositions.

The key for achieving this objective consist of the analytical and meticulous study of the excavation sequence, verifying the temporal succession of phenomena. However, conventional study methods may fall short of reconstructing all processes comprehensively, as a single post-depositional event can often yield multiple effects on the archaeological record.

The other fundamental premise of the present work is that of Virtual Archaeology. In 1990, P. Reilly used, for the first time, the definition of what would become a proper discipline: "*The key concept is virtual, an allusion to a model, a replica, the notion that something can act as a surrogate or replacement for an original. In other words, it refers to a description of an archaeological formation or to simulated archaeological formation*". Furthermore, the idea that virtual approaches would allow the recording of data from contexts no longer in existence after archaeological excavation was already clear [13].

2. STATE OF ART

From 1990 to the present day, the use of 3D technologies has not only become commonplace but is considered such as a scientific tool and means to thoroughly understand archaeological contexts [14].

The present research aims to explore and analyse the dynamics of an archaeological deposit using a dynamic 3D model. In particular, the goal is to verify the effects caused by internal stresses, such as falling or shifting artifacts, within the context of a tomb. The analysed context is Burial 22 of the Piovego necropolis, with a focus on the dynamics of some of its artifacts.

Data from the reference excavation provide clear indications of the dispersion of the fragments of the objects analysed during their fall within the burial. The objective of the simulation is to generate, within a three-dimensional virtual environment, the fall of vase 61 to compare the simulated result with the actual location of the fragments recorded during the excavation. The 3D model of the burial is expected to accurately reproduce the dispersal of the fragments, thus providing an accurate and detailed representation of the events that occurred *in situ*.

Through the reconstruction of these changes in a 3D environment, a dynamic model can be generated, illustrating the original arrangement of the burial and its evolution over time. Approaches that use 3D physical simulations are commonly used in various fields of research, such as civil engineering [15], structural mechanics [16], and medical filed [17], [18]. These approaches are particularly useful for understanding the structural behaviour of buildings and structures in response to different stresses [19], [20].

The statement highlights that are many examples of 3D static reconstructions of funerary contexts in the literature. In many cases, 3D reconstructions refer to still-existing contexts, often burials dug into stone. The methodologies employed can vary widely, as do the purposes of these projects. Terrestrial Laser Scanning and Close-Range Photogrammetry have been utilized for the reconstruction of three funerary complexes in the Quebbet el Hawa necropolis (Egypt), aiming to assess the spatial behaviour of these structures and the ancient excavation processes [21]. Photogrammetric techniques were also applied at the same site to survey areas of difficult access [22].

The tomb of Ipi at the site of Deir el-Bahari (Egypt) was surveyed using a Laser Scanner. The obtained model was utilized to assess the current state of the structure and guide restoration, conservation, and enhancement efforts [23].

Other research endeavours aim to preserve ancient sites from modern interventions, as seen in the case of the necropolis of Verin Naver (Armenia). The site was acquired using Photogrammetric techniques, specifically with the purpose of providing a tool for interventions to protect the site [24].

These methodologies are also useful for contexts that are not always accessible or partially in ruins due to conflict or natural disasters, such as the tomb of Hairan (Syria) [25], or of the Governor's tomb, (Egypt) [26].

The project involving the ITC-CNR of L'Aquila and the University of L'Aquila is mentioned. Thise research focused on the analysis of medieval tombs and their skeletal remains from the site of *Amiternum* (Italy). The approach combines 3D models with GIS environment [27].

Particularly useful for the management of ruined burials is the combined use of LiDAR and UAVs, such as the project for the Yaoheyuan site (China). In this case the aim was to provide a tool for virtual restoration and protection of the site [28].

Finally, the use of multi-sensory 3D scanning method was used to obtain a complete 3D model of the Shofukuji (Japan) tomb to be used for virtual preservation and restoration of tombs [29].

To a much lesser extent, there are also studies on funerary contexts where both their structure and the objects deposited within them, such as burial goods, are replicated in 3D. An example is the Tomba Regolini Galassi in Italy. In this case, a combination of 3D survey techniques and digitization was employed to reconstruct the burial in all its complexity, with the aim of creating navigable VR content for users [30]. However, there is a noted absence of approaches to dynamically investigate cremation burials using virtual methodologies.

However, in the fields of taphonomy and archeothanatology, several works oriented towards a dynamic analysis of the context are highlighted, focusing on transformative dynamics [31]. The work of Wilhelmson and Dell'Unto [32] utilizes image-based 3D modelling techniques to reconstruct the various steps of the excavation sequence, aiming to achieve a result termed a 'dynamic' simulation.

Decidedly focused on the analysis of transformative processes in a virtual context is the study of Mickleburgh, Stutz, and Fokkens. The work was carried out on an inhumation burial from the Netherlands. Starting with excavation data, the position of the body at the time of discovery was replicated; thanks to dynamic simulations run with Maxon Cinema 4D, several hypotheses of the probable post-depositional movements undergone by the body were tested until a reproduction of the original position of the inhumed was formalized [33].

The absence of such simulations hinders a comprehensive understanding of the long-term impacts on archaeological sites, obscuring the intricate interplay between natural and anthropogenic factors.

