

# Reconstructing Conimbriga

## *Digital Cantaber*

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**Abstract:** Being the ancient cultural heritage structures and artefacts so full of detail and relevance to studies related to our past, it would be desirable to have precise virtual replicas that could be freely explored without endangering important pieces of history. However, the costs to produce three-dimensional environments are sometimes discouraging, due to the significant cost of some 3D authoring tools, and to the time necessary to manually produce the models. This paper presents a low-cost alternative to the classic manual modelling process, towards the production of highly detailed virtual models, by using open source software and a low-cost moving depth camera. The ambition is the dissemination of our cultural heritage legacy, making it accessible, not only to experts, but also to the general public, without requiring any high-performance hardware, authoring software or professional 3D skills. For the visualization, our virtual reconstructions will be available through a three-dimensional live model viewer, based on recent technologies such as HTML5 and WebGL. Those may be triggered from a wide variety of device, contributing in this way to a true democratization of history knowledge. The proposed approach was applied to create a virtual model of the so-called “House of Cantaber”.

## 1 INTRODUCTION

Over the years several tools have emerged, that intended to respond to the need to have exact replicas of archaeological heritage that can be exploited without endangering them. However, these have proved discouraging since they are associated with high costs, time consuming processes and obstacles regarding the online availability to target audiences. As a solution to this problem, the creation of a tool based on open-source software and a moving depth camera is presented. This results in a website, which provides an interactive model with exact replicas of the artefacts, without the need to install additional plugins in the browser.

Nowadays it is possible to perform three-dimensional acquisitions without the need for major infrastructures, using low-cost equipment, which enables mapping real scenarios with a high level of detail. This possibility opens up new prospects for the virtual and augmented reality scenarios. These technological advances allow us to reach levels of reliable reconstruction of cultural heritage spaces.

The case study presented in this paper is located in the ruins of an important Lusitanian city of the ancient Roman Empire: Conimbriga. Excavated since 1899, opened to the public in 1930 and with less than 20% of its full length brought to the surface, this site has a prominent role in the Portuguese cultural heritage.

Discovered during excavations that took place between 1930 and 1934, completed in 1938, the *House of Cantaber* is one of the largest and richest in the western part of the empire (V. N. H. Correia, 2011).

It is precisely the *House of Cantaber* that was chosen for a virtual reconstruction to be made available on the Internet so that it can be accessed interactively everywhere in the world.

## 2 VIRTUAL RECONSTRUCTIONS

In recent years the so-called Virtual Archaeology led to a significant growth of virtual reconstructions of

cultural heritage spaces, including Conimbriga. As an example, Eduardo Barragán presents on his personal page (<http://italicaromana.blogspot.pt/>) excerpts from videos with a possible reconstruction of the city of Conimbriga, namely the *Insula do vaso fállico*. There are several apparent problems in the architectural model chosen, namely those of Pompeii/Herculaneum, breaking down, in our view, the historical realism desirable that must take into account the particularities of the local architectures. Another Roman site propitious to being virtually rebuilt is Bracara Augusta (Bernardes et al., 2000) and (Bernardes and Martins, 2003). These, despite representing fundamental resources for research and being extremely important for raising cultural heritage consciousness, lack reality quality for today's standards.

Regarding the acquisition of three-dimensional archaeological structures there are several tools available for the task. For instance, in wide exterior environments, the *DeltaSphere 3000 time-of-flight laser scanner* (3rdTech, 2000), used by some police departments by the forensics team to scan crime scenes, which uses readings from infrared lasers combined with digital photographs, in order to acquire textures. However, despite its good results it is quite a slow process (Zhu et al., 2007). Another solution is the *Metric Vision LR200 Laser Scanner* which was the first device that combines software acquisition by radar, laser and 3D. It was used in the famous case of the "*Plastico di Roma antica*" (Guidi et al., 2005) acquisition. Despite being a large model in size it was tiny in detail and high on price.

