Virtual Archaeology Review

Understanding Virtual Objects through Reverse Engineering

Vera Moitinho y Juan Anton Barceló

Departamento de Prehistoria de la Universidad Autónoma de Barcelona. Barcelona. España

Resumen

El principal objetivo de nuestra investigación consiste en desarrollar una nueva metodología de análisis e interpretación de artefactos arqueológicos para el estudio de la relación entre forma y función de los artefactos. El fundamento de nuestra propuesta es un enfoque basado en técnicas de Ingeniería Inversa que partiendo de datos visuales procedentes de escaneo 3D, los pone en relación con las consecuencias esperadas de las acciones sociales que tuvieron lugar en el pasado en un enfoque de Inteligencia Artificial y análisis cuantitativo de datos. Además, nuestro trabajo está basado en la nueva manera de "ver" la realidad arqueológica. El procedimiento consiste en la "simulación" computacional de la cinemática de esas acciones y ele estudio de las características geométricas y visuales de sus consecuencias potenciales, expresando los resultados en términos de relaciones entrada-salida.

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

Abstract

The main objective of our research is to develop a new methodology, based on Reverse Engineering processes – 3D scan, quantitative data analysis and Artificial Intelligence techniques, in particular simulation – to study the relationship between form and function of artefacts. Furthermore, we aim to provide new data, as well as possible explanations of the archaeological record according to what it expects about social activity, including working processes, by simulating the potentialities of such actions in terms of input-output relationships.

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

1. Introduction

In archaeology, capturing and processing 3D digital data have been frequently directed for preservation and dissemination purposes, through a wide number of virtual reconstructions, virtual reality and visualizations, virtual museums, replicas or even entertainment. Although these technologies have been around for some time, it appears that there are still few studies and research projects in virtual archaeology that go in further directions (Fig. 1). How to capture and process these new digital data? What kind of information can these accurate data provide us?

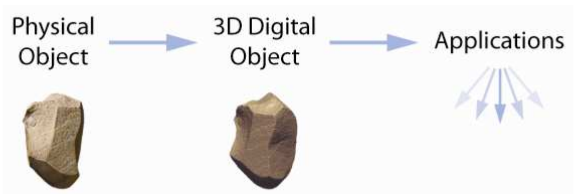

Figure 1. Basic framework.

As each discipline of engineering has a different definition for Reverse Engineering (RE), henceforth when we refer to RE we refer to the process of extracting missing knowledge from anything man-made, by going backwards through its development cycle and analysing its structure, function and operation (ITA; DENNET, 1991; EILAM, 2005; RAJA, 2008; WANG, 2011). The same way RE has been used for a variety of different purposes – for instance, industrial manufacture, aerospace, automotive, software, medicine, inspection and quality control – we may also ask: Can RE be of any use in archaeology? If so, how can it play an important role in solving certain archaeological questions?

The main objective of this research is to develop a new methodology, based on RE processes – 3D scan, quantitative data analysis and Artificial Intelligence techniques, in particular simulation – to study the relationship between form and function of artefacts. Furthermore, it aims to provide new data, as well as possible explanations of the archaeological record according to what it expects about social activity, including working processes, by simulating the potentialities of such actions in terms of input-output relationships.

2. Methodology

Ever since the studies of materials from direct observation and handling has provided data of great and unquestionable relevance. Visual perception makes us aware of many fundamental properties of material evidences from past human activities. Different visual characteristics have almost certainly been of great importance for different explanations. For their study it is essential to measure, to compare and to classify the various attributes of the shapes and forms of archaeological materials, as much as to quantify them, since these allow to describe its (ir)regularity and to some extent making possible the study of its causes (BARCELÓ, 2010).

In this context, it becomes critical to understand on the one hand the meanings of both Form and Function and how to describe each one of them. In an archaeological perspective, it is essential to understand and define objective parameters, as well as the characteristics, attributes and quantitative properties that are to be taken into account. What and how to identify, characterize and classify? And how to extract and use the geometrical and structural information therein contained? On the other hand, to understand the different types of possible relationships between form and function. Hitherto, the insufficiency and lack of a clear consensus on the traditional methods of form description – mostly visual, descriptive, ambiguous, subjective and qualitative – have invariably led to ambiguous and subjective interpretations of its functions. It is thus strongly advisable to systematize, formalize and standardize methods and procedures more objective, precise, mathematical and quantitative, and whenever possible automated. Can the form of an artefact determine its function(s)? How can form be a key factor in determining the actions that can be and/or were possibly performed with a specific artefact? Thus, how to determine the working processes that produced certain artefacts with specific forms?

