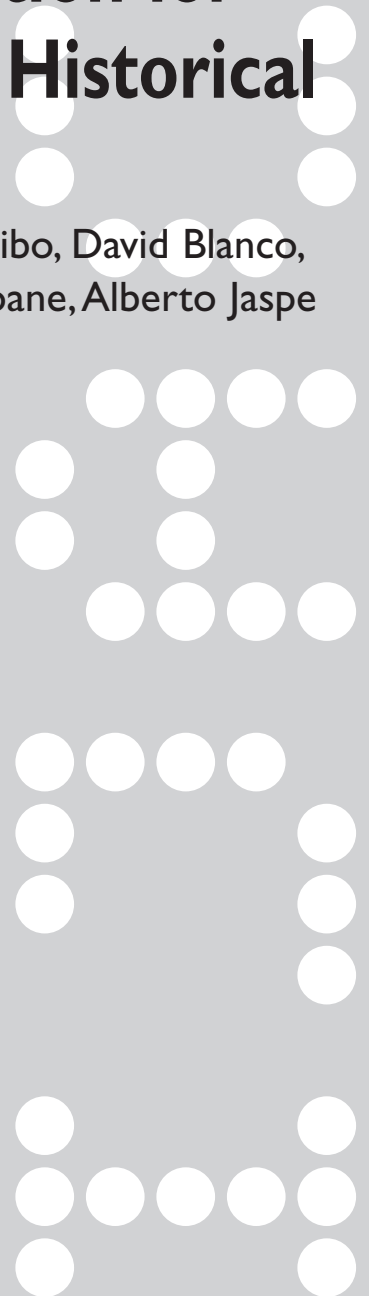# Physically Walking in Digital Spaces - A Virtual Reality Installation for Exploration of Historical Heritage

Luis A. Hernández, Javier Taibo, David Blanco, José A. Iglesias, Antonio Seoane, Alberto Jaspe and Rocío López

Physically Walking in Digital Spaces - A Virtual Reality Installation for Exploration of Historical Heritage

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Immersive Virtual Reality Systems have been extensively used during recent years for the exploration of architectonic spaces. This paper describes how the use of *transitable* immersive virtual reality systems, that is, those that allow the user to physically walk while exploring the virtual world, can greatly empower the experience of perception of space in architecture. The text describes a particular example of one installation of this kind that was developed by the authors and how it was implemented for the interactive experience of the virtual reconstruction of a housing unit on a pre-roman settlement. This installation is open to the public as part of a permanent exhibition and constitutes the final output of the research at this time.

1. PERCEPTION OF SPACE IN VIRTUAL REALITY ENVIRONMENTS

The way humans perceive space has several facets, most of them located in the field of perception psychology. Understanding our environment involves various factors, ranging from vision physiology to socio-cultural considerations. The process of space perception may be initially defined as that through which a person is conscious of his/her physical position in relation to the surroundings, and the interrelationship with these in terms of distance, relative size of objects, and orientation, all of which are necessary for the subject's movement through the environment.[1]

The individual carries out this process mainly by judging distance and depth, receiving sensorial stimulation through sight and hearing, while performing gestaltic cognitive processes in which, for example, two identical objects situated at different distances are understood to be equal, although appearing to the eye to be of different size.

Although at first one might think that the stimuli of spatial perception are exclusively visual, a more detailed analysis shows the action of other factors which powerfully complement them. These come from the kinaesthetic senses (the sense of movement), the vestibular system (balance), hearing, and more generally, from whatever other stimulation source contributing to the sensation of bodily presence in the environment. These include such things as body size and height, altitude of vision, walking-speed, etc, which collectively constitute reference patterns for estimating distances, positions of objects, etc, both from a quantitative viewpoint, such as accurate measurement, and qualitatively, as in subjective considerations (near, far, large, small). These reference patterns change during the individuals lifetime and personal evolution, so that the same space, seen as very large in childhood, seems surprisingly small to the same individual as an adult; or a room seen as spacious in adolescence becomes small when the individual becomes accustomed to living in even larger ones.

In any case, the principal means of comprehending space are the perception of depth and distance. This is achieved through cross-referencing and interrelating the input from various senses so as to extract the relevant information. Some of these cues come directly through eye accommodation (focusing the eye lens for near or far vision) and convergence (modification of the angle of vision and direction of the gaze for each eye relevant to the closeness or distance of the object viewed) [2]. Another and possibly more influential cue is parallax. It can be obtained with the subject being static, due to binocular vision, which involves the cognitive process of comparison between two different images coming to the brain from each eye. Binocular vision is especially useful for close distance perception, becoming more subtle and less accurate as the distance to objects increases. In this case, parallax can be obtained from movement, through comparison of images of the same object through time as the individual moves. This is especially

effective if the subject is clearly aware of the amount of displacement produced, as happens when movement is carried out by the individual's own means, (i.e. walking), using very familiar and well established cues for comparison such as the distance that he knows that he can travel with every step. Movement parallax is especially useful for judging distances when only one eye is used (monocular vision) or when both eyes are exposed to the same image (as in monoscopic virtual reality devices).