To acquire smaller objects the *NextEngine Multi-Laser 3D Scanner* (NextEngine, 2001) can be considered a good solution, since it has several advantages in recreating textures and colours of objects, thus capturing an accurate picture of the real object. Though, it has some drawbacks, such as the high price and the fact that it needs a specific scenario with a swivel base. This base has to run at a constant speed, making the procedure very time consuming.

There is also another type of device that allows three-dimensional acquisitions at a significantly reduced cost when compared with the aforementioned solutions: the Microsoft Kinect™. This piece of hardware was originally aimed at the game industry, designed for the *Xbox 360*™ video game console. It allows interaction in a human natural way (PrimeSense, 2013), but due to its capabilities when it comes to capturing geometric data, proved to be an asset in the process of acquiring three dimensional objects. A

demonstration of the potential of the Kinect in three-dimensional modelling of an indoor environment may be observed in the work of (Henry et al., 2010). Indeed, the potential of this equipment and its growing popularity in a number of areas beyond the video games led to the emergence of a new version, called Kinect for Windows, largely identical to the console model but with significant improvements in catchment details on objects of small size (Pheatt and McMullen, 2012).

The solution presented in this paper uses the first version of the Kinect sensor, available at a relatively low cost. However, the launch of the second version of this device, the Kinect 2, is already planned by Microsoft's. Amongst other features it will have a resolution of 1080p (instead of the 480p from the previous version). It is expected that with a few adjustments the ConimbrigaCG, a small tool which was developed to capture Conimbriga's artefacts, and using the soon to be released *Kinect SDK 1.8* (a free development kit developed for this version of the Kinect sensor (Microsoft, 2011)), acquisitions will become much more accurate due to the improved depth perception of the new sensor.

When it comes to be able to interactively create and control three-dimensional scenes, these may be produced using specific modelling software. However, some have high costs, not only monetary but also associated with the learning time necessary to master the software.

Table 1 compares some of the most frequently used modelling software available in the market.

For this work *Blender* was chosen, since it is a free open-source software that was created as an alternative to high priced programs currently on the market. Blender is in constant development since 1995 and currently provides many features matching some of the main market competitors.

Finally, the representation of three-dimensional models of cultural heritage sites through the Internet, particularly Roman structures, has also been highlighted by several authors. For example, (Gonçalves and Mendes, 2003) and (Silva and Gonçalves, 2004) present an interesting approach to provide relatively realistic environments, with special emphasis on the small size of the models, using one of the popular standards at that time, VRML. However, it was necessary to install a specific plugin.

The solution presented in this paper to display the three-dimensional heritage models is based on HTML5 and WebGL and, for this reason, it only requires a HTML5 compatible browser.

Table 1: 3D modelling software.

Application	Mainly used for	Licence	Price
3DS Max	Modelling, Animation (Video Games), Lighting, Rendering	Proprietary	\$3,495
Cinema 4D	Animation, Lighting, Modelling, Visual 3D Effects, Rendering, Simulation	Proprietary	\$995 - \$3,695
Maya	Modelling, Animation (Video), Lighting, Rendering, Visual 3D Effects	Proprietary	\$1495
LightWave 3D	Modelling, Animation, Lighting, Rendering, Film and Television Previz, Videogame Asset Creation	Proprietary	\$3,495
Blender	Animation, Lighting, Modelling, Rendering, Video Game Creation, Visual 3D Effects, Sculpting, Basic Post-Production Video Editing	GPL 2+	Free
SketchUp / SketchUp Pro	Computer Aided Design	Proprietary	Free / \$495

### 3 HOUSE OF CANTABER

The house of Cantaber is an extraordinarily large house, actually the larger one excavated in the town that covers more than 3200 sq. m.

The house is articulated around five different perystyles, and about 1/3 of its area was originally a large garden. This architectural setting responds to a social need for large urban houses to give to their owners the commodities expected from country houses, the *rus in urbe* of the Roman poet Martial. The artistic side of this social and cultural fashion has already been studied (Alarcão, 2011), and can be dated in the Flavian period (69-96 AD), which is an epoch of outstanding urban development in Conimbriga.