Hence, based on the premises that form identification is fundamental to the archaeological study; and that form should be considered as a quantitative property, referring to the metric characteristics of an object and therefore be expressed geometrically and not verbally, emerges the need to investigate:

a) Since archaeological objects have at least three dimensions and belong to a physical space in which we human being move – i.e. the archaeological context – why not study all this geometry, instead of only its two-dimensional representation – e.g., sketches, drawings or photographs – and the obvious loss of information?

The major problem of two-dimensional representations has been that assumptions, rather than measurements, have often sufficed for a missing third dimension – for instance, assumptions that surfaces are plane or that they are truly vertical or horizontal. So, if one needs to study an artefact in depth, two-dimension context is not generally sufficient (MOITINHO, 2007).

b) If computational analysis of forms of archaeological evidences can play an important role in solving certain archaeological problems. If so, how? Since computational analysis allows identifying forms and inferring its mapping, responding to questions raised by visual perception, its potentialities let us clearly foresee many practical applications, such as geometric morphometrics in three-dimensional space; forms and patterns recognition; lithic, bone and pottery refitting and reconstruction, among others.

c) If it is possible to automate the recording, processing and transformation of archaeological data in a systematic and efficient way, in order to enable its analysis and classification. If so, how? If it is then possible to interpret in a systematic and efficient way the relationship between form and function of different archaeological artefacts, from different geographical and chronological contexts, to thereafter be able to suggest working processes and deduct past social dynamics. If so, how?

2.1. Reverse Engineering

As mentioned earlier, RE is the process of extracting missing knowledge from anything man-made, by going backwards through its development cycle and analyzing its structure, function and operation. It consists of a series of iterative steps, each addressing different questions regarding, in this case, an overall artefact. These steps may be repeated as often as needed until all steps are sufficiently satisfied.

In this research, the scope of RE processes refers only to geometric features of the form of artefacts. We intend to apply RE from the physical-to-digital stage to the interpretation, by simulating the artefacts' function and inferring possible inherent working processes (Fig. 2). During this experimental work, it will be important to analyse its potentialities, constraints and limitations. At the end, we aim to use these processes in the effort to achieve more efficiently better results, as well as to decrease research time and efforts.

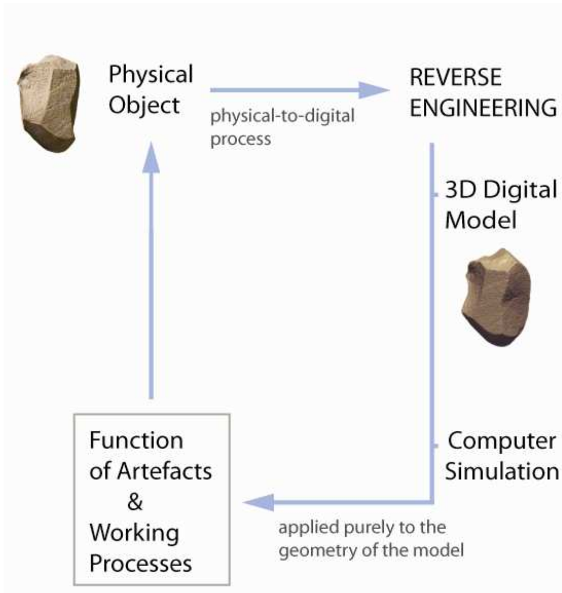

Figure 2. Proposed framework.

3. 3D Digital Model

Given the fragile nature of many archaeological material evidences, we intend to use a non-contact close-range 3D scanner to first proceed with the capture of three dimensional geometric digital models and new data concerning to the form of several artefacts from different spatial and chronological provenances.

Secondly, we will have to deal with several issues related with data processing – e.g. scans alignment, point cloud processing, polygonization, hole filling, data filtering (algorithms) – levels of detail and desired accuracy.