As the field of archaeology continues to advance, incorporating dynamic simulations into the study of funerary contexts becomes imperative to fill this knowledge gap.

Such simulations not only contribute to a detailed interpretation of the past, but also offer valuable insights into how archaeological sites respond to the stresses of various environmental and anthropogenic factors. Addressing this limitation in the current body of research is critical to advancing our methodological approaches and refining the accuracy of archaeological reconstructions.

3. MATERIALS

3.1. The necropolis of Piovego

The burial studied comes from the Iron Age necropolis of CUS-Piovego. The cemetery occupied a space bordered to the north by the medieval channel of the Piovego and to the south by the course of the Roncaiette [34] which partially corresponds to the ancient course of the Brenta: known as the *Meduacus*, the pivotal axis of pre-Roman and Roman Padua. The necropolis is in the Est of the modern city.

The archaeological investigations have involved the site since 1964, the year in which construction works brought to light remains of pre-Roman burials [35].

Subsequently, various interventions were carried out over the years; archaeological excavations covered the area between 1975/77 [36], [37] and 1988/1989 [38]. Today, there is no trace left of the ancient cemetery, as, after the excavation of the tombs was completed, the area underwent various construction interventions.

The analysis of material has enabled dating the use of the necropolis to the end of the 6th and the beginning of the 4th century BC, a crucial moment in the history of the ancient city of Padua, when it transitioned from a pre-urban settlement to an urban one.

Over the years, the Department of Cultural Heritage at the University of Padua, first under the direction of G. Leonardi and subsequently under the direction of M. Cupitò, has undertaken various archaeological and anthropological studies. Anthropological studies have focused on the analysis of cremated remains and the skeletons [39], [40], [41], [42].

Since the early 2000s, there have been studies on specific contexts of the necropolis, using methodologies such as photogrammetry [43], CT scans [44], [45], laser scanner [46] and Image Enhancement techniques for the analysis of the cremation ground composition [47].

A recently published article synthesizes the studies and results of research conducted over decades on the Piovego necropolis, [48].

Particular attention has been devoted to study the formative processes of the Piovego burials, with various investigations of this kind conducted by Leonardi and his team [11], [12], [49], [50]. The aim is to understand how complex archaeological contexts, such as burials, have evolved over time due to both natural and anthropogenic phenomena. One of the primary objectives is to recover the entire depositional sequence and comprehend the funerary codes employed by ancient human groups.

In addition to traditional study approaches, some burials have been reconstructed in a 3D environment [51], [52], [53], [54]. This approach has proven useful in recovering information not deducible from traditional 2D archaeological documentation. The goal has been to retrieve the spatial arrangements of artifacts within tomb structures to obtain a comprehensive 360° view of the context and analyse the transformative dynamics of the record from a different perspective over time. Piovego burials, in fact, are characterized by repeated reopening, leading to the burial of new individuals or rearrangements of the tomb contents. This practice falls within the well-known phenomenon of the reopening of burials, which affects the pre-Roman Veneto [55], [56]. The phenomenon also concerns the Piovego necropolis.

3.2. The burial 22

In a previous research project, a team from the Department of Cultural Heritage at the University of Padua focused on the 3D reconstruction of some of the cremations from the necropolis.

The starting point for these reconstructions was the existing two-dimensional traditional documentation, generated during both excavation and burial studies, namely plans, sections, and drawings of individual objects. Using the drawings of the artifacts, the individual items of the grave goods were modelled, respecting their shape and metrics. Subsequently, the obtained 3D models were placed in a 3D software environment using 2D plans and sections as spatial references. This process provided morphometrically accurate replicas of the archaeological context. Thanks to this methodology, it is possible to navigate 360° within the three-dimensional model to examine specific aspects of each tomb, such as the potential presence of perishable material elements and the accurate arrangement of the equipment within the available real space in each burial.

Among the analysed tombs was also burial 22 [53], [54]. These previous works consisted of 3D reconstructions of the context, but from a static perspective. The objective was to define, within the confined space of the burial, the correct positions of each artifact, hypothesize the morphology and metrics of the perishable material elements, and determine the overall minimum shape and size of the pit.

The burial 22 was a cremation burial containing the remains of a single adult with a rich array of vessels and metallic artifacts such as ornaments and weapons (Figure 1). The cremated

