Recreating a prehistoric village: from the Epipaleolithic to the Iron Age

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ABSTRACT

The visualization of data is an important process in all archaeological works (P. Reilly, 1989, p.569-579). This paper describes the different stages in the virtual reconstruction of a prehistoric village, known as Cabezo de la Cruz, near Zaragoza, in Spain, done by the Light Simulation Lab (LSLUZ). The discovery of the remains of the village was soon endangered by plans of a new highway, which is to pass right across the archaeological site. Given the site's extraordinary scientific value, and its importance as cultural heritage, it was decided to virtually recreate the three constructive phases found in the site (epipaleolithic, the Bronze Age and the Iron Age).

1. INTRODUCTION

Achieving the desired goal required a multidisciplinary effort, spanning very different professions, which required fluid communication protocols between archaeologists, paleontologists and computer scientists. The latter were in charge of creating the digital worlds that would help visualize all the data gathered in the excavation.

Special attention was given to the final appearance of the images: to be truthful to the original village and in order not to mislead the spectators, photorealism was chosen over real time interaction. Virtual reconstructions limited by real-time constraints usually do not mimic reality as it was, but an oversimplification of reality (the actual level of simplifications governed by the available hardware). Computers need to calculate images fast, to achieve the desired frame rate; to do so, polygon counts in the models go down, simplifying geometry, and lighting calculations use smart cheats that have nothing do to with the actual interaction between light and matter. The result is that no real data is obtained, when in reality archaeologists need to have reliable data if they are to interpret their discoveries. Light can also be precalculated and baked into the textures in a pre-processing step, allowing for very realistic-looking reconstructions to be moved in real-time. However, dynamic lighting or moving shadows cannot be achieved this way.

In this work, lighting calculations are performed with true sunlight simulations, including its exact position any given day. Firelight has been accurately simulated as well, to better capture the sensation of being inside one of the buildings at night. Finally, before the images are displayed, the raw data obtained from the simulation is fed to a human visual system model, which mimics the way the human eye and brain interpret it, thus increasing realism. It is based on the fact that the human eye is actually good at perceiving contrasts, but fails at obtaining precise measures of luminance values. Colour perception also changes depending on a number of conditions.

As well as a detailed description of the geometry, photorealistic textures and a physically-based lighting simulation, the terrain, trees and plants that surrounded the village have also been recreated in detail. A great wild fire between the Bronze and the Iron ages radically changed the natural surroundings of the village, and the archaeologists wanted to see those changes in the virtual reconstruction.

The final images have been rendered in stereoscopic pairs, to be seen in immersive environments using passive polarized glasses (D. McAllister, 1993).

2. THE CABEZO DE LA CRUZ SITE

The complete Cabezo de la Cruz site has an extensión of 13.000 square meters, next to the Zaragoza-Teruel highway, in Spain. After a study by the Servicio de Patrimonio Arqueológico (Archaeological Heritage Service) of the local government (the Diputación General de Aragón), a 1.800-square-meter surface of intervention was decided upon. Later, it was discovered that the archaeological interest of the area spanned over a much broader area of roughly 2.856 square meters, over a 84x36-meter square, security area included.

To facilitate the excavation and description processes, the site was divided in three big areas that corresponded to three different units of occupation with different structures. Zone A included the south-west of the site, with the remains of a first defensive wall, torn apart over time. Several rectangular structures can also be appreciated. The middle zone or Zone B represents a transition space between that wall and the houses, whereas Zone C includes the whole housing area. Figure 1 shows a picture of the described excavation.

3. THE DIGITAL RECONSTRUCTION

Once the excavation was completed, the data were processed to adapt it to the needs of the digital reconstruction task. This produced a CAD image of the ground plan of the site, which was used by LSLUZ to start building the suburb. During the whole reconstruction process, a team of archaeologists and historians complemented the work at every stage. This required setting up a collaborative workspace based on the internet, so everybody could have instant access to the updated information and images as they were being created. Since nobody really knows how the site looked like thousands of years ago, every single thing had to be approved by the two teams, which often relied on common sense or actual well-preserved remains to decide certain features. A new iteration would then begin, with LSLUZ building a new solution based on the archaeologists' and historians' comments and them providing input again, until the cycle converged to a final solution. This procedure is worthy of remark, since it means that absolutely no arbitrary decisions were taken by LSLUZ, and that every object that appears on screen is 100% accurate.

