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The *Lapedo Child* Reborn: Contributions of CT Scanning and Rapid Prototyping for an Upper Paleolithic Infant Burial and Face Reconstruction. The Case of Lagar Velho Interpretation Centre, Leiria, Portugal

F. Almeida[1], P. Bártolo[2], N. Alves[2], H. Almeida[2], M. Ponce de Léon[3], C. Zollikofer[3], B. Pierson[4], P. Serra[5], C. Duarte[6], E. Trinkaus[7], and J. Zilhão[8]

[1]IGESPAR, IP. Lisbon, Portugal
[2]CDPRsp, IPL, Leiria, Portugal
[3]Anthropological Institute, Zurich University, Switzerland
[4]Tulane University, New Orleans, USA
[5]IPT, Tomar, Portugal
[6]Câmara Municipal do Porto, Porto, Portugal
[7]Washington University, Saint Louis, USA
[8]Bristol University, Bristol, UK

Abstract

The Lagar Velho rock shelter became known worldwide since the discovery, in late 1998, of a nicely preserved Upper Paleolithic burial, containing an almost complete child skeleton, whose later anatomical study provided strong evidence for an admixture between the latest Neanderthal communities of Iberia and the first anatomically modern humans during the few millennia that the two populations co-existed.

Given the importance of the find and the fragility of the skeleton, it was decided, for exhibition purposes, to make a replica of the burial context. This endeavor implied the combination of CT scanning of the complete skeleton, virtual reconstruction of the severely shattered skull, and rapid prototyping of the totality of the bone inventory through different methods (stereolithography and 3D printing).The burial depression was reproduced through traditional modeling techniques. In addition, Rapid prototyping was also essential for the facial reconstruction of the "Lapedo Kid", which will be available to visitors of the Lagar Velho Interpretation Centre, in Leiria, Portugal. This paper presents the main stages of production of two of the most appealing objects of this local museum facility, evaluating the combined use of scanning techniques, virtual and physical prototyping for the improvement of public access to archeological heritage.

1. Introduction

Lagar Velho, located in the Lapedo Valley (Leiria, Portugal) is a rock shelter where, since 1998, archeological fieldwork has yielded one of the most complete sequences for the Portuguese Upper Paleolithic, spanning from c. 30,000 years to 20,000 years BP (Before Present). During this period of 10,000 years, the shelter was successively occupied by animal and human communities, allowing, through systematic multidisciplinary research, to reconstruct the evolution of paleoenvironmental conditions for that slice of time, and also the variability of human behavior, as revealed by different functional uses of the rock shelter [ZT02]. Among the latter, one of the most surprising discoveries was an occupation surface dated to ca. 22 493±107 years BP, in a *Pompeii* – like state of preservation, where the excavation of c. 20 square meters revealed the presence of habitat features (hearths of different architectures and functions), special activity areas, and thousands of faunal remains, essential for the study of the hunting and carcass processing strategies of our earlier ancestors.

The most important archeological discovery at Lagar Velho, however, continues to be an infant burial dated to c. 24,500 years BP. When first discovered, this context was the first Upper Paleolithic burial found in Iberia, and constituted one of the most complete skeletons from the European Paleolithic record. The subsequent anatomical study of the bone inventory yielded surprising results: the *Lapedo Child* revealed a mosaic of anatomic characteristics which have been interpreted as a result of continued admixture between the latest European Neandertal communities, and the first anatomically modern humans to arrive to Iberia. Such interpretation of the fossil had worldwide repercussion, not only among the scientific community, but also on the general media.

Taking into consideration the scientific importance of the rock shelter site, the Portuguese Institute of Archaeology (IPA) and the Câmara Municipal de Leiria (local municipality) joined efforts towards the construction of a small museum facility, in order to facilitate the access of the general public to this rare and important archeological heritage. The main goals of the project, besides exhibiting the spectrum of the various human

occupations and uses of the site, focused on the explanation of how a multidisciplinary perspective permits us to better understand a wide range of aspects of the past: from climate, environment and related landscapes, to animal communities and human adaptation strategies. The Interpretation Centre has been co-financed by the European program *Leader+*, and will open its doors in December 2007, almost 9 years after the initial discovery of Lagar Velho as an archeological site.

Figure 1: *The LV1 Infant Burial, during its excavation, in late 1998*.