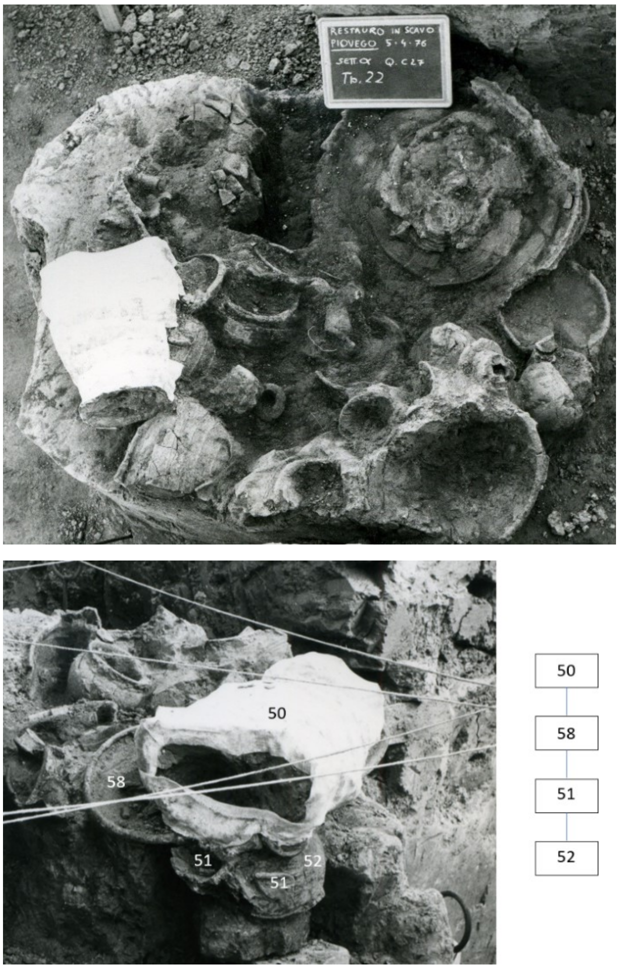

Figure 1. The burial 22 as it appeared at the moment of its discovery and detail with the collapse sequence of the vessels deposited on the perishable material support (©D. Vicenzutto).

remains were deposited inside an ossuary whit the metal objects; the interior of the burial was characterized by the deposition of the funerary assemblage on two levels. The deposition on multiple levels was made possible using perishable materials, which allowed the objects to be placed on different levels. However, these elements were not found during the excavation, but their presence was suggested by the arrangement of the funerary assemblage itself (Figure 1).

The typochronology of the metal objects and the bronze sheet vessels of the grave goods date the burial between the end of the 6th and the beginning of the 5th century BC. The 3D reconstruction of this burial allowed the definition of the original position of all its elements, including objects of the structure itself (such as the perishable material support) and the funerary equipment (ceramic and bronze sheet vessels).

Additionally, by repositioning all elements, plausible hypotheses were proposed regarding the actual extent of the pit (width and length). The reconstruction presented was of a static nature. However, observations by Leonardi and Vicenzutto indicated that this burial had experienced over time phenomena of collapse and displacement of objects within it.

3.3. Case study: the vessel 61

The research presented here aims to investigate the transformations that archaeological contexts undergo due to post-depositional processes using three-dimensional reconstructions.

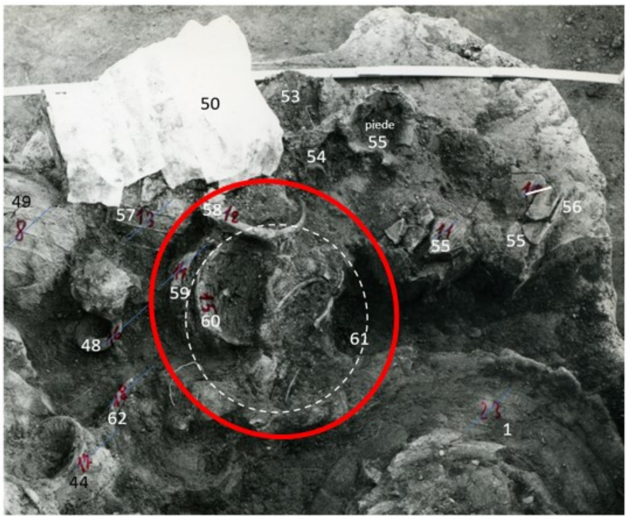

Figure 2. In red the dispersal area of the pot sherds 61 (© D. Vicenzutto).

This study moves in this direction by applying the analysis of dynamic factors to Iron Age cremation burials, which have already been obtained through 3D modelling, using tools provided by computer graphics software integrated with physical engines. This work is focused on the reconstruction of the dynamic of the fall of vessel 61 from an upper to a lower level. During the excavation phase, the collection of data was excellent because it was done from a genetic-processual perspective, aimed to define the formative genesis of the archaeological deposit. In the post-excavation phase, the initial location of vessel 61 could not be determined, but it was learned that some fragments of it were found in the pit and on the shoulder of the ossuary (Figure 2).

Previous 3D simulations showed that there was not enough space to place vessel 61 on the floor of the pit (Figure 3A) [53].

Thus, vessel 61 was placed on a surface made of perishable material located along the south side of the pit. This position is the only one that is compatible with the locations where the fragments of the vessel were found; in addition to this, the discovery of the fragments above the shoulder of the ossuary, can only be explained by assuming a fall from above of the object.

The vessel fell from a height of about 22 cm, impacting the shoulder of the ossuary (causing fragments to be released) while others fell into the pit, between vessel 1 and vessel 59 (Figure 3B). Probably the fall of the vessel occurred when the surface made of perishable material was still entirely or partially intact.