Texturing and shading was done in pretty much the same way, iterating proposals until the both archaeologists and historians agreed on a solution. All the textures produced, whenever possible, were recreated from original pieces found during the excavation, in order to achieve the maximum historical accuracy. This usually implied careful reconstruction work in 2D, since a whole texture and pattern had to be extrapolated and deduced from a single little remain.

Lighting was done using two of our in-house software: Lucifer and SICARA 3D (Juan A. Magallón et al, 2004, p. 266-269). The goal was to use advanced Global Illumination algorithms that would add more realism to the images, instead of using simpler ray-tracing techniques. By using our won software we could specify a time and a day, as well as atmospheric conditions, and have a complete sun and sky model ready to light the scene. Only natural light was to be used, although at very different times of the day, from just after sunup, to midday, to the magic hour of the sunset. Given the complexity of the scenes and the wide variety of lighting setups, being able to use this capability of the systems instead of having to adjust the lighting by hand was priceless.

3.1 SEKER: PERCEPTION-BASED IMAGERY

The goal of creating photorealistic synthetic imagery is to capture the visual appearance of the modelled scenes as exactly as possible. Part of the intended added value of this work was to use our software for the simulation of the human visual system in order to increase the realism of the images. Physics-based rendering methods let us calculate the energy distribution in the scene with a great degree of accuracy. However, the exact calculation of this energy distribution does not guarantee that the visual appearance of the synthetic image matches that of the real scene, since the range of luminance in a real scene usually surpasses by several degrees of magnitude the dynamic range of an output device can handle. Pictures in a paper extend over a maximum contrast of 30:1; CRT monitors usually span no more than 100:1, and only a few high-quality prints can reach a 1.000:1 contrast ratio. In the real world, nevertheless, it is easy to find contrasts of over 100.000.000:1 or even more.

Tone reproduction provides a method of mapping (scaling) luminance values in the real world to a displayable range. The wide range of light in a real-world scene must be conveyed on a display with limited capabilities. In addition to compressing the range of luminance values, tone reproduction is often used to mimic perceptual qualities of the human visual system. The goal is to generate an image that provokes the same physiological responses as when viewing the real scene in the real world. To do this, we must first obtain a model of this human visual system, to include it in the rendering pipeline. No commercial software does that, which is yet another reason why we used our own software to produce the images in this work.

Yet another reason exists for which both human perception mechanisms and their application to tone reproduction are worth studying, and that is to save rendering times. Understanding how our brain is going to interpret the image, solutions can then be calculated with less precision from a physics point of view, but knowing that a more physically-accurate solution will not add anything to the image as perceived by a human observer, while also being more expensive in terms of rendering time. This is especially interesting in fields such as Virtual Reality or immersive systems, where the ultimate goal is to be able to produce photorealistic imagery in real time. We do not just want to see an image through an output device, however physically accurate it might be, but we want to create the feeling of actually being there instead, and that cannot be accomplished ignoring perceptual issues. For instance, the visual perception of a scene varies considerably under different light conditions, mainly owed to the human visual limitations. Dark environments cause a loss of colour sensitivity and visual acuity, while bright sources produce veiling glare effects.

In this context, a tone reproduction application, as well as a model of the human visual system, was developed by the authors in a software environment called S·E·K·E·R (Oscar Ansón, 2001, p. 8-10). Our tests with different audiences show that correct tone mapping based on the simulation of several perception issues pay off in terms of increasing the sensation of realism in the images. Figure 2 shows a general scheme of the workflow of SEKER. It receives High Dynamic Range (HDR) images (where each pixel has physics-based magnitudes of luminance from the light simulation packages), applies some of the mechanisms of the human visual system based on those values, and finally shows the image correctly tone mapped to the display luminance values.