Next step will consist in utilizing form descriptors to extract quantitative data, in a way it can be decoded and understood by the archaeologist. By describing objectively the form of an artefact ambiguities or subjectivities are avoided, and quantifications and comparisons become less tough. This new information is expected to provide sufficient and meaningful data to distinguish one artefact from another, by evaluating its mathematical function; thus to allow surface and volumetric comparisons, according to standards universally considered among the different types of archaeological artefacts. It seems obvious to us that one can only explain and interpret, if one has previously measured and described correctly.

However, before proceeding with the data capture, processing and extraction, it is crucial to define previously what sort of data are archaeologically relevant to solve a specific problematic. In other words, what data to extract from the 3D geometrical digital models and to what purview are they representative of what is intended to demonstrate? How can these 3D digital data be useful in our archaeological research? What sort of gains to expect in the present project? In what way can the collected data generate useful information and how to translate it into knowledge? The intrinsic value of the data comes from the ability to be able to extract useful information from them, i.e. semantic data.

4. Computer Simulation

Based on the extracted descriptors, in this case the quantitative data previously obtained, we aim to develop and experiment advanced computational techniques, in the effort to automate geometric morphometrics analysis of different types of archaeological artefacts – with an emphasis on the analysis of three-dimensional simple and complex geometries – and execute more efficiently part of the proposed methodology.

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 physical properties and thereafter manipulate virtually these enhanced multidimensional models (REICHENBACH, 2003; KAMAT, 2007; PERROS, 2009).

The advantages of including mass and assigning raw-material properties to distinct artefacts components, the mechanical properties of raw materials (including artefact and destiny impact surfaces), the mechanics between artefacts' components, the mechanics of human movement, the type of medium (air, water, etc.) and physics are considered in order to conduct tests, analyze and predict how the virtual artefact would behave as a physical object in real world operating conditions. Ergo, enabling a wide variety of "what if" scenarios, in order to determine probable functions of artefacts and working processes that produced objects with specific forms.

Computer simulation and visualization tools offer several possibilities to tackle. Among them is Finite Element Analysis (FEA), which allows the body of an artefact, or even a component, to be divided in a large number of sections, i.e. elements, where each element intersection is called a node. By applying a force and indicating its magnitude on each node, FEA can determine how it will react, for example, to certain stress levels, while indicating the distribution of stress, displacement and potential body deformation. Besides FEA, it is also possible to apply restraints to the whole assembly and analyze how it will react to the effect of, for instance, stress, forces and torsions, pressures, strains and deflections, fatigue, bearing load, drop, movement, gravity, temperature, and deformations; or to predict buckling or collapse, flexibility and breakage susceptibility, crack propagation, or even to evaluate a component's lifetime.

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. Meshes density, component contacts and connections, and material properties are also to be taken into account, when simulating motion capabilities in order 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.

5. Conclusions

It seems quite clear to us that, on the one hand, the choice of appropriate methods and techniques should definitely depend on the archaeological problem to solve. On the other, that the use of any technological or methodological advance should assume an important step for the archaeological research in question.

Given that the purpose of this paper is to introduce a preliminary methodology, there is of course much work ahead. The next step will then consist in its implementation.

The potentialities of 3D scanning and some of the advantages of working and conducting experiments with 3D digital models are already well-known (BERALDIN, 2004; MARA, 2004; BATHOW, 2008; GEORGOPOULOS, 2010). 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 elements, properties and data.

At the end, we intend to evaluate RE processes' constraints, quality, robustness and effectiveness, by controlling the flow of information and vulnerabilities of the system.

While the priority here is given to the computational study of the geometry of archaeological artefacts in order to deduct its possible functions and consequently to be able to suggest working processes and inherent past social activities – to a greater extent, to build new hypothesis and to improve understanding of the data – ideally these achieved results should be both compared and supported by other sorts of data – e.g., use-trace and sediment analyzes, indirect information (ethnoarchaeology, photographs, documents), geographical and chronological context – to enable more complete "what if?" scenarios and therefore an overall understanding of the subject. Moreover, if feasible, one should also conduct real world testing to completely verify.

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