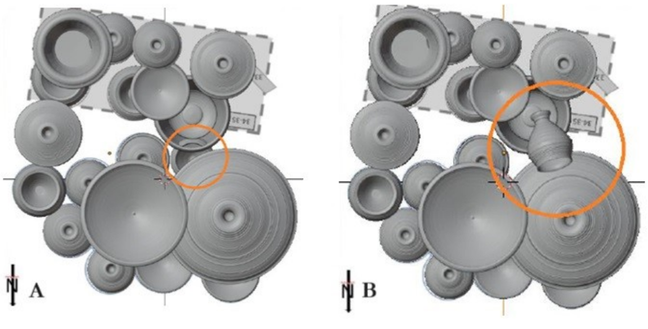

Figure 3. A: Evidence from previous simulations has shown that it is impossible to position vase 61 between vase 1 and vase 59.B: Static simulation of the direction of the fall of vase 61.

4. METHODS

The methodological workflow outlined for the present research unfolds on two distinct yet interconnected levels: the first level is analytical, while the second is interpretative (Figure 4).

From an analytical perspective, the procedure begins with the comprehensive collection and analysis of all excavation data available for the examined context, the burial 22. These data encompass photographs, notes, and observations recorded during both the excavation process and the post-analytical phase study of the context, as well as all relevant site plans and sections.

The philological recovery of information from data of various kinds is a common point in all works proposing reconstructions of the past, from individual objects to entire sites [14].

This is a methodology applied *a posteriori*, namely when the deposit has already been excavated, which is why the dataset for this research is made up of excavation data. For this reason, it is necessary that the collected data are complete and detailed enough to accurately recognize the formative genesis of the archaeological deposit.

The second step is linked to the aforementioned data analysis and focuses on isolating and recognizing post-depositional phenomena. The complexity of these phenomena that accumulate over time on the archaeological deposit is such that it cannot be managed overall. The first phase of this step is to recognize a hierarchy of phenomena to identify the relative sequence of the dynamics of fall and/or transformation. Secondly, it seemed useful to simulate them individually at the beginning and then bring them together in a general framework. The aim is to simulate the changes that have occurred in a diachronic sequence.

The subsequent phase constitutes the actual operational aspect of the process: once understanding what occurs in the analysed context and how it happens, the necessary parameters are introduced into the three-dimensional environment (the sequence of steps will be detailed in the "Discussion and Results" section). Specifically, passive and active objects in the scene are defined. Passive objects act as limits and obstacles in the simulation, behaving as physical boundaries unaffected by gravity or other stresses. Active objects, on the other hand, are directly involved in the simulation, moving, falling, or fragmenting. Subsequently, the simulation can be generated, and the obtained results are compared with the actual excavation data.

In this phase, it may be necessary to return to the excavation data analysis to verify the simulation's progress, highlighting a close connection between the first and third points of the workflow. If the excavation data confirm the simulation, it is deemed plausible; otherwise, it is necessary to review the initial data (returning to point 1) or adjust the simulation settings.

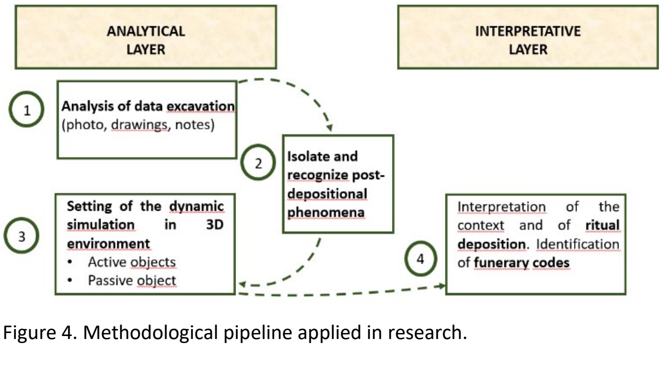

Figure 4. Methodological pipeline applied in research.

Blender 3.6 [57], a free and open-source software also commonly used to perform physical simulations [58], [59] was used to manage all phases of work. The software can handle realistic rigid body interactions. It has several simulation features. For this research, physics-based simulations were used with which Blender is able to simulate the force of gravity [60].

Rigid body simulations can be considered as a subgroup of multi-body simulations; the purpose is to study the response of non-deformable bodies subjected to the action of external forces.

They are widely applied for the development of video games or in the field of engineering [61]. Simulations of this type can generate realistic results starting from few parameters, such as the initial speed and position of the objects. The results generated can differ from each other at the slightest change in the same initial parameters [62]. Blender is equipped with the necessary parameters to produce realistic simulations. The difference between passive or active objects (Physics - Rigid Body – Type) was mentioned in the previous section. A key parameter, and one that greatly affects the result of the simulation, is how the objects collide with each other (Physics - Rigid Body -Collision). Several options can be set in the Shape section. In the case presented here, it is set to Convex Hull. In this way the surface the objects behave as a mesh that includes all vertices. The object, in this way, undergoes a convex approximation; generally good simulation results and stability are achieved in this way. In the course of the work some simulation tests were also carried out with the Mesh parameter. In this way the meshes of the scene are composed of triangles; generally, it allows for more detailed interactions, but the simulation could be unstable and slow; for this reason, for all the final simulations we returned to the collision based on the Convex Hull parameter.