Two criteria have been followed to make a reliable tone reproduction and, consequently, a better approach to the desired photorealism. On the one hand, the reproduction of visibility; an object in the synthetic scene can be seen if and only if it can be seen in the real scene. Objects are correctly showed in both overexposed and underexposed regions. On the other hand, the vision of the image produces a subjective experience that matches the vision of the real scene. That is to say, what is showed in the display has to match the *memory* of the real scene. Bright, contrast and colour impression have then to be correctly reproduced.

4. RESULTS AND CONCLUSIONS

A virtual reconstruction of the archaeology site of the Cabezo de la Cruz (Zaragoza, Spain) has been achieved, with the guidance of the Servicio de Patrimonio Arqueológico (Archaeological Heritage Service) of the local government (the Diputación General de Aragón). Three different epochs have been modeled, based on the archaeological findings and the insight from experts: epipaleolithic, the Bronze Age and the Iron Age. This allows observing the evolution of the site and its buildings over time, and analyzing the way the village grew and evolved.
The job consists in a complete digital 3D reconstruction, including the interior of some of the houses, in a realistic way. This required accurate models and textures that capture all the wear and tear of a real village populated by real characters. A multidisciplinary tea of: archaeologists, historians and computer scientists were involved in the project.
Precise lighting algorithms developed by LSLUZ give the images a photoreal look. With these algorithms, a time of the day, the day itself and various atmospheric conditions can be specified, and a complete sun and sky model is ready to light the scene. Only simulated natural light has been used, although at very different times of the day, from just after sunup, to midday, to the magic hour of the sunset and finally at night.
Figure 3 shows some of the resulting images. From left to right, top to bottom, the figure shows:

- First two images: a complete view of the surroundings, showing how they change as agriculture sets in. The images represent the epipaleolithic and the Iron Age respectively.
- Image number three: the village in the epipaleolithic age
- Images four and five: the interior of a house, highlighting its evolution over time (image four shows the interior of a house in the Bronze Age, whereas image five represents the Iron Age).
- Images six, seven and eight: several views of the defending walls of the village and one of its narrow street, during the Iron Age.

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FIGURES

Fig. 1 – The excavation at Cabezo de la Cruz.

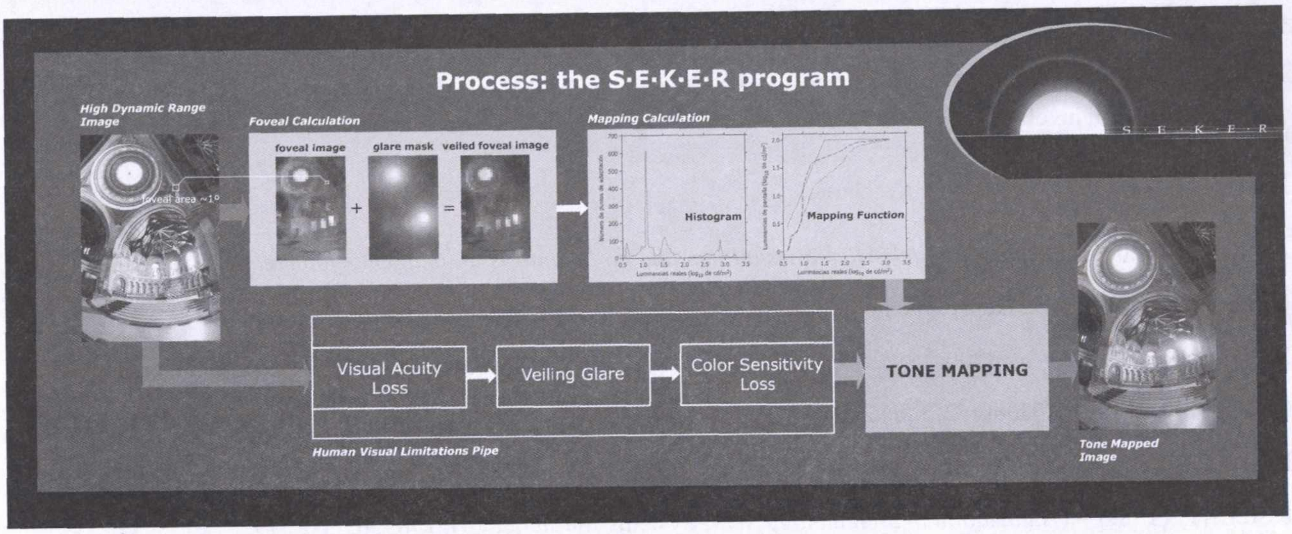

Fig. 2 – The workflow of our S·E·K·E·R software.

