Virtual Archaeology Review

# Computer Simulation of Multidimensional Archaeological Artefacts

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***Resumen***

*El principal propósito de esta investigación consiste en comprender la(s) función(es) más probable(s) de los artefactos arqueológicos a través de un proceso de Ingeniería Inversa. Además, intentamos proporcionar nuevos datos y, en la medida de lo posible, explicaciones, del registro arqueológico de acuerdo con lo que sabemos de las actividades sociales y procesos de trabajo, por medio de la simulación de las potencialidades de esas acciones en términos de relaciones input-output. Nuestro proyecto se centra en el sitio lacustre neolítico de La Draga (Banyoles, Girona). En este artículo empezamos proporcionando un resumen exhaustivo de los procedimientos usados para capturar y procesar datos digitales 3D de diversos objetos de madera. A continuación presentamos el uso de métodos semi-automáticos de extracción de rasgos relevantes. Finalmente, se discuten cuestiones preliminares acerca de simulación computacional.*

***Palabras Clave**: DIGITALIZACIÓN 3D, INTELIGENCIA ARTIFICIAL, INGENIERÍA INVERSA, SIMULACIÓN, RECONSTRUCCIÓN VIRTUAL.*

***Abstract***

*The main purpose of this ongoing research is to understand possible function(s) of archaeological artefacts through Reverse Engineering processes. In addition, we intend to provide new data, as well as possible explications of the archaeological record according to what it expects about social activities and working processes, by simulating the potentialities of such actions in terms of input-output relationships.*

*Our project focuses on the Neolithic lakeside site of La Draga (Banyoles, Catalonia). In this presentation we will begin by providing a clear overview of the major guidelines used to capture and process 3D digital data of several wooden artefacts. Then, we shall present the use of semi-automated relevant feature extractions. Finally, we intend to share preliminary computer simulation issues.*

***Key words**: 3D SCAN, ARTIFICIAL INTELLIGENCE, REVERSE ENGINEERING, SIMULATION, VIRTUAL RECONSTRUCTION.*

## 1. Introduction

The archaeological lakeside site of La Draga is located on the eastern shore of the Banyoles Lake (Catalonia, Spain). It was discovered in 1990 during the construction works of the Olympic channel and it is the first prehistoric site in a lakeside environment found in the Iberian Peninsula. This early Neolithic village dates from the second half of the 6th millennium cal BC.

One of the aspects that make this settlement so unique is the recovery of a vast number and variety of wooden and other vegetable fibres objects. The contact between the archaeological level and the water table in two of the excavated sectors enabled the preservation of the most important collection of organic materials finds from this period, like the remains of large rectangular huts with oak posts, various wooden and basketry objects and large quantities of cereal grains and animal bones. Hence, making this settlement a very rich source of information and contributing substantially to our knowledge of early Neolithic settlements in the Iberian Peninsula, as well as in the Mediterranean area [Bosch, 2006; Tarrús, 2008].

## 2. Multidimensional Archaeological Data

Before proceeding with the technical procedures of three dimensional data capturing, processing and extraction, it is crucial to define previously what sorts of information are archaeologically relevant to solve a specific problematic. In other words, in which way can such data generate useful information and how can we translate it into knowledge? These kinds of questions are not very usual in our disciplines, and as a result, archaeological data are insufficiently described, and historical knowledge cannot be extracted. Even when using complex technology as photogrammetry, 3D scan and the like, archaeological data remain passive entities, whose descriptions are so ambiguous that no explanation is possible. In this paper we approach this problem distinguishing data capture from data representation, and introducing the need of archaeological artefacts as dynamic entities, whose description should enable researchers and the public to "use" them in the way scientific hypotheses suggest.

It is our view that the real value of archaeological data should come from the ability to extract useful information from them. This is only possible when all relevant information has been captured and coded. Nevertheless, archaeologists usually tend to only consider very basic physical properties, like size and shape.

Sometimes, texture, that is, the visual appearance of a surface is also taken into account, or the mineral/chemical composition. The problem is that in most cases, such properties are not rigorously measured and coded. They are applied as subjective adjectives, expressed as verbal descriptions preventing other people will use the description without having seen the object. Instead of traditional data files, the best way to code size and shape information, and even textural details of archaeological objects, we suggest to use full solid models, as generated using 3D scanning and appropriate softwares. The same problem affects the temporal and spatial location of the object. If spatial coordinates or dates have been measured, they are neither integrated in the same database, nor formalized as basic properties of the historical object.