In the simulation steps involving the fragmented object (with the Cell Fracture add-on), the result was unstable, causing not a realistic fall but a kind of explosion of the object fragments. To circumvent this problem, the Collision Margin (Physics - Rigid Body - Sensitivity) parameter is activated and set to 4 cm; this parameter is used to improve the performance and stability of rigid bodies, and better results are obtained when the value does not correspond to zero [63]. This generates a realistic collapse of the vessel 61 fragments.

It is possible to modify the parameters known as "Damping Translation" and "Rotation," which respectively indicate the linear and angular velocities lost over time. These two parameters are set in the software at 0.040 and 0.100, respectively. The "Speed" parameter (Scene – Rigid Body World -Settings – Speed) accelerates or decelerates the simulation; in our case, the value is set to 1.000. Mass is another adjustable parameter in Blender (Physics – Rigid Body – Setting – Mass). To achieve realistic interaction between two objects of different sizes, the mass has been set to two different values for vase 55 and vase 61, considering the different proportions between the two objects (in a 1:3 ratio) and assuming they were partially filled with sediment. All other parameters that have not been made explicit are left at their default values.

The final point is, ultimately, exclusively interpretative in nature and pertains to the considerations that can be drawn from the results obtained through the simulation.

5. DISCUSSION AND RESULTS

The analytical premises of the operational phase in this research concern what is known about the analysed context, what remains unknown, and the points that must necessarily be taken

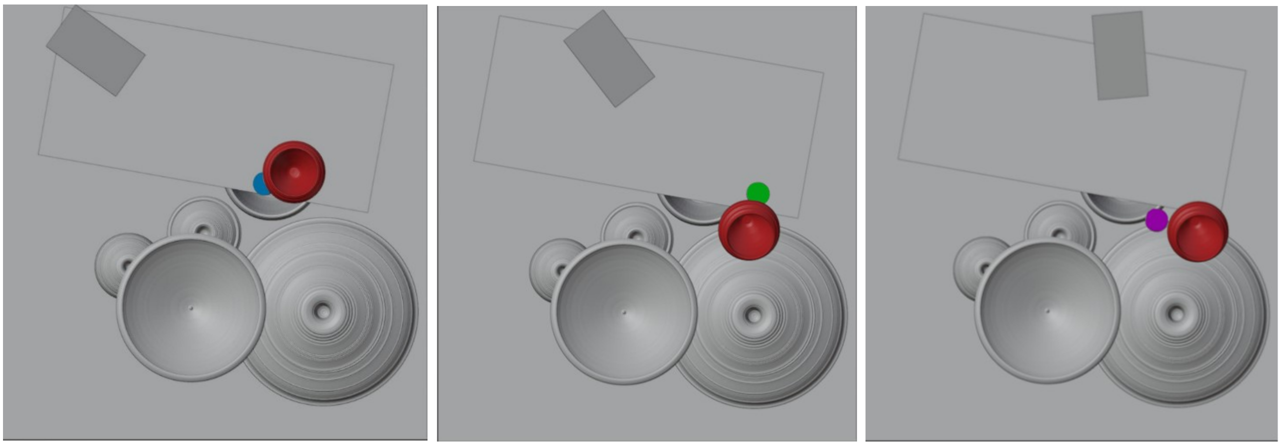

Figure 5. To left to the right: Last frame of 150 of first, second and third scenarios.

into consideration. It is known that the object at the centre of the simulation, vase 61, falls from a considerable height, as its fragments were found on the shoulder of the ossuary (positioned at a certain height above the base of the ossuary itself) and at the base of the pit. This indicates that its original position was on the surface of the support in perishable material.

The cause of the fall, the direction, and the behaviour of the fragments of vase 61 are not known. It should be considered, however, that the west wall of the pit could have been an obstacle during the fall, and similarly, the vases arranged at the bottom of the pit may have influenced the descent of vessel 61.

The operational phase at point 3 of Figure 4 can be further divided into 3 sub-phases: *i)* simulating the possible directions along which the fall occurred, *ii)* identifying all the vessels involved in the dynamics and simulating their behaviour, and *iii)* finally, simulating the fall of the fragments.

Determining where the fall originates is a key point to identify the cause of the fall. To understand this aspect, it is necessary to set the scene by placing the perishable material support, vessel 61 and the other vessels deposited at the bottom of the pit. It is known that the fall of the object occurs from above, it is likely that the push originated from the same plane of deposition as vase 61.

To verify the angle of the stress that causes the vessel 61 to fall, 5 possible scenarios with different directions were simulated. The simulations were simplified at this stage and carried out with a sphere falling on an inclined plane (Figure 5 and Figure 6). In the first scenario the sphere causes no effect but grazes the vessel 61 without causing it to fall. In the second scenario the object is stressed but tends to fall in a space not compatible with the excavation data. In the third attempt the collision between the sphere and the vase causes the vase to fall to a space inconsistent with the data (as in the case of the second scenario). The last two scenarios (Figure 6) are the most realistic because they push vase 61 into the area in which its fragments were found.

Both are located in the southwest corner of the perishable material stand and coincide with the position of vessel 55. An excavation photo (Figure 2) clearly shows that vase 55 falls following a direction very similar to those simulated in the 3D environment. Taking these factors into account, vase 55 may have triggered the falling dynamics of vase 61; for these reasons it is referred to as the object that triggers and determines the fall that is the subject of this research (Figure 7 top).

