CAA2015

KEEP THE REVOLUTION GOING >>>

Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology

Edited by

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Introduction

Stefano Campana

Roberto Scopigno

Chairmen of the 43rd CAA

KEEP THE REVOLUTION GOING

This volume brings together all the successful peer-reviewed papers that have been submitted for the proceedings of the 43rd conference on Computer Applications and Quantitative Methods in Archaeology that took place in Siena (Italy) from March 31st to April 2nd 2015.

The number of people who signed on for CAA 2015 really took us by surprise: 550 delegates registered for the conference, from many more places than we would ever have anticipated. Altogether, within the four days of the conference 280 papers were presented in 48 sections divided into ten macro topics, 113 posters, 7 roundtables and 12 workshops.

That number, in itself, has prompted a thought or two. Above all it says to us that CAA is very much alive and kicking, that it is in robust good health, and that it remains a wholly relevant force in the scientific community, fully engaged with the questions of the day, and a continuing focal point for the profession. All of that speaks well for the motto of CAA 2015: KEEP THE REVOLUTION GOING

Although the significance of our motto is obvious, we think it is worth some thoughts. Few would deny that in the past 30 years or so, digital technologies have profoundly revolutionised archaeology – in the office and laboratory, in the field and in the classroom. The progressive introduction of digital techniques in the archaeological process has of course led to a general increase in efficiency. But perhaps more importantly it has provided a spur to the discussion of methodology and through that has strongly influenced not only the way we go about things but also the outcomes that we have been able to achieve.

The pioneering phase in the application of digital techniques in archaeological research has clearly been fruitful and today computer applications such as GIS, databases, remote sensing and spatial analysis as well as virtual and cyber archaeology are deeply embedded within our universities. This is all good, of course, but we must not assume that the task has been completed. An intrinsic revolutionary instinct towards technological development has been awakened. But it will only survive by virtue of the results that it brings about. Or using the words of our Chairman Prof Gary Lock: 'Computers not only change the way we do things, but more importantly they change the way we *think* about what we do and why we do it'. The general thrust of this statement can be summed up and reinforced by recalling a quote from the philosopher Don Ihde, who has argued we should never forget that all technologies should be regarded as '*cultural instruments*', which as well as strategies and methodologies implemented in our researches are also '*non-neutral*'.

So KEEP THE REVOLUTION GOING is a motto that lays stress on the need to maintain innovation in archaeology through technological advances. But innovation must have at its root the fostering of critical thought and the framing of new archaeological questions. So there is much work still to be done, and fresh challenges to be faced in the months, years and decades ahead.

One final thought. The date of this conference, and most of all the opening ceremony, has not come about by chance. The 30th of March, for the University of Siena and in particular for the human sciences and archaeology, represents a sad but enduring anniversary. Eight years ago on this day we lost a key figure in the Italian archaeological community of the last 50 years; a man who had an extraordinary influence on many aspects of medieval and archaeological studies. Not least we call to mind his role in the promotion and development of digital archaeology. Our thoughts and memories go therefore to our friend and mentor Professor Riccardo Francovich. He always inspired us to seek new horizons and without him we doubt that this conference would have found its way to Siena.

Introductory Speech

Professor Gabriella Piccinni
Dean of the Department of History and Cultural Heritage, University of Siena

First of all, on behalf of the Rector of the University, and as Dean of the Department of History and Cultural Heritage, I wish you all a very warm welcome to the University of Siena.

This greeting goes in the first instance to all of the distinguished speakers at this meeting but also to all who are here in our company to listen and to take part in scientific debate. A warm welcome, naturally, goes to all of the institutions represented at this table, to the Chairman of CAA International, Professor Gary Lock, to the National Research Council, our partner in the organization of this congress, and to the Ministry of Heritage, Culture and Tourism. Last but not least I extend my thanks to all who have committed their time and energy to the organisation of this meeting: the scientific secretariat, the conference office, our student volunteers, the institutions that have kindly agreed to act as patrons, and the sponsors who have so generously supported this initiative.

I confess that when Stefano Campana first told me about the opportunity for our university here in Siena to organise such a prestigious event as the international meeting of the CAA, now in its forty-third year, I was immediately excited and engaged because I strongly believe that events like this represent one of the most tangible and concrete demonstrations of how a University works, how it forms and reinforces knowledge; these kinds of events delight me as a scholar and as a teacher, as well as the director of a university department.

It is a great honour for us to host CAA International, bearing in mind the history of our university, and in particular its tradition of archaeological studies, within which it has played a pioneering and leading role in the field of Digital Archaeology. I cannot but recall how the University of Siena has, since the early nineties, played a central role both nationally and internationally in the development of computer applications in archaeology. My thoughts and deep gratitude go inevitably to our late colleague and friend, Professor Riccardo Francovich, who remains always in our work and in our hearts. His exceptional energy and his qualities as an innovator provided an extraordinary impetus in this area of studies; an impetus that lives on through the work of his students and through the many many people who were inspired by his example.