Nowadays, it is popular to discuss about cultural heritage data semantics and "metadata". Metadata can provide more insight into the object, by overlaying them with increasing meaningful information. Therefore, ease the interpretation and exchange of the descriptive data and ensure that these are more accessible and retrievable for digital archives and repositories. However, the lack of 3D documentation standards lead us to follow the 3D-COFORM [3D-COFORM, 2009] recommendations and a conjunction of scattered data fields to set out what information to record in our archaeological dataset. In the near future we intend to start converting this dataset to the CARARE's metadata schema [PAPATHEODOROU, 2012], as well as including it in the PADICAT system [PADICAT].

Data representation must be so complex because archaeological objects must be documented in their past functional terms. What the current metadata lacks are structural properties, relevant for technical and functional knowledge of physical movements that were possible with that object given what we know about their use in the past. There are not yet any formalized semantics for technical and functional properties, therefore we are working from the point of view of current research in Artificial Intelligence and Object Recognition. Our approach to document the functional aspects of historical objects involves applying Reverse Engineering processes, by simulating the artefacts' function(s) and inferring possible inherent working processes [MOITINHO, 2011].

## 3. Reverse Engineering Archaeological Artefacts

### 3.1. 3D Surface Data Capture

Even though these artefacts have been restored and given its still fragile nature, we used a non-contact close-range 3D structured light scanner (SmartSCAN3D Duo System, Breukmann) to first proceed with the capture of the three dimensional geometric digital models and new data concerning to the individual form of each item.

Because of the specificities of these artefacts – overall dimensions, type of raw-material, macro-topography and desired level of detail (as these artefacts are very fragile and made of a perishable material, it is important for us to document them with as much detail as possible, to avoid manipulating them further, for cyclic monitoring and preservation, and for future researches) – we decided to use the shortest FOV available for this scanner, the 90 mm set of lenses, which has the highest resolution and gives the maximum level of detail (x,y resolution: 50 μm).

Due to logistic matters and to the short time available, after calibrating the scanner we decided to continue only with the point cloud capture – including their pre alignment and alignment, to ensure that there weren´t any relevant parts of the form missing, as well as the quality of the recorded data – at the MACB, using the scanner's capturing software Optocat 2009.

It is crucial to have a thorough understanding of these sequential steps, because the final outcome depends intrinsically on all of them. Consequently, each step's parameters must be specially tailored according to clear objectives previously set. Nonetheless, the resulting geometric model is not exact. There are many factors that limit the precision and even reliability of the 3D geometrical data. Among them we can mention: alterations of the original artefact in form, size, texture and colour, due to taphonomic or post-excavation factors; the present and overall geometry of the artefact (i.e. the macro-topography of the object); the type of raw material and archaeological surface finishing (e.g. wood hardened with fire); distinct surface characteristics on a specific area (e.g. wood hardened with fire, plus restoring product, plus natural wood surface); restoration techniques; identification code on the artefact's surface; environment lightning conditions; and hardware-software issues.

### 3.2. 3D Surface Data Post-processing

The 3D surface data post-processing stage consists in processing the 3D data formerly captured by the acquisition system – from scan data cleaning, to point clouds final alignment, scans merging and polygonal mesh generating. At the end of this stage, we aim to obtain a 3D surface model.

As mentioned earlier, since each stage of the process depends on the outcome of the previous ones and determines the following ones, here again all parameters must be tailored accordingly.

Finally, the 3D surface model was ready and we were able to carry on with feature extraction.

### 3.3. 3D Surface Feature Extraction

This stage consisted in extracting quantitative data from the 3D surface model, in a way it could be decoded and understood by the archaeologist. We used both Rapidform XO Scan 2010 (INUS Technology) and MeshLab V1.3.0 (Visual Computing Lab, ISTI-CNR) softwares.

We used mostly MeshLab software to compute geometric data (e.g. width, height, depth and diagonal of bounding box; mesh volume and surface; mass and volume centres) and topological measurements; and Rapidform to semi-automatically analyze the curvature angles of the surface. Analyzing these curvatures allows detecting edges and patterns, in other words possible use-wear macro traces and working surfaces (Fig. 1).