The second point of the simulation is the behavior and interaction between vessels 55 and 61 and the consequential behavior of vessel 61. The parameters in the scene are as follows:

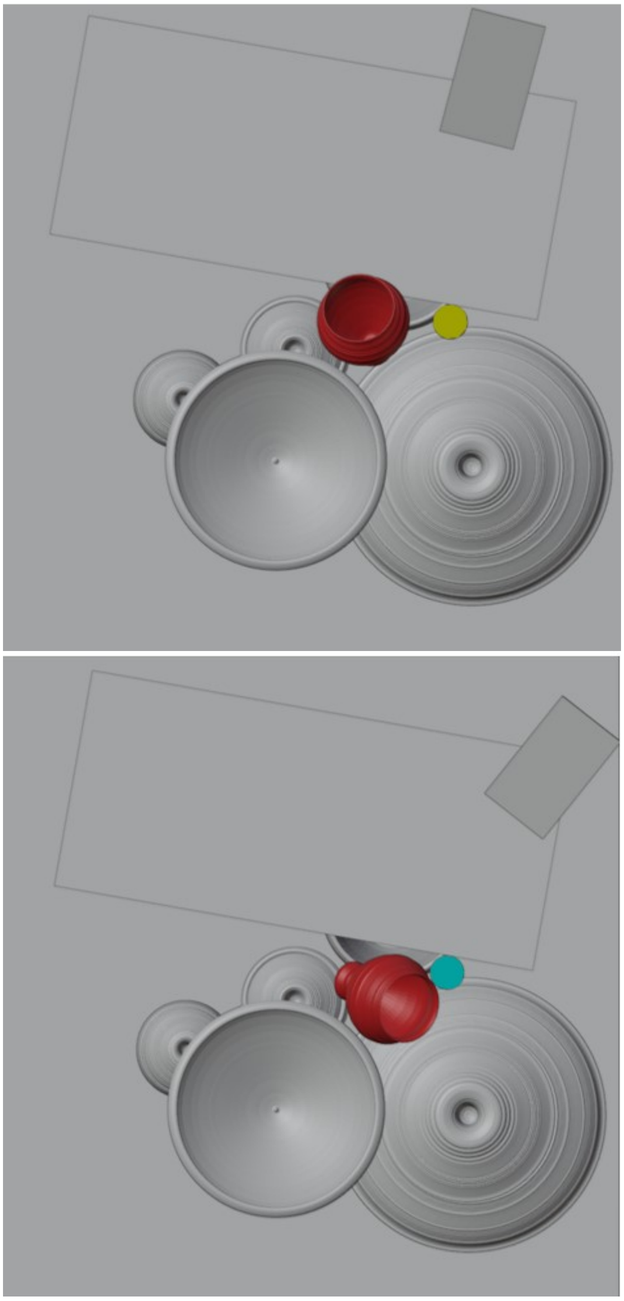

Figure 6. From top to bottom: Last frame of 150 of the fourth and fifth scenarios.

some elements (vessels not involved in the fall, floor, walls and perishable material support) are passive objects. The active objects are vase 55 (in green) and vase 61 in red (Figure 7 bottom).

Another aspect to consider is that vase 61 is found in fragments. For this reason, it was necessary to work on the degree of fragmentation of this object to achieve a plausible breakage and to realistically reproduce the clusters where its fragments were found.

Thanks to the simulation of the object's breakage it is possibile to understand whether the dynamics of collapse and rupture are compatible with the data collected during excavation. Excavation data confirm that fragments were found on the shoulder of the ossuary and at the bottom of the pit, between the foot of the ossuary itself and a second vessel. Based on these data, it is not possible to determine how many fragments the vessel broke into during the impact. Therefore, scenarios with different degrees of fragmentation were simulated.