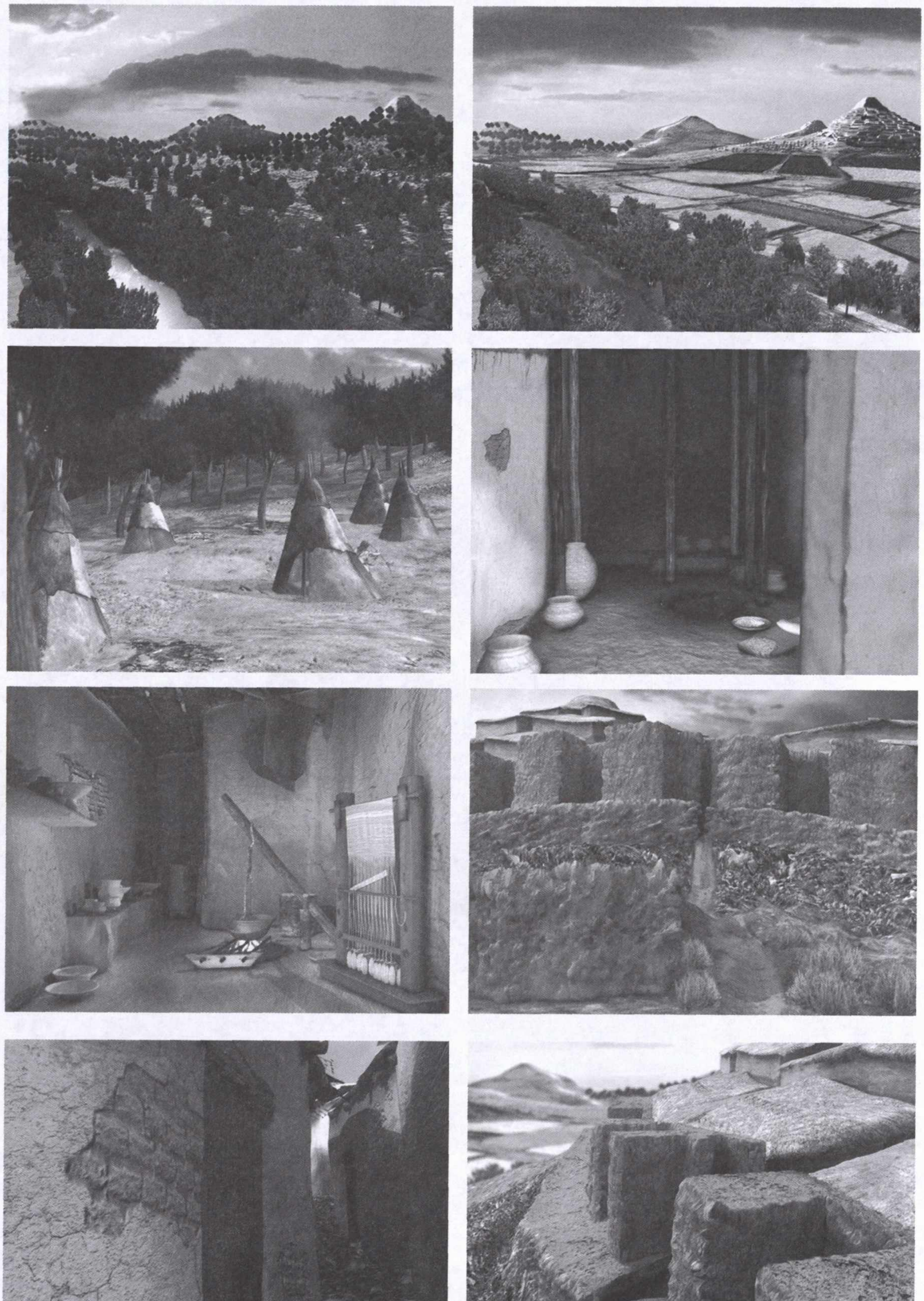

Fig. 3 – Several images of the final reconstructions.