These new information provide meaningful data to distinguish one artefact from another.

### 3.4. Computer Simulation

The purpose of documenting historical objects is to be able to "use" them in the same way they were used in the past. Obviously, historical objects cannot be used in a real way, because they must be preserved, but we can approach them in a virtual way. Computer simulation is then a fundamental aspect of heritage documentation because it allows seeing ancient artefacts as dynamic entities and not as passive objects. Artificial Intelligence techniques, in particular computer simulation, permit to test different features and replicate distinct behaviours on a specific 3D digital model of an archaeological artefact – here described as a mathematical model that incorporates several variables. That is to say, the use of computer simulation as an experimentation and validation tool towards a better understanding of archaeological artefacts, by endowing 3D digital models with both physical and mechanical properties, and thereafter manipulate virtually these enhanced multidimensional models [REICHENBACH, 2003; KAMAT, 2007; PERROS, 2009].

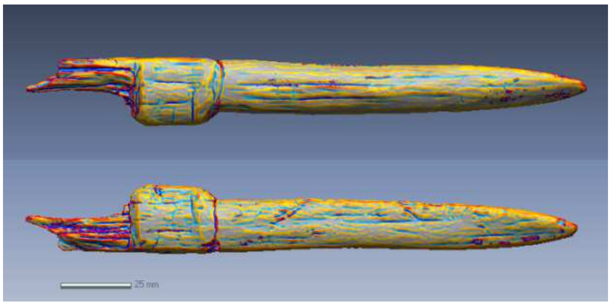

*Figure 1. 3D digital surface model of spear (D03-JF88-3), curvature extraction.*

Given that we already have the 3D digital surface model, we can now convert it to a 3D digital solid model, to then simulate and analyze possible functions of each of the archaeological artefacts initially scanned. Here we present a work in progress. For this project we are using Solidworks Simulation Premium 2011 software (Dassault Systèmes). It provides several tools for testing and analyzing the form, motion, function, and multi-physics of artefacts, wether they are parts or assemblies, by setting up virtual real-world environments and operating conditions. Before running any type of simulation tests it is necessary to follow a few steps, to ensure best results.

#### 3.4.1. 3D Solid Model

The objective of this step is to obtain a 3D digital solid model. It comprises, first of all, preparing the surface mesh. Next, creating a filled surface. Last, converting the surface into a solid model, by generating parabolic tetrahedral solid elements.

Finite Element Analysis (FEA) allows the body of an artefact, or even a component, to be divided in a discrete number of interconnected smaller elements, where each element intersection, a node, can have different degrees of freedom. This permits to model more complex behaviours, by combining the information obtained from all its elements and nodes.

Even though the geometry of the model has to be optimized before a simulation can be achieved, the final solid model has to carry all the relevant information. The accuracy of the simulation results is intrinsically linked to the quality of this new mesh, while being easier to handle and process than the initial form directly.

#### 3.4.2. Material Composition

Including mass and assigning the raw-materials' physical and mechanical properties to each artefact and its components can benefit reasoning about object functionality. In fact, these are properties that should be included – along with, for instance, geometry, texture, colour or weight of the raw-material – whenever describing an artefact.

Each type of simulation analysis and material model determines which mandatory properties' values fields must be filled in – i.e. mass density, tensile strength, compressive strength, yield strength, elastic modulus, shear modulus, material damping ratio, thermal conductivity, thermal expansion coefficient and specific heat values.

Since we weren't able to find neither existing material libraries with the woods which the artefacts of our study are made of – Taxus baccata, Buxus sempervirens, Salix sp, Cornus and Corylus Avellana –, nor in the available literature all the required physical and mechanical properties' quantitative data, the only way out was to conduct real-world tests to obtain these values.

All the wood samples were cut according to the ASTM D international standard. Yet, both physical and mechanical tests had to be conducted according to the equivalent Spanish standards UNE, since these require smaller samples and some of the wood logs were rather small.