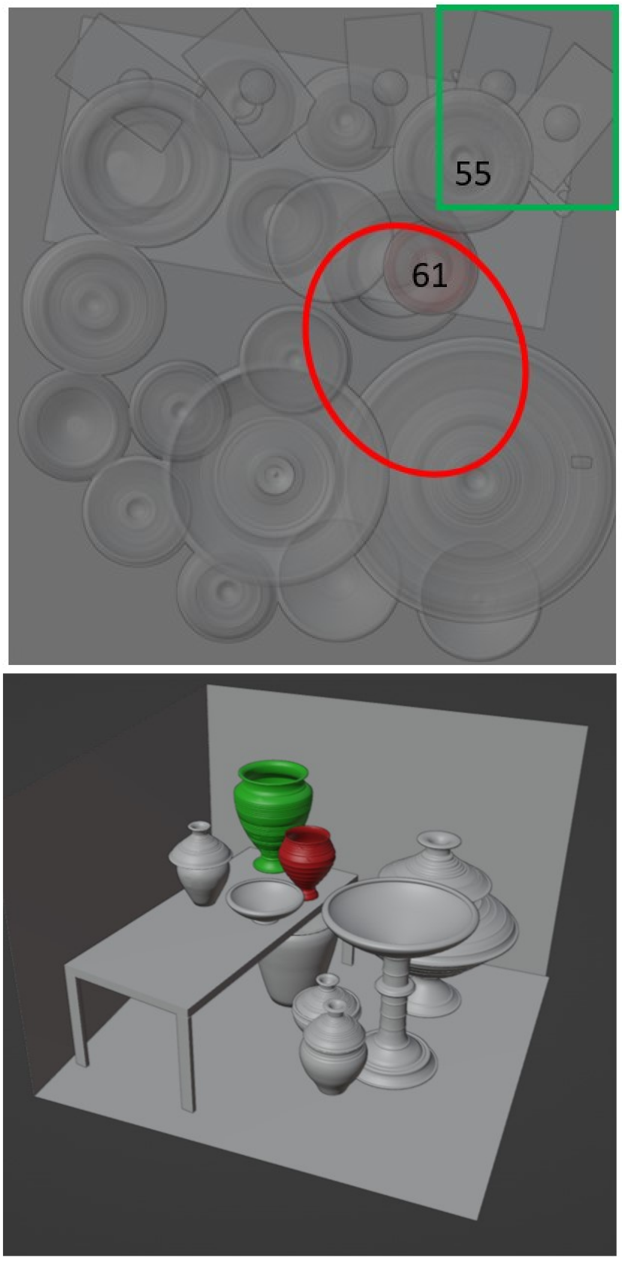

Figure 7. Top: Detail of the 3D model showing in green the angle from which the fall originates and the object that causes it; in red the vase 61 that falls and the area of dispersion of its fragments. Bottom: Final scene setup: active objects in red and green; passive objects in grey.

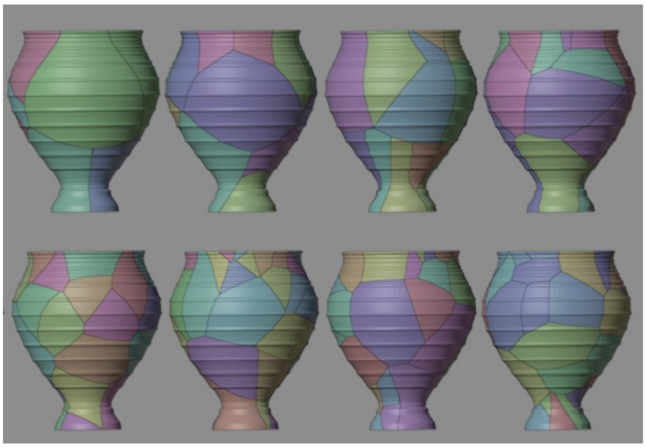

Figure 8. Simulation of the different breakage of vase 61. To top to bottom and left to right: 10; 15; 20; 25; 30; 35; 40; 50 fragments.

This was made possible using a Blender add-on called Cell Fracture, which applied to rigid bodies, allows the mesh to be divided into a number of fragments chosen by the operator. In this case study the degrees of fragmentation were set to 10, 15, 20, 25, 30, 35, 40 and 50 fragments. (Figure 8).

Once the object fragmentation is applied, the gravity force acting in the simulation shows how the different elements fall and disperse in the scene. Again, the properties of rigid bodies are applied; in particular, all objects in the scene (both structural and vascular) are considered passive bodies, except for the vessel subjected to fragmentation.

In the first scenario, a simulation was carried out with a degree of breakage of 10 and 15 sherds (Figure 9 A, B). As shown in the figure, the dispersal area is quite small, and the fragments are placed exactly where they were found during the excavation of the burial. When the vessel fragmentation is set to 20 and 25 fragments (Figure 9 C, D), only a few fragments come to rest on the shoulder of the ossuary. The area of dispersion is much wider, and no cluster well confined of fragments is formed.

When the fragmentation of the vessel is set from 30 to 50 fragments (Figure 10 A-D), few pieces are placed on the shoulder of the ossuary. The dispersal area is very similar in these scenarios. Many fragments are dispersed mainly in the central part of the pit, while we know that during excavation fragments are found concentrated mainly between two vessels (the ossuary and vessel 59).

Taking into consideration the excavation data, it appears unlikely that the object broke into a large number of fragments. As depicted in Figure 10, the scenarios indicate that, using the same input parameters, the greater the number of fragments, the larger the area of dispersion. Conversely, the scenarios presented in Figure 9 align more closely with the archaeological data.

In conclusion, although all the scenarios are realistic, it is likely that the degree of fragmentation was not very high.