Other factors influencing distance perception include convergence of parallel lines due to perspective, and tonal variations of colors due to the scattering of blue light in the atmosphere. This effect also produces a reduction in the contrast and sharpness or contour that is perceived as a distance cue as well.

In the realm of computer graphics, space-perception requires the introduction of the immersion-concept provided by virtual reality. Although it is possible to *describe space* by means of walkthroughs on virtual models on the computer screen, the sensation of *presence in space* requires the user to feel he is within the space, surrounded by it, immersed in it. There are several approaches to achieve this effect. On the one hand, there are systems based on a complete coverage of the user's field of vision from a given physical location, as is the case of cylindrical screen projection systems, such as Reality Centers ®: spherical systems, e-Lumens ® domes or CAVE® systems; in some cases the spatial effect is reinforced with the use of stereoscopic projection. The other way of achieving immersion is by equipping the user with a head mounted display (HMD), which continuously renders the view of the model before the eyes of the user according to his viewing direction, allowing free head movement. This liberates the user from the limitation of having to look only at the screen, or screens, all the time.

However, for a truly realistic experience of virtual reality space, one of the most important aspects has to do with parallax. As already said, parallax can be perceived statically through binocular vision. In this case, the effect is thus greatly reduced as the distance to the viewed objects increases, as happens in large architectural spaces and outdoor environments. The other source of parallax, of greater influence in these cases, comes from the user's movement.

Early experiments were conducted by Henry and Furness [3] to compare and explore the relationship between the way people perceive real and virtual spaces. Twenty-four architects toured either a real museum gallery or a real-time computer generated model in increasingly immersive conditions (a monitor, a fixed HMD and an orientation tracked HMD). Subjects were asked to perform spatial dimension, orientation and evaluation tasks. The most significant results indicated that subjects consistently underestimated the dimensions of the gallery in all three computer simulations, being the differences greater in the most immersive conditions. Later experiments carried out by Loomis et Al. confirmed that

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distance is systematically under-perceived in virtual reality using HMD in static conditions [4]. Thompson et Al. determined that render quality, even in photorealistic environments does not improve this perception [5]. Lack of motion parallax was pointed out by these authors to be a critical factor for distance judgment.

Hence, to increase the sensation of immersion and to obtain a more vivid and accurate experience of the virtual space, sensations can therefore be reinforced by giving the user freedom of movement through the model. Most simulation systems do this by providing the user with a device that controls his location, allowing the displacement through the virtual environment in any given direction. Through a joystick, wand, mouse or other similar direction controlling interface, the user is expected to imagine that she is moving through the model in a virtual vehicle or by other means of propulsion. The user in such systems is moved, instead of moving herself.

Exploration of real spaces requires a personal rhythm of movement quite different from that of a vehicle. When exploring a cathedral or museum, the visitor makes rhythmic pauses, changes speed, accelerates, changes direction, position, and direction of gaze, and moves backwards and forwards. This is extremely difficult to emulate with gadgetry such as a joystick, especially considering that movement with these devices is usually limited to two modes, i.e. standstill and forward at a constant speed, generally with an abrupt and non gradual transit from one state to the other. Performing very simple tasks such as aiming towards a point, aligning with a straight path or steering a curved path becomes a non trivial issue under these conditions. [6]

The most effective way of resembling the user's natural movements is by letting the user walk around, feeling all the associated kinaesthetic sensations. For this purpose, the user can be equipped with a virtual reality kit which the user carries around. Various such systems have been developed in recent years [7, 8], some of which have been designed for outdoor use, by establishing the user's position through GPS. Though not totally accurate, they can be adequate for use in large spaces such as urban areas. There are also several examples of transitable virtual reality systems designed for interior use. They require much greater precision in locating the user within a walkable zone limited to the extent of the range of the tracking system. This limitation can be surpassed using several strategies that will be discussed later. The Empty Museum is one such system, which we will now describe.

2. THE EMPTY MUSEUM. WALKING IN DIGITAL SPACES

2.1. A HYBRID SPACE

The Empty Museum is an immersive virtual reality installation which allows one or more users to move freely in a real space surrounded by virtual

elements with which they can interact. These is made possible through the use of two supporting subsystems, one controlling the user's position in real and virtual space, while the other, carried around by the user in a backpack, generates the images to her HMD and provides data of the user's movements.