Modern research about the house (V. H. Correia, 2001) has, to some extent, contributed with data about the chronology, the original plan and the actual construction of the house, supplementing the

poor conservation of the remains (with the research and conservation problems already mentioned). This has allowed for a theoretical reconstruction proposal, based on the fact that the house was built in an isolated insula in the town, with few, if any, constraints due to earlier construction on site. A “Vitruvian” structure could thus be posited; the different sectors of the plan of the house were assumed to be made evident also in the overall development of the building and some expression of the relative importance of individual rooms was made to be clear in the elevations (vg. the main *triclinium*). With the evidence available concerning actual architectonic elements, on which the town is poor, due to the fact that they were mostly brick-and-mortar built and have not survived for the most part, the final result is thought to be credible, although within a margin of error that has to be acknowledged (on the theoretical implications of this issue (Panhuysen, 2011)).

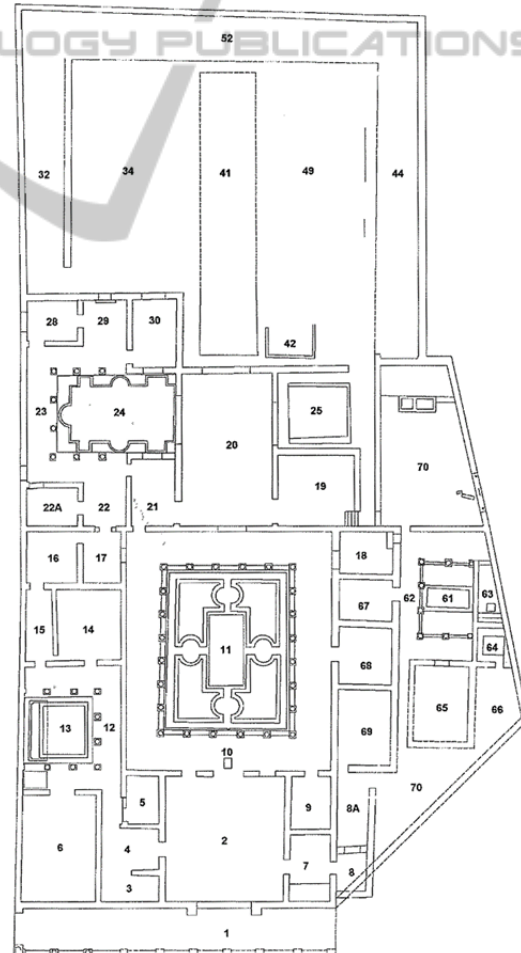


Figure 1: House of Cantaber plan.



Figure 2: Real photo of the House of Cantaber.

## 4 VIRTUAL RECONSTRUCTION

The virtual reconstruction of the House of *Cantaber* was carefully prepared based on information collected on the site and in the knowledge of experts, through a collaborative process between the areas of Archaeology and Informatics. The goal is to provide a low cost solution for similar cases with

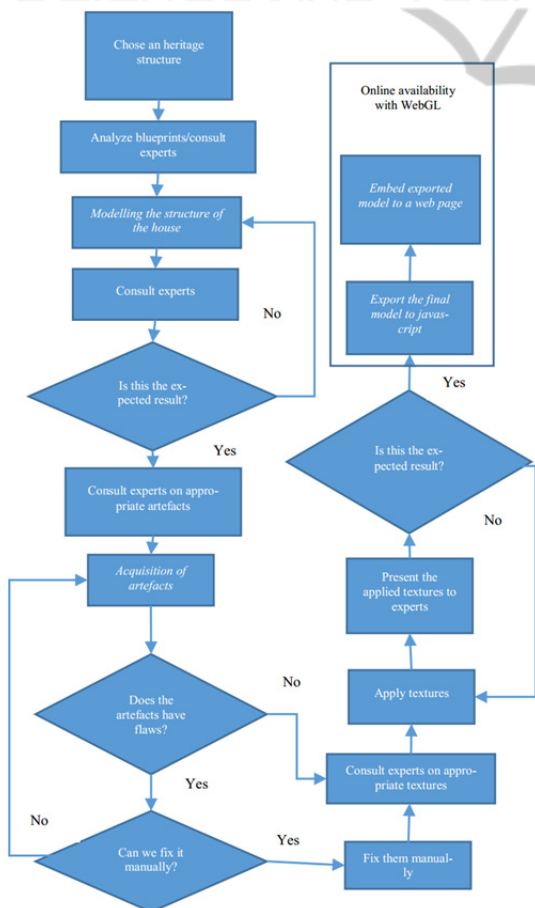


Figure 3: Reconstruction workflow.

high accuracy both historical and archaeologically, which will make the results available via the Internet efficiently. Figure 3 illustrates the workflow followed for the virtual reconstruction of the *House of Cantaber*.

The next three sections address the workflow emphasizing on the main processes presented (in italic) on Figure 1, namely the modelling of the house (section 4.1), the acquisition of the artefacts (section 4.2) and the three-dimensional representation of the model (section 4.3).

### 4.1 Modelling the House of Cantaber

As aforementioned for the intended purpose the modelling software chosen was *Blender* which allowed to recreate the house three-dimensionally.

First of all we had to consult an expert in archaeology which provided us with a detailed plan of the house (Figure 1) on which we extruded all the walls from the house of Cantaber, then a detailed study of the roof structure of the house was also supplied, as well as a document with the heights of the walls and columns of the entire complex.

Upon completion of the extruding walls phase, we moved to the modelling of the different types of columns (both Ionic and Tuscan). Lastly we travelled to the storage rooms of the Monographic Museum of Conimbriga, where there are pieces of mosaics that once belonged to the House of Cantaber floor, which were photographed in order to apply them as textures in our newly created three-dimensional models.

### 4.2 Acquisition of the Artefacts

Although at the time the model of the *House of Cantaber* was presented to experts it received a favourable appreciation, though the fact is that, without any kind of ornaments it does not give the feeling that at somewhere in time someone actually lived there. In order to deliver a more realistic sensation it is important to have some kind of human evidence, more than just the building structure of the house. For this reason, furniture, decorations and other kinds of artefacts are indispensable to provide a more human feeling, something which is unrealizable in the real Conimbriga location.

Since Conimbriga's artefacts are very ancient relics, it was necessary to travel to the Monographic Museum of Conimbriga. There, it was possible to carry out the 3D acquisition of the artefacts, to use in the virtual model of the *House of Cantaber*, without compromising the real pieces. The process consisted

of placing the objects on a tripod (one by one) and to move the Kinect manually around them.

Conceptually, there are two equivalent approaches: make an acquisition of a static object while moving the sensor, or having the object moving in a rotating tripod while the sensor is static. This may be achieved with Kinect Fusion, an Application Programming Interface (API) which provides the ability to scan and create a model of any three-dimensional object from the real world using the Kinect sensor. This API supports both approaches, but moving the sensor in a static object is a more robust solution with a significantly lower data loss.

#### 4.2.1 Kinect Fusion

While mobile cameras depth are not a new concept, Microsoft has made such sensors become available to all at an affordable price through its Microsoft Kinect. The quality of depth sensors, given the low price and the nature of the technology which requires a real-time high throughput, made it immediately very popular among researchers and enthusiasts. The user can create a scene with the camera and simultaneously view and interact with the detailed three-dimensional version of the reality. Since it is a demanding computational work the need to use GPGPU (General-Purpose Graphics Processing Unit) arose to attain a fluid interaction with the real environment.

The Kinect Fusion allows dense surfaces to be reconstructed in real time (Newcombe et al., 2011), with a much higher level and robustness than any 3D modelling professional could do in hours or days of work. Within seconds after the acquisition is accomplished a file is ready to be freely manipulated without posing any threat to the integrity of the real object.

#### 4.2.2 ConimbrigaCG

In order to use the Kinect Fusion a small application was built, which reconstructs a single dense surface model with smooth surfaces, by integrating the depth data from the Kinect sensor over time from multiple viewpoints. The camera pose is tracked as the sensor is moved (its location and orientation) and because we now know each frame's pose and how it relates to the others, these multiple viewpoints of the objects or environment can be fused together into a single reconstruction voxel volume.

You can see a screenshot of our tool in Figure 4 as we scan an ancient clay plate.

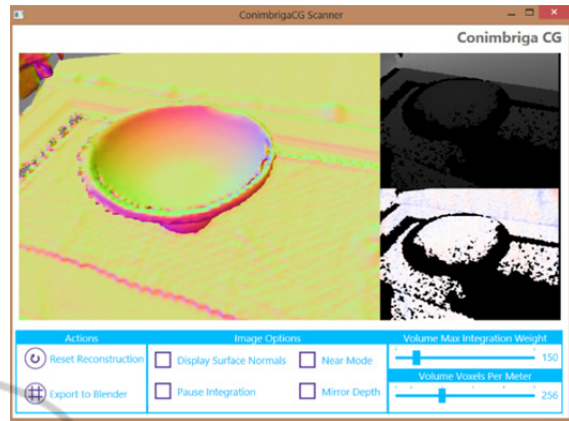


Figure 4: ConimbrigaCG (Conimbriga Computer Generated) screenshot.

The reconstruction is made in three steps. The first step is the depth map conversion. This takes the raw depth from Kinect and converts it into floating point depth in meters; The second step consists in the calculation of the global camera position (location and orientation) and tracks this position as the sensor moves in each frame, using an iterative alignment algorithm, so that the system always knows the current sensor posing, relative to the initial starting frame; The third step is the integration of the depth data from the known sensor pose into a single volumetric representation of the space around the camera. As a moving sensor sees a surface from slightly different viewpoints, any gaps or holes where depth data is not present in the original Kinect image can also be filled in and surfaces are continuously refined with newer data as the camera approaches the surface more closely.

We learned that small, slow movement in both translation and rotation are best for maintaining stable tracking. Dropped frames can adversely affect tracking, as a dropped frame can effectively lead to twice the translational and rotational movement between processed frames. If this occurs we need to reset the reconstruction and start over.

#### 4.2.3 Conimbriga's Artefacts

Several artefacts collected in Conimbriga were chosen by experts to be acquired to virtual 3D objects to complete the house model. These include amphorae, dishes, bowls, pots, clay lamps and jars amongst others.

The acquisition procedure resulted in overly complex models, with some flaws. For this reason, in a first step, arose the need to conduct tests, to attain a geometric simplification, without

compromising the visual quality of the artefacts. Since the Kinect produces models with a high number of polygons (see Figure 5), they are unfit for the internet availability, since the geometric complexity of the models will lead to a significant degradation in performance when using them in an interactive mode.



Figure 5: 3D scan of an amphora with 669'000 faces.

To reduce the complexity of the geometric model without compromising the realism, a feature of *Blender* was utilized: the *Decimate modifier* add-on. This allows reducing the total number of vertices/faces without significantly change the shape of the object.

This feature has proved its value with a configuration of 95% ratio of collapse. The model shrank to 33'000 faces (Figure 6), without any noticeable loss of quality.



Figure 6: Amphora after applying the Decimation modifier.

In a second step the failures that occurred during the geometrical capture of some of the artefacts with the Kinect were corrected. In this particular case, a *Blender modifier* called *Remesh Modifier* was utilized to alter the topology of the model filling any holes and to smooth the result by applying a smooth shading. The final result may be observed in Figure 7.



Figure 7: Final amphora model with the necessary corrections.

Finally, textures were applied to enhance the realism of the models. Figure 8 shows a clay plate attained by the same method with the texture applied to it.

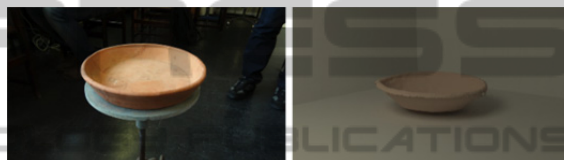


Figure 8: Three-dimensional model from the acquisition (right) and the real object (left).

To complete the process, both the model of the house and the artefacts were exported to a format which allows the embedding in a web page.

### 4.3 Online Availability with WebGL

In the recent past, in order to create and/or visualize 3D models, it would be necessary to utilize specialized three-dimensional modelling programs (*Maya*, *3D Studio Max*, *SketchUp*, etc...). These use languages to create and export models or even to compile stand-alone applications with them. These tools have access to the Graphics Processing Unit (GPU) of a given computer, which would allow it to render effects such as shadows, reflections and atmospheric distortions at speed rates that otherwise would not be possible.

In web browsers however, when the standard used to represent three-dimensional models were *VRML* or even *X3D*, not all of these features were available and plugins were necessary to allow the visualization (Gonçalves et al., 2005). Due to advances in the current characteristics of the current browsers, they enable the implementation of *WebGL* (KhronosGroup, 2013), a low-level API in *Javascript* that accesses directly the GPU capabilities where the browser is running. Therefore the process of three-dimensional visualization in real

time is easier. Since it is based on web standards it does not require any specific plugin to present these results. It also has the advantage of being fully interactive, running on any personal computer, and it is estimated that will shortly be available in practically all prominent mobile devices. In this sequence, the Three.js (MrDoob, 2013), developed by *MrDoob*, is an extremely lightweight 3D engine with a low level of complexity that allows to mix all of the technologies aforementioned and create interactive three-dimensional models which may be freely navigated in any compatible browser.

To finalize the process, both the model of the house and artefacts were exported using a Blender plugin that is included in the Three.js library to a format that allows the embedding of them in a web page (Figures 9, 10, 11 and 12). The web page is available at: <http://cesarferreira.com/work/cantaber/>.

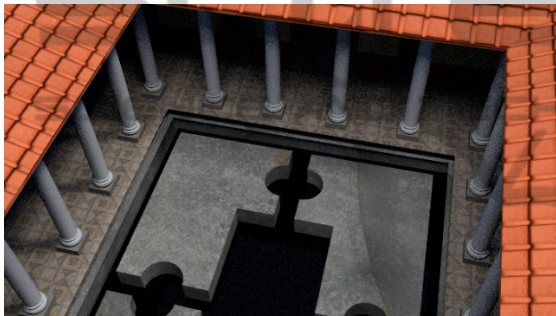


Figure 9: Final result of the house exterior.



Figure 10: Final result of the house interior.



Figure 11 - House exterior overview.



Figure 12 – A look through the window of the dining room.

## 5 CONCLUSIONS

In recent years there has been an increment on the concern about the legacy left by our ancestors and, with the development of powerful new technologies, it is now possible to use the latest to explore new ways to increase the knowledge about our past.

This work featured the creation of a three-dimensional model of the *House of Cantaber*, including virtual replicas of artefacts used at the time, allowing interactive virtual tours online. This process was implemented through manual modelling using open source software and a low cost moving depth camera.

Three-dimensional modelling presents itself as a real reliable alternative making it an asset, not only for historians and archaeologists but also for the simply curious common user. Beside the low cost advantages proposed by this alternative, the combination of manual modelling and automatic acquisitions gets the best of both worlds: the high level of realism which can only be achieved with manual modelling processes and the reduced time necessary to have 3D models of objects.

Unlike other alternatives presented, this solution is operating system agnostic, requires no additional plugins for viewing in a browser and shows no excessive costs.

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