6. CONCLUSIONS

The potential of this approach allows for a broadening of perspective in archaeologic research and provides the necessary means to carry out dynamic simulations. Three-dimensional reconstructions often proposed in the literature, take the form of static reconstructions in which it is possible to visualize the object of research (objects, monuments, burials or sites) in their

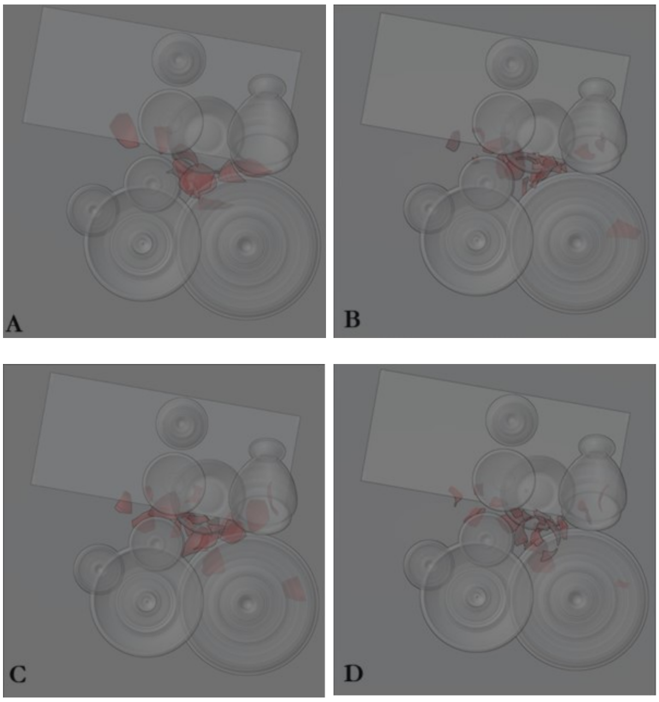

Figure 9. Blender transparent top view. Final frames of the simulations of the fall of vase 61. A: 10 fragments. B: 15 fragments. C: 20 fragments. D: 25 fragments.

entirety but limited to a well-defined moment of the object itself. These types of reconstructions, in fact, fix the state of the object to a moment determined by the operator. What is not sufficiently considered is that everything that belongs to our past undergoes changes that distort their current perception. With this perspective, it therefore seems important both to recover their appearance at origin and to assess how objects, monuments or contexts, have changed over time.

The study presented marks the initial endeavour to examine and replicate a dynamic physical simulation in a 3D setting within an archaeological framework. Focusing on burial 22, a complex pit cremation articulated on multiple deposition levels, a singular event was singled out for analysis: the fall of vase 61 from above. In this specific case, data collect during excavation was carried out with an approach aimed to recognize transformative dynamics.

However, not all archaeological contexts are excavated with care and with an approach aimed at recognizing the formative processes of the deposits. This could be a limitation in terms of application, and for this reason that the progress of research in this field could implement the applicative contexts.

The dynamic simulations thus carried out could become a research tool even for those contexts that have already been excavated and do not have such precise data. The aim is to define a workflow applicable to different case studies, not necessarily excavated with a genetic-processual approach.

The next steps will be to analyse the other transformative phenomena that occurred in burial 22 and establish a relative chronology to recognize which processes occurred before others. The aim is to understand which was the first phenomenon (or the first ones) to have acted on the archaeological deposit, to create a diachronic sequence of transformations.

Subsequently, it will be necessary to simulate these actions in a 3D environment to obtain a global reconstruction of burial 22. This reconstruction will show the transformation and degradation phenomena that occurred from the moment of burial closure to its excavation.

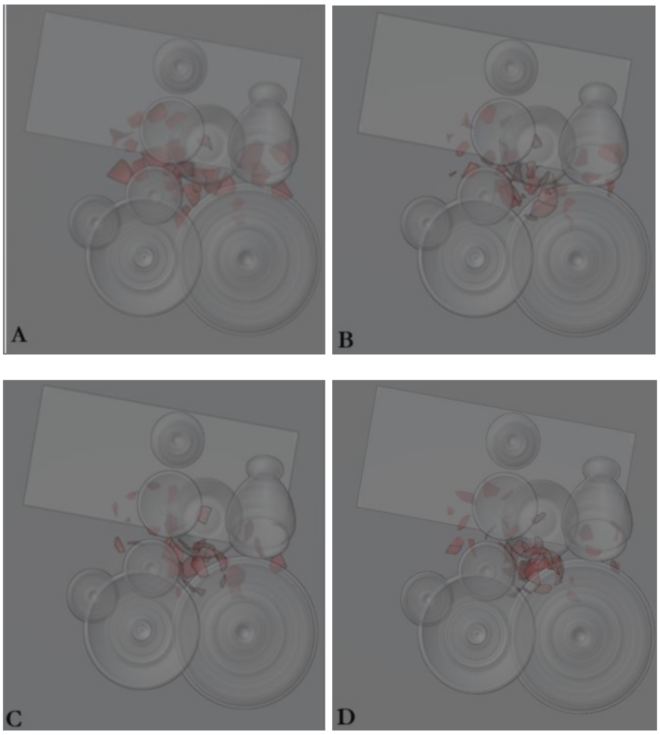

Figure 10. Blender transparent top view. Final frames of the simulations of the fall of vase 61. A: 30 fragments. B: 35 fragments. C: 40 fragments. D: 50 fragments.

ACKNOWLEDGEMENT

We would like to express our gratitude to Prof. G. Leonardi, who conducted the excavation of the Piovego necropolis and analysed the depositional and post-depositional processes of the necropolis. Our thanks extend to Prof. M. Cupitò, the current director of research on the Piovego necropolis. Finally, we acknowledge Dr. D. Vicenzutto and Dr. V. Gallo from the University of Padua, who generously shared the necessary information with the author to formulate the reconstructive hypotheses for burial 22.

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