The fundamental structure of wood, from the molecular to the cellular or anatomical level, determines the properties and behaviour of wood. Because of the fact that this material is heterogeneous and anisotropic – i.e. its structure and properties vary in different directions: radial (perpendicular to the grain in the radial direction), tangential (perpendicular to the grain, but tangent to the growth rings) and longitudinal (parallel to the grain) – in both its hygroscopic and mechanical behaviours [Forest, 1999], it is necessary to perform tests not only parallel but also perpendicular to the wood's grain. We are currently entering the outcome data into Solidworks Simulation software, and finally starting to create a material library specifically for the artefacts of La Draga to then proceed with the simulation tests [Moitinho, 2012].

#### 3.4.3. Tests and Analysis

This step will consist in first selecting the type of simulation, namely static, which calculates displacements, reaction forces, strains, stresses, and factor of safety distribution; frequency, calculates stresses caused by resonance; buckling, calculates large displacements and failure due to axial loads; fatigue, calculates the total lifetime, damage, and load factors due to cyclic loading; nonlinear, calculates displacements, reaction forces, strains, and stresses at incrementally varying levels of loads and restraints; dynamic, calculates the model's response due to loads that are applied suddenly or change with time or frequency [Solidworks, 2012]. Another possibility is to conduct motion simulation, which allows defining parameters such as gravity, type of contact and position relationship between components or assemblies. Besides simulation type and settings, the form and dimension of the model, the material(s) properties, the relation between the artefacts' components, the mechanics of human movement (kinematics), the type of medium and physics, are all considered in order to conduct tests, analyze and predict how the virtual artefact would behave as a physical object in possible scenarios of real world operating conditions.

Then, in defining the parameters for the simulation and assigning the parameters' values and settings. In addition, FEA enables to determine how each node will react to distinct forces and magnitudes, such as certain stress levels, while indicating the distribution of stress, displacement and potential body deformation. As mentioned before, it is also possible to apply restraints to the whole assembly.

After that, running the real-time simulation test. And last, analyzing, comparing and evaluating the output data or checking possible behaviours and functions of the enhanced multidimensional virtual artefact under certain working conditions. If necessary, one can modify the mesh density and other characteristics (FEA), redefine parameters, assign new values and settings or any other input data, select another simulation study or run a new simulation test, to troubleshoot problems or equation the validity of the model itself.

Simulation results may provide new insights into the complex dynamics of certain phenomena, such as event-based motion or kinematics. Here, the computer simulates the motion of an artefact or an assembly and tries to determine its behaviour by incorporating the effects of force and friction – e.g., ballistic, where the parameters of possible trajectories, elements positions, velocity, acceleration, friction and distance can be successively changed and tested. Meshes density, component contacts and connections, and material properties are also to be taken into account, when simulating motion capabilities to assess artefacts' functions. Mechanism Analysis allows to understand how the mechanism of an artefact assembly performs – e.g., to analyze the needed force to activate a specific mechanism or to exert mechanical forces to study phenomena and processes such as wear resistance.

Of course, one should keep in mind that depending on the problematic and artefacts to be studied, some of these simulations might be more or less suitable, not suitable at all, or should even be used in conjunction with each others.

## 4. CONCLUSIONS

At the methodological level, we haven´t fully implemented RE processes in our project, for the reason that we haven´t yet reached all the stages and steps of the workflow. There is still much work ahead.

When planning survey strategies, there are technical issues, operational imperatives and environmental conditions which must be taken into account, in order to prevent or troubleshoot problems. Likewise, on the one hand, it is fundamental to have a thorough understanding and knowledge of how the workflow functions, since each stage of the process depends on the outcome of the previous ones and determines the subsequent ones. On the other hand, to set clear objectives when tailoring each step's parameters.

The archaeological artefact can be faced as an enhanced multidimensional model, and computer simulation can be understood as an experimentation and validation tool that takes care of many different tasks, as well as a kind of coordinator between the different artefact's components, properties and behaviours

## Aknowledgements

This research is part of the project PADICAT ("Patrimoni Digital Arqueològic de Catalunya), funded by the Obra Social la Caixa and the Asociació d'Universitats Catalanes (Programa RecerCaixa, RECER2010-05), as well as of the project "Social and environmental transitions: Simulating the Past to understand human behaviour", funded by the Spanish Ministry for Science and Innovation, under the program CONSOLIDER-INGENIO 2010, CSD2010-00034. This research also benefits from Vera Moitinho's Ph. D. grant from the Fundação para a Ciência e Tecnologia (FCT), Portugal.

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