The conference numbers are frankly astonishing: roughly 550 delegates – the organizers were actually forced to close registration because the results were beyond their wildest dreams. The University's halls are overflowing, its facilities at full stretch to host this event. The congress has representatives from more than 50 countries and from all of the most prestigious universities and institutions in Europe and beyond. In the short space of the next four days the work programme will be intense, with 46 thematic sessions, 12 workshops, 7 panel discussions, 4 key-note speeches and all sorts of informal discussions and social activities that will promote the continuing exchange of ideas.

Let me end with a simple thought. Without entering into discussions and analyses that lie outside my role (or even competence) here today, I feel that seeing so much dynamism and so many young scholars, teachers and researchers coming together here in Siena from all around the world to talk about the new opportunities offered by the application of technology within archaeological studies should prompt a few moments of reflection about the ways and means through which we deliver our higher education and training. Today more than ever, in front of this audience, we see how vibrant and strong is the demand for discussion and training in these topics. In keeping with the motto of the conference, the future is still to be built, let us show the same commitment that enabled our predecessors to overcome the first heroic phase of the 1990s and the early years of the new millennium. Always, of course, keeping alive the flame of innovation that has from the outset been the guiding light of this of CAA International initiative.

Acknowledgements

It goes without saying that the organization of an event such as CAA is a complex and demanding task that only achieves success through real teamwork. So we will start by offering heartfelt thanks to all who have helped to make this meeting possible: the University of Siena. We are particularly grateful to the Rector prof Angelo Riccaboni and the Director of the Department of History and Cultural Heritage prof Gabriella Piccinni for their constant support and valuable advice. Particular thanks are offered to the conference office Giuliana Pasquini, Roberta Corsi, Elisa Pratali and Serena Mazza and to our many students volunteers, Mirko Buono, Marta De Pari, Valery Del Segato, Cesare Felici, Ilenia Galluccio, Nadia Messina, Michele Pellegrino, Sara Linda Russo. Last but by no means least we owe a deep debt of gratitude to all who have given their time and enthusiasm to the organisation of the meeting – to the Scientific Secretariat under the leadership of Dr Marianna Cirillo.

For the same reasons, I am most grateful to the Monte dei Paschi Foundation and to Verince srl for the outstanding work in organizing the social events including the 'ice-breaker' party, visits to various monuments and cultural activities within the city of Siena, the social dinner and the field trip. In particular I would like to mention Marco Forte, Laura Tassi and Laura Manzi, who have substantially contributed towards making CAA Siena unforgettable for their delegates.

Particular thanks are offered of course to the Steering Committee of CAA International, and especially to its chairman Prof Gary Lock and treasurer Axel Posluschny, and all the many others for their unfailing support; they were always there when needed and they helped immensely in creating a happy working atmosphere. A special thanks is must also go to the OCS 'guru', Hembo Pagi, who patiently supported us while using the new CAA conference management system.

We would like to acknowledge the skill and generosity of our outstanding key-note speakers: Nicolò Dell'Unto (University of Lund,Sweden), Maurizio Forte (Duke University, USA), Martin Millett (University of Cambridge, UK) and Holly Rushmeier (Yale University, USA). A sincere thank you also goes to the special guest of the 43rd CAA, Professor Dominic Powlesland (Landscape Research Centre, UK).

We are indebted to the many bodies who have given us their willing support: Ministero dei Beni Culturali e del Turismo, Comune di Siena, Soprintendenza per I Beni Archeologici della Toscana, Regione Toscana, Provincia di Siena, Comune di San Giovanni d'Asso, Comune di Montalcino, Comune di Pienza, Accademia Chigiana, Opera del Duomo, Eurographics, Fondazione Ing. Carlo Maurilio Lerici, Archeologia e Calcolatori, Bruno Kessler Foundation 3DOM, Polytechnic of Milan, CNR Institute of Technology Applied (Cultural Heritage).

Special thanks are also due to all the many sponsors, whose generosity played such a crucial role in sustaining us in this enterprise: Monte dei Paschi di Siena (dott. Carlo Lisi), ESRI Italy (Paolo Gull) & ESRI Europe, IDS Ingegneria dei Sistemi (Paolo Papeschi), ATS srl (a spin-off company of the University of Siena), ArcTron 3D Expertise in Three Dimensions, Aicon 3D systems, Breuckmann 3D scanner, Beta Radiocarbon Dating, Geocarta, Geostudi Astier, Eurotec Pisa, INARI, V-must, Menci software, Archeopress, All'Insegna del Giglio,

Finally, heartfelt and grateful thanks must go to **Dr Marianna Cirillo** and **Dr Gabriella Carpentiero** for their tenacity, rigour and outstanding work