The first prototype of the Empty Museum was developed in 2002 for the *Galicia Dixital* exhibition in Santiago de Compostela (Spain) to display contents related to Galician culture (Figure 1). Although initially ideal for exploration of architectural space, it has, in the intervening years, developed well beyond this. More than 70.000 visitors have since used the installation, walking around in specially designed virtual environments to experience very different contents that range from Galician traditional fishery to surrealist paintings [9].

As already explained, one of the main strong points of the system is the very natural way in which the visitor can explore the virtual worlds. Though limited to a space of 5m x 7m, it may be technically expanded to larger areas. This space is defined as "transitable area" where the user can physically move. The virtual world can, of course, extend much further than this zone, and the user can see it although he may not reach it. The interactive elements are located within the limits of the transitable area, which is also "virtually" limited by elements in the digital world that dissuade the user from crossing the borders such as virtual walls, trees and absence of virtual floor under the users feet.

The experience of space in this installation is extremely vivid in a double manner. On the one hand, the space is what he knows as such, with known dimensions, in a real area the person is aware of being in. On the other hand, in that same space there are virtual objects. Not only does the user see and accept these as inserted in the space, as happens in the augmented reality systems, but is also able to experiment their size in relation to

himself through parallax and movement around, towards and away from them to the point in which he associates his real movement as taking place in the virtual world. The actual virtual space (not the objects inserted in it) is, therefore, as genuine as the actual real space, inasmuch as it has the same properties. As a user, you see yourself immersed in a hybrid space in which it is easy to move around, observe and interact with objects. Real space thus becomes part of the interface [10].

Moving in larger virtual worlds

Although the transitable area is confined to the limits of the physical installation, the Empty Museum allows the user to experience larger areas. Three different methods have been developed to achieve this:
- *Scaled user movement*

The user's horizontal movement can be magnified, allowing the user to take "giant steps". Several tests were carried out using this approach, and most users reported this kind of movement to be unnatural and uncomfortable, especially when they were walking in one direction while looking in another.
- *Teleporting*

Several worlds designed for the Empty Museum contain different secondary spaces that are reachable through a main one. The space initially entered contains sensible areas that act as "teleport cabins". When the user enters these areas, the world around her changes. Visitors found this surprisingly intuitive, natural and easy to use. An example of this kind of world was a virtual paint gallery, where users had to walk through the paintings to enter into a space that recreated a 3D version of the artwork that she selected. After exploring this three-dimensional pictorial space, they only had to find the teleport cabin in the 3D painting to get back to the gallery.
- *The Magic Carpet*

Providing the installation with a wireless pointing device, the user can displace the full hybrid space in whatever direction she wishes in the virtual world just by looking in that direction and pressing the button. Hence, the user may transfer the transitable area from one point to another inside a big virtual building.

Multi-user. Real and virtual visitors

The Empty Museum is designed for use by up to four people at a time. To avoid collisions among the visitors, each user is represented in the virtual world by an avatar which occupies his position and reproduces part of his behavior (i.e. body and head orientation). Avatars are usually designed to complement the theme of the contents being displayed, hence becoming part of the exhibition itself.

The system also allows the presence of virtual animated characters, whose use is illustrated in the last part of this paper.

3. SYSTEM DESIGN OF THE EMPTY MUSEUM

3.1. Hardware architecture

Having studied the problems of previous systems, the following technical requirements were determined. We had to develop a comfortable, transitable, immersive, multi-user virtual reality system for the Empty Museum. To fulfill the first prerequisites, the system should be lightweight, autonomous and wireless. Keeping in mind the drawbacks of immersive projection systems given in the introduction, we decided to use lightweight, battery operated HMDs.

As laptops with graphics hardware powerful enough for our purpose were readily available, we decided to put the computer responsible for the rendering in a backpack carried by the user. All devices needed to be carried by the user are installed in this backpack (HMD electronic unit, wireless head tracker transmitter/battery and laptop), as well as all batteries needed to operate the devices.

The non-essential elements (DVD drive, computer screen, and keyboard) were removed to reduce weight.

The last element essential to the system was the head tracking. Alternatives based on magnetic, inertial and ultrasonic technologies were studied.

Various wireless tracking systems were analyzed before finally selecting a combined ultrasonic/inertial system.

The ultrasonic tracking system operation is based on several beacons located in fixed positions near transitable space, usually in the ceiling, as they need to keep visual contact with the mobile sensor located on the HMD. These beacons, used as a spatial reference, are connected to the electronic unit of the tracking system. The mobile sensor and the beacons communicate through ultrasonic pulses. As the exact position of the beacons is known with great accuracy, the electronic unit can measure the time of flight of the signals and use it to compute the position in space of the mobile sensor. The mobile sensors need communication (line of sight) with at least three beacons to be able to compute its location. The greater the number of connections to beacons, the more accurate the position will be.

The inertial system is based on gyroscopes and accelerometers. It tracks the user's head movement with six degrees of freedom (position and orientation).

The tracking system used was Intersense IS-900. This system integrates, in a single device, two ultrasonic sensors with one inertial sensor. This way it combines the advantages of both technologies. The device communicates via radio with the electronic unit responsible for the computation of position and orientation from the ultrasonic and inertial readings. This system fulfils the wireless requirement for the head tracking. The results computed by the

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electronic unit are sent through a wireless network (IEEE 802.11b/g) to the laptops. Moreover, the mobile sensor is small and battery operated.

Combining ultrasonic and inertial systems, the drawbacks of each technology are mutually compensated, taking benefit from their advantages. The inertial system provides smooth tracking and compensates for the interruptions of the ultrasonic system because of broken connection or the presence of noise interferences in the environment. On the other hand, the ultrasonic system provides more accurate readings in absolute terms, correcting possible deviations accumulated by the inertial system if working alone. The overall result is a system of good accuracy, stability and fast response, providing the user with a strong sense of presence.

The selection of an adequate HMD is a compromise solution between visual quality, comfort and cost, the first of these being in direct opposition to the other two.

Quality of visualization depends on screen characteristics and the technologies used. The most important parameters considered are: field of view (horizontal and vertical), screen resolution, and image frequency and stability.

It is difficult to find an HMD on the market with adequate field of view that doesn't severely increase size, weight and cost. Although the cost problem can be solved, the aspects of size, weight and difficulty to operate on batteries, meant that some good HMD models available had to be discarded from the project.

The final option was a SONY Glasstron-like HMD, which offered comfort, lightness, battery operation and very good image quality with PAL resolution. The major limitation is the field of view being about 30° (H) x22° (V). The HMD is the most important limitation at present, and will have to be improved when technology allows it. The hardware architecture is illustrated in Figure 2.

► Figure 2. Hardware architecture of the Empty Museum
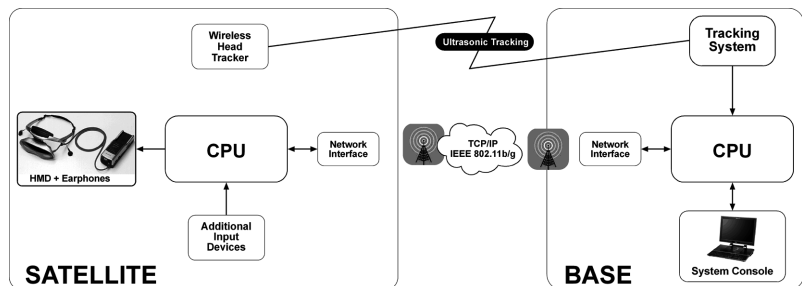
3.2. Software Design

From the software point of view, the system is divided into two modules: base and satellite. The satellite is the mobile system carried by each user,

comprising computer, HMD and head tracker. The base is run on a computer connected to the electronic unit of the tracking system and is responsible for the following tasks:

- Tracking of all users and distribution of their position through the wireless network.
- Management of connection and disconnection of users.
- Monitoring satellites operation: information about the virtual world, state of interaction, position and orientation of mobile sensors, battery charge level, battery remaining time, CPU load, memory usage, sound volume level, etc.
- World assignment to the users connected to the system and establishment of parameters to these scenarios.
- Distribution of dynamic information shared among satellites for multi-user interactive worlds.

The satellites' main tasks are to manage interaction in the virtual worlds, render 3D scenes from the point of view of the user and generate spatialized sound so that the user hears it coming from the proper locations within virtual space.

For real-time rendering, the engine is based on OpenSceneGraph (OSG) and uses OpenAL for managing 3D audio.

Interaction is programmed using our own engine (ONE), based on state machines and rule systems. These rules are defined from logical expressions, sensors and actions. This system is prepared for distributed usage throughout a network, so it can define coordinated behaviors among users of the virtual world.
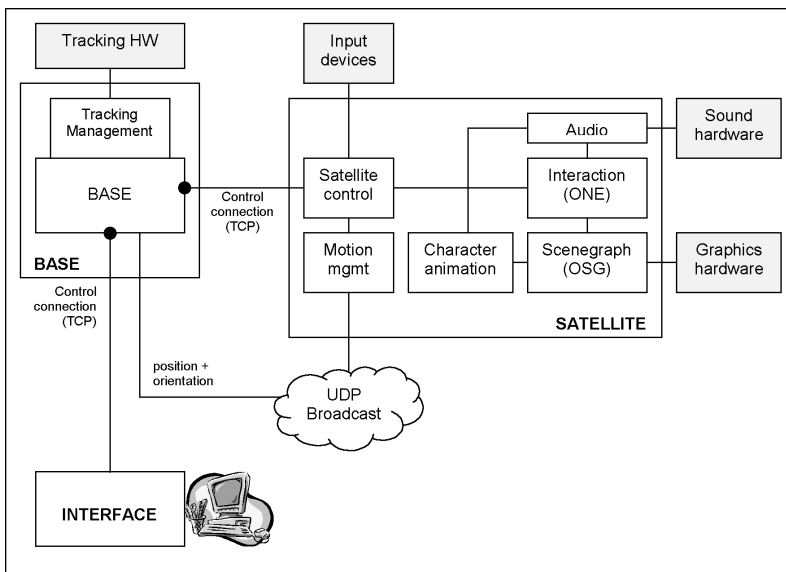
◀ Figure 3. Software architecture of the Empty Museum

Satellites receive position and orientation from themselves and other users from the base. Other users are represented in the virtual space as avatars. The avatars are articulated so that their heads follow the movements of the users' heads when they look up or down or from side to side, while the body maintains itself in a vertical position.

Skeleton based animations can be included in more sophisticated models, simulating the behavior of other users of the system. These animations are mixed in, following the users' actions, or according to the states inferred from the head movements: stopping, walking, crouching, etc.

One of the most important reasons for including avatars in the multi-user worlds is to avoid physical collisions among the real users.

These components, base and satellites, follow a client-server architecture. The base accepts satellite connections and remotely controls them so that it is never necessary to go inside the backpack. In fact, screens and keyboards have been removed from the laptops.

All these communications are made through TCP and UDP protocols. A custom-made protocol over TCP has been designed for communication between base and satellites. Also with a view to making a versatile and robust system, base management kernel has been kept separate from the user interface. So the base is implemented as a daemon or system service, accepting connections from satellites as well as interface modules. The above mentioned control protocol also defines communication between base and interfaces.

Different interface implementations have been developed for different objectives, including command-line ones, easy to use from a remote terminal for maintenance and debugging purposes. The interface normally used with the Empty Museum consists of a friendly and easy to use graphical application in which all the information about system operating and connected users can be seen at a glance and managed easily.

A problem between the system operator and the users came to light when testing the system; once having put on the HMD and in movement through the virtual environment and listening to the sounds of the virtual world, the user has serious difficulties in hearing the voice of the operator.

To solve this problem, a voice network transmission system, based on GSM, has been developed. Using this, the operator can speak to the user through a microphone connected to the base, being heard by the user through the HMD earphones.

The last incorporation to the Empty Museum engine was the integration of animated characters, both by use of skeletons and by gestural animation (blend shapes). A modified version of open source Cal3D system was used to implement skeleton based character animation. A custom-made per-vertex mesh deformation system, called blendal, was used for facial animation. Both systems were adapted for working together and integrated with OSG, ONE and artist's digital content creation tools.

3.3. The content creation process

Development of an interactive space in the Empty Museum involved engineers and artists from different fields. The generic workflow can be seen in Figure 4.

As well as the virtual reality interactive system, the import, export and translation tools for converting between different file formats and different author tools were developed to facilitate the creation of the audiovisual contents.

These contents include 3D models, materials, textures, lighting (real-time or pre-calculated), spatialized sound, effects (dynamics simulation, particle systems ...), and animation (including transformations, per-vertex deformations, and skeleton based animation).
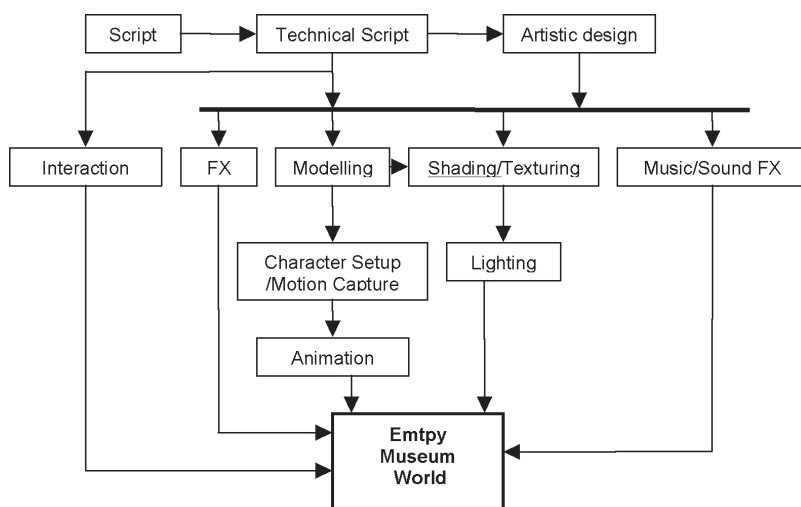
◄ Figure 4. Workflow of content creation for the Empty Museum.

4. EXAMPLE OF APPLICATION: THE CASTRO CULTURE.

4.1. Historical background

The *Castro* Culture in the northwest of the Iberian Peninsula is one of the most attractive fields related to prehistoric Galicia, for the spectacular aspect of its existing remains, for the more-or-less justifiable belief that the peculiarities of Galician idiosyncrasy originates in that culture, and for impressions which these remains have imprinted on the collective imagination.

The *Castro* Culture may be defined as a conjunction of knowledge and ideology and behavior patterns characteristic of the human society that lived in the *Castros*, these being the well-known populated settlements that both define the culture and give it its name. It is known through information

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provided by archaeology, epigraphy, textual sources and, in certain ways, from ethnography.

It developed during the Iron Age, based on a solid underlay of population from the end of the Bronze Age who combined their native north-western precastrian characteristics with Central European cultural influences, and also some from Atlantic and Mediterranean sources.

Of all the archaeological remains related to this culture, two in particular predominate: *architecture* and *material culture*.

Architecture of the Settlements:

The settlements, as the most visible external archaeological evidence of this culture, fall into three categories:
- Inland settlements: the most frequent and characteristic type.
- Settlements situated in hilly areas, usually on hillsides
- Coastal settlements: very abundant on the Galician coast, usually well-defined and of simple plan.

Material Culture:

The Castro Culture has left us many material remains, most notably:
- Jewels and ornaments showing the culmination of an economic and artistic activity with deep roots in the Bronze Age. Torques (rigid, curved collars in great variety of sorts) bracelets, pendants.
- Sculptures, characterized above all by schematic and geometric volume, especially abounding in the southern half of the Castro region.
- Very plentiful finds of ceramics have turned up on Castro excavation sites. Globular and spherical forms predominate, more or less stylized, in various sizes and functionally adapted.

► Figure 5. Sculpture and jewels of Castro Culture.
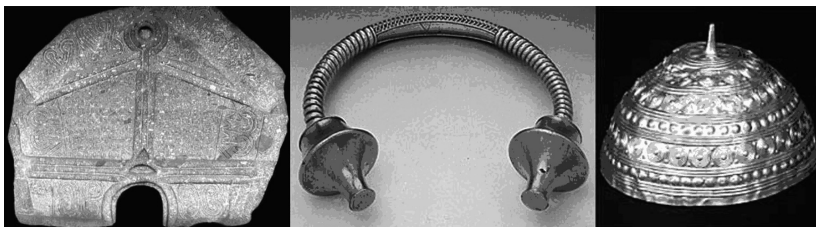
San Cibrán de Las.

The settlement of San Cibrán de Las (in the Province of Ourense, Spain), is a site which, from its formal and monumental configuration, constitutes a veritable archetype of the *Castros* of the final phase of the Castro Culture, coinciding with the Romanization of the north-western Iberian Peninsula.

This settlement, one of the most extensive in Galicia, is made up of two almost concentric, walled enclosures, slightly extended in the north-south direction. The crown being the central enclosure is surrounded by a simple, but strongly constructed wall. The present height is small in relation to the conserved one at the time of the first excavations. Access to the high part is by way of set-in steps, both double and simple, and by way of stones jutting out of the wall, though we do not know where these ended or how high the wall originally was.

◄ Figure 6. San Cibrán de Las. Hypothetical reconstruction and present state

The reconstruction carried out in *The Empty Museum* is centered on a *casa-patio* (house with patio), called Unit 14. This unit is distinguished for its architectural complexity, its various occupational units and the abundance of cultural material found in it.

4.2. Objectives

The present work seeks to achieve a genuine, virtual reconstruction, rigorously and archeologically accurate, of a housing unit typical of the pre-Roman settlement of San Cibrán de Las, to be shown in the Empty Museum and experienced by general and specialist users; the virtual model thus being a means of diffusion and study of the domestic life of the Castro Culture. With this in mind, not only the architecture and elements of the material culture are represented, but also virtual humans populating the site.

By way of description, the house with patio 3D model consists of a housing unit including the kitchen as principal feature, modeled without and within, and other inhabited parts modeled externally only, which are the storage area, bedrooms and stables, complemented by walls and divisions generally separating the different parts of the housing unit. The kitchen was chosen as the pivotal point of the reconstruction, because of its archaeological importance, as it was here that most social activities took place, and in it we have 3D reconstructions of various examples of material culture, all with household connections (fire, cooking utensils, ceramic firing, objects on shelves, tools...). It is sought not only to make the reconstruction from the architectural point of view, but to add the element of functionality by including the elements which would have likely been present there.

4.3. Methodology

3D Representation

When beginning the study of the archaeological site, and keeping in mind the necessities presented by the reconstruction of the housing unit, the methodology used was mainly involved with an archaeological current called Archaeotecture, an Architecture Archaeology. [11]

This discipline, based on the study of historic constructions using archaeological methodology, incorporates analytic models and methodological tools which contribute significantly to the various dimensions of the reconstructed unit [12]. Some of these analytical processes, such as analysis of visibility and analysis of approaches, are now applied successfully in other sites, such as Scottish Iron Age sites.

These studies were further supported by ethnological analysis of existing structural evidence.

With the objective of maximizing the potential of the architecture remains of the settlement, an analytic model has been applied, combining the formal description of the structures with the application of new procedures and techniques developed within Architecture Archaeology (formal analysis, analysis of approaches, analysis of visibility conditions). Following this method, various analytical methodologies have been used in conjunction for purposes of the study: [13]

- Construction Analysis: Starting from a descriptive study of the constructions, the generic characteristics of the domestic architecture of the site become visible.
- Formal Analysis: these architectural forms not only characterize the built up space, but also model the internal domestic living space. They also generate a series of spatial relationship and organizational patterns inside, answering the needs of the inhabitants and builders of the site.
- Syntactic Space Analysis: Once having defined the structures and established the spatial relationships involved, one can make an approximation of the social significance underlying. The application of the following methodologies help to reconstruct the social logic governing the spatial order involved:
  - *Gamma Analysis*: quantifies the depth and permeability of the spaces, along with the easiness of access, evaluating the existing level of dependency between them.
  - *Circulation Analysis*: identifies the perceptive order of a building through movement in its spaces.
  - *Analysis of Visibility*: defines the degree of privacy inside a closed architectural construction.

The aspects taken into account to give more realistic, historic validity to the reconstruction are as follows:

- *Floor*: A circular area of 5 m. diameter. This is the approximate average measurement of the roundhouses of most *Castros* in Galicia.
- *Foundations*: The walls rise directly from the rock base, or are only slightly sunk into the earth. This scarcity of foundation, characteristic of many *Castros*, depends on previous conditioning efforts and on the outcrops of granite available. Overall, the orography of the settlement is taken advantage of as much as possible.
- *Height of the walls*: as the architecture remains are practically reduced to the level of the foundations and wall-bases, it is difficult to estimate their original height. The resulting reconstruction is therefore merely hypothetical. In the case of San Cibrán de Las, the most plausible hypothesis makes for a height of three meters.
- *Entrance*: The form of access to the roundhouses is another problematic architectural question. The doorways give dimensions similar to these already documented in this field (width 1 meter and height about 1.60-1.80 meters).
- *Roofing*: documented archaeological data from excavations of these circular structures show the generalized use of straw roofing. A conical framework made of wooden beams, seated in the wall tops, the other ends joining and supporting one another at the top of the cone.

Up to this point, we have dealt with the architectural structure without taking the possible functional use into account. For this, we must include the particular characteristics of archaeological finds in the interiors. We can, therefore, establish three groups into which the interiors fall as clearly defined by archaeological sources, domestic structures, storage spaces and funerary structures. We are here concerned in our reconstruction with moveable, domestic objects.

The possible use of a building as a dwelling is manifested through the documentation of those elements that typically define a domestic space, that is, the presence of a fireplace and the existence of artifacts denoting daily activity in the living space, as are mills, fire-place ceramics or fusaiolas (stone weights used in looms). In this regard, remains of the lareira (fire-place) and cooking utensils have been found in the excavation we are dealing with. There is sufficient information to interpret that the building was a housing unit with one undivided interior space, having the fire-place located in the centre of the building. The household's daily life took place in this single space. Although it is not possible to define separate areas of activity, we can be sure that most of the domestic tasks, such as preparation and cooking of meals, weaving, or manufacturing of utensils, were undertaken in this space. Many items have been found, such as bags of ash, round and oval grinding-stones, bits of kitchenware and storage jars, pieces of ceramic and stoneware.

All of these are represented inside the model, and located according to archaeological criteria, using other reconstructions such as the settlement of Neixón (at Boiro, in the Province of A Coruña, Spain) as points of reference:

- The Fireplace: this is the most important element, usually located in the centre of the dwelling, with the various other spaces of domestic activity radiating out from it.

◀ Figure 7. Drawing and 3D reconstruction of *Lareira* (fireplace).
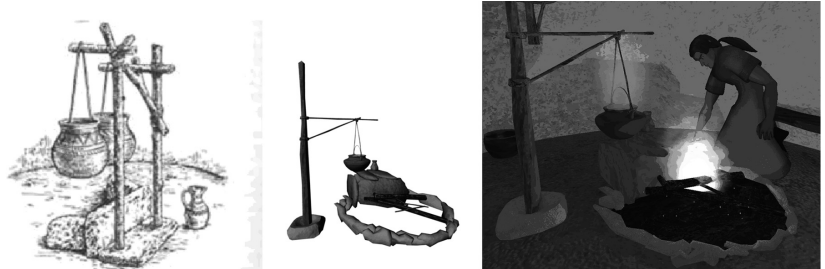
- Shelvings containing domestic ceramic cooking utensils
- Raised area: storage of grain and other food provisions

The User Experience. Mobility and Interaction

Once having established the forms and elements of the model, interaction and mobility were defined, according to the Empty Museum's technical specifications, to establish how to introduce the users into the reconstruction (what the user would be able to experience, what degree of interaction she would have, what sort of information would be presented to her and how).

We began with the problem of space. Installation of the Empty Museum we had worked with covered an area of 7x5 meters, whereas the reconstruction of the housing unit covered more than 20x15 meters. The problem was solved by dividing the reconstruction in three levels, each level being defined by the user's possibility of moving within it, by the geometry complexity and texture detail, and by the user's possibility of interaction within it.

◀ Figure 8. Level 1. The Kitchen.

The main and most important level, both for the quality of the 3D reconstruction (greater number of geometric shapes and textures) and for being the transitable and interactive area, is the kitchen, with a detailed interior reconstruction, and an exterior including the porch surrounding the entrance door. This is where the user begins the experience, freely passing interactively through the environment and seeing the virtual humans there.

The second level corresponds to the rest of the housing unit. It is of similar geometric complexity and texture detail to the first, but without the possibility of the user passing through it, as it is outside the limits of the system... The level of detail is maintained, given its proximity to the user.

◄ Figure 9. Level 2. Rest of housing unit

The third level is, in keeping with the analysis, what the user can see from any given point. It includes the outer walls, dwellings, entrance gate to the inner enclosure, etc, with lesser degree of details, and without the possibility of moving through it. It acts rather as an adequate background for the transitable area.

The practical design not only had to define what it represented and how it represented it, but also establish what could happen in each area, how the user could act, and how to ensure the experience would be both entertaining and educational. Thus, two types of interaction were established in the transitable area. There are three sensitive, explicative zones with recorded spoken texts that are activated when approached by the user. These zones are: the kitchen entrance, activating an explanation of the use of stone in the construction of the settlement; the household, where the use and importance of fire in that culture is dealt with, and the ceramics area, with a spoken explanation on manufacturing methods and use of the utensils produced.

The other type of interaction is that produced when the user approaches or looks at one of the virtual humans, activating various animations related to the surroundings: for example, a person in front of the kitchen fire, on being looked at from close range, transfers the embers from the cooking fire to the brazier.

4.4. CONCLUSIONS

New technologies of Virtual Reality applied to Cultural Heritage, especially in immersive transitable environments, permit new and interesting forms of study and interpretation of past constructions, showing contents in a different way from heretofore.

Systems such as the Empty Museum are not only powerful tools for the integral study of the architecture- in this case prehistoric - going deeply into aspects such as the special construction solutions used, the building techniques employed, etc, but they also give the sensation of space, movement through it, and relationship with the people and culture of that time, though yet in a limited but very promising way.

Future developments of this research will go in two directions. On the one hand, it will focus on the measurement of the improvement of space perception related to the inclusion of movement parallax. On the other hand, new historical scenarios will be set up in the installation allowing the visitors of the exhibition to explore other moments of their cultural past.

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VideaLAB. Universidade da Coruña.

E.T.S.I. Caminos, Canales y Puertos. Campus de Elviña, s/n

lhernandez@udc.es, jtaibo@udc.es, dmiguez@udc.es, jalley@videalab.udc.es, ynot@videalab.udc.es, jaspe@videalab.udc.es, mihura@udc.es

Luis A. Hernández, Javier Taibo, David Blanco, José A. Iglesias, Antonio Seoane, Alberto Jaspe and Rocío López