The most important element of the whole exhibit, for obvious reasons, is the *Lapedo Child* burial context. The excavation of the funerary feature was undertaken in late 1998, through traditional archeological and anthropological methodologies, with systematic record, by 3-dimensional plotting of the recovered bones and illustration and photography of the successive phases of the excavation. The vast majority of the non cranial skeleton was preserved *in situ*, but the fragility of the bones made any casting through the usual methods (e.g. latex or silicone) impossible. The skull, on the other hand, was severely damaged by the bulldozing that affected the site previously to its archeological discovery. This resulted in several fractures of the already deformed (by post-depositional natural conditions) cranial fragments.

The replication of the burial context and an always appealing facial reconstruction of the *Lapedo child* implied, therefore, a combination of different methodologies. CT scanning and rapid prototyping took an important role on the process. This paper summarizes the different phases that were necessary on the making of two of the most important artifacts from the Lagar Velho small exhibit. It also points to possible research roads for future collaborations between archaeology, heritage management, computer applied sciences, and engineering.

2. The skeleton reconstruction

The original CT data acquisition of the Lagar Velho skeleton, performed at the Radiology Service of the Curry Cabral Hospital (Lisbon) with a Picker PQ 5000 medical computer tomograph, had mainly paleoanthropological purposes, related to the anatomical study of the skeleton [TREC*02] [TREC*02]: not only to obtain volume data, which permitted the electronic preparation, isolation, 3-dimensional reconstruction and virtual (graphical) representation of the original fragments and detailed internal structures, but also to provide cross-sectional images allowing for paleopathological research.

CT scanning also became essential for the reconstruction of the LV1 skull [ZLES*02], since physical conjoining, although partially possible, was limited not only by the recent fractures but also by post-depositional taphonomic deformations that affected the fragments during the millennia that had passed since the original burial ritual. Computer aided reconstruction of the *Lapedo child* cranium fragments allowed us to conclude, for instance, that, in general, disintegration through fracturing and dislocation of parts seems to have preceded plastic deformation. In addition, it provided clues concerning the original position of the skull – slightly turned towards the left – a pattern impossible to discern during the excavation of the *in situ* burial, since almost the entire skull was affected by bulldozing action and scattered over an area of ca.3 square meters. The reassembly of the virtual fragments was carried out on a Silicon Graphics Onyx II workstation with the software tool kit *FoRM-IT*. With the use of stereo viewing equipment (Crystal Eyes® stereo glasses), it became possible to perform complex manipulatory tasks on the computer screen with a high degree of perceptual reality. The skull virtual reconstruction, together with that of the mandible, was accompanied by the production of a first series of resin prototypes through stereolithography. One of these, property of IPA, has already been exposed on an award winning exhibit dedicated to the Pre and Protohistoric record of Leiria region, and organized by the local municipality [Car05].

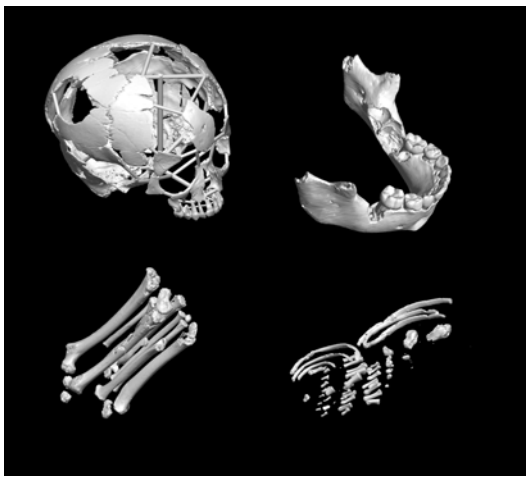

Figure 2: *Aspect of the STL files of the LV1 skeletal inventory, before final processing for rapid prototyping.*

From the onset, the project for the Interpretation Centre considered as essential the presence of a replica of the complete skeleton of the *Lapedo child*. The fragility of the original prevented any possibility of exhibition at the small museum facility, with inefficient environmental control, and always subject to security risks. Since the CT scanning had been applied to the totality of the skeletal inventory, the choice for the application of

rapid prototyping techniques of reproduction became evident. Contacts were immediately made to the Anthropological Institute of Zurich University (where the skull reconstruction and first prototypes had been made, and where the original CT scanning files were allocated and being processed), so that STL files of the complete skeletal inventory could be sent to CDPRsp, at IPL, Leiria, one of the few rapid prototyping installations in Portugal.

The next step involved the processing, using the software Magics 9.54, of the STL files, already at Leiria, in order not only to prepare them for the physical prototyping operation, but also to allow for the calculation of necessary volume of material for the prototypes (using Geomagic Studio 8), and budget the whole process of replication. Special consideration was given to an equilibrium between a reasonable price, durable materials which allowed for finishing jobs (like painting), accuracy of the reproduction (as expressed by the thickness of impressed layers), and processing time. For the total calculated volume of 675683.57cm^3, it was concluded that the most balanced accuracy, for resin based stereolithography, was one where each layer of material deposition possessed 0.12mm of thickness. Still, the resulting budget for a such a prototype of the complete Lapedo skeleton was beyond the financial capacities of the Interpretation Center. For this reason, and after a first wax-based prototype of the skull was successfully produced at CDPRsp, it was decided to produce the final replica through 3d printing, with equipment available at the Mechanical Engineering Department of Instituto Superior Técnico (Lisboa, Portugal). The production was co-financed by IPL and the Leiria Municipality.

Figure 3: *The 3D printed skeleton replica, after the first stage of painting.*

After the reproduction of the complete skeleton, the prototyped skull, mandible, and remainder of bones were transported to IPA, in Lisbon, where the finishing of the replica was made. This involved a first painting of each element with an acrylic based paint. The creation of the painting palette was undertaken with direct access to the original fossil, thus allowing for an accurate reproduction of bone colors. The *Lapedo child* copy became thus ready to be located on a replica of the burial pit, which, as seen below, demanded the application of more traditional modeling techniques.

3. The burial reconstruction

As we have seen, the application of CT scanning and rapid prototyping techniques permitted a relatively fast reproduction of the skeleton. No 3-dimensional scanning was undertaken, however, when the original skeleton was still *in situ*, during the excavation. This implied that, for the reproduction of the burial, the surface had to be recreated after the 3-dimensional measurements taken manually in the field, and sculpted in *Styrofoam*, a light material which accepts water based glue. The topographic model for reproducing the burial pit was created with the aid of Surfer 8.0, and sculpted, with a *Dremel* device, on a rectangular piece with 85x45x9cm^3. After this initial sculpting was finished, the surface was painted with acrylic paint similar in color to the original burial sediment.

Each piece of the skeleton was then located on its approximate place of the burial pit, its limits being marked with pencil on the base. A second phase of sculpting followed, creating the “beds” for each of the reproduced bones. After fixing each part of the prototyped replica to the *Styrofoam* base, all the area around the skeleton was filled with original excavation sediments, collected near the burial pit. The reconstruction was concluded by a final painting job, with acrylic based colors and pigments, which reproduced not only the ochre stains on the bones and sediment, but also the charcoal fragments of a Scots pine branch that were found associated with the burial.

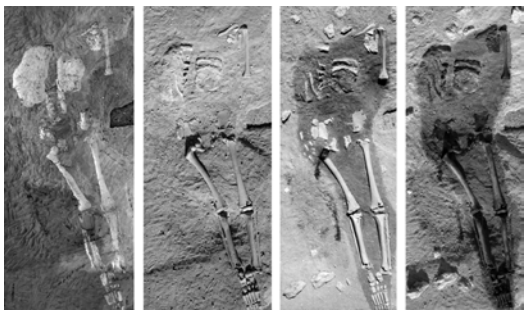

Figure 4: *Progress images of the burial replica production.*

4. The facial reconstruction

Facial reconstruction [PN97] has become an essential tool not only for forensic investigation [CMGB*04] [HR91] [Phi00] [SGMc70], but also for our overall understanding of earlier human fossils [BGJ87] and our ability to relay their appearance to the public [Lew99] [TECG97]. The accurate facial reconstruction of the *Lapedo child* by modern techniques will provide the public of the Interpretation Centre with a clear vision of how this kid really looked like, much more than by solely looking at the prototyped skull or at computerized virtual reconstructions of the face [ABFG*00]. The facial reconstruction of LV1 was financed by the Anthropology Department of Tulane University

(USA), on the scope of an ongoing collaboration project with IPA, and undertaken by Brian Pierson in New Orleans, following the methodology previously applied on his reconstruction of the *Nariokotome boy*.

The process implied the production of a replica of the skull and mandible. For budgetary reasons, it was decided to produce a wax prototype that could be used as a basis for the facial reproduction. The production was undertaken, at CDPRsp facilities, at IPL, Leiria. The option for wax, however, became impracticable, mainly by the extreme compulsiveness of North American Customs, which completely destroyed the skull wax prototype prior to its arrival to New Orleans. For this reason, it was decided to use one of the original resin prototypes, made through stereolithography at Zurich University.

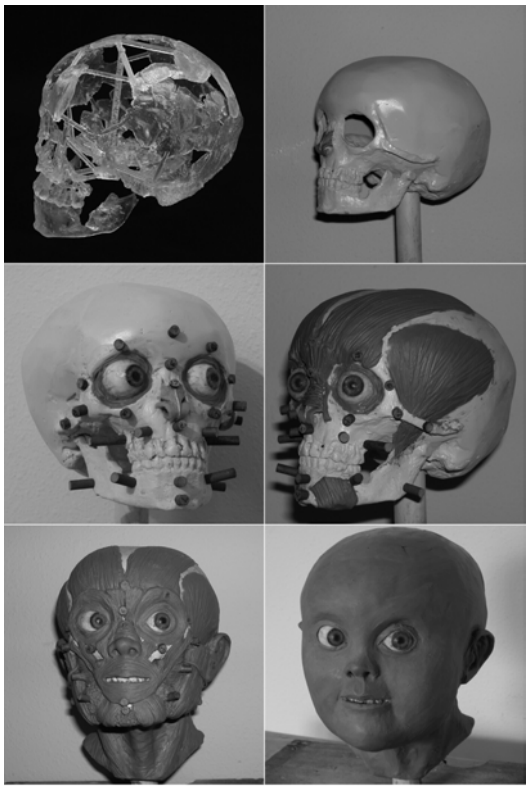

Figure 5: *Progress images of the facial reconstruction of the Lapedo child.*

The reconstruction followed a precise sequence of operations, where forensic reconstruction techniques played a major role [PN97]. In a first stage, the voids on the skull were filled, and the missing nasal bones rebuilt [Ube00], together with zygomatics, and supraorbital torus. Next, the eyes (in resin) were created and put into place. The soft tissue was laid on, through the use of modeling clay. Then, through techniques usually applied by FBI investigators, known facial depths on certain points of the skull were marked [Phi00] [RC80] [SH02] [WNR02], the voids being filled with a latticework of clay to approximate the face. The "Gerasimov method" [Ger40] [Ger55], an alternative approach, builds up the musculature of the face and then covers it with a skin to finish the reconstruction. Both methods present similar final results, and their combined application was used on the facial reconstruction of the *Lapedo child*. The creation of the nose and the mouth width estimation was equally based on forensic science patterns. Finally, a silicone skin was applied, airbrush painted, the reconstruction process ending with the application of the eyebrows and the hair.

5. Bridging CT scanning, rapid prototyping, and forensic techniques on the scope of archeological heritage

The *Lapedo child* burial context replication and facial reconstruction, two of the most important pieces from the Lagar Velho Interpretation Centre, would have been impossible without the aid of CT scanning, and 3d printing techniques. This first collaboration clearly revealed to all of us the potential of the application of inverse engineering and rapid prototyping for reproducing archaeological heritage items, at a wide range of scales.

While for the moment the prohibitive prices of 3-dimensional scanning portable equipment make its access almost impossible for archaeological teams in the field, one should still point out that such a prospect might became a standard in the near future. For the Lapedo case, for instance, the application of a 3D scanning device during the excavation would not only have allowed for an accurate record of all the spatial data of the find, but would facilitate (read automate) the reproduction of the totality of the burial context.

Computer aided reconstruction of the skull helped, as we have seen, not only on the evaluation of taphonomic processes that affected the fossil, but even in defining the original position of the *Lapedo child*'s head, during the burial. We cannot but be certain that over the next years the field of paleoanthropology and archaeology will be vastly involved in such type of scientific bridging.

On a larger scale, the potential of inverse engineering and rapid prototyping is almost infinite for archaeology. One can imagine excavating a new Paleolithic burial, scanning it, and sharing the 3-dimensional information via Internet to all the scientific community, within a few hours. In addition, we can imagine that for a small scale museum in a town like Leiria, one could organize an exhibit of all the burial contexts from the European Gravettian, based on rapid prototyped replicas. In a different room, one would find forensic facial reconstructions of all the known Gravettian skulls from Italy, and try to figure out if some of them might have been related to each other in the past. Still using our imagination, we could 3D scan live actors reproducing Paleolithic activities on a rock shelter, like knapping a projectile point, scraping an ibex hide, or eating a nicely roasted red deer, and reproduce, also through rapid prototyping, lively small scale dioramas of our ancestors lifestyles, an item always appellative for children. And it was, after all, a child - the *Lapedo child* - buried more than 24 500 years ago, that opened our imagination for the enormous potential of these new ways of collaborative multidisciplinary research: recording, reproducing, and sharing information about our Human History and Past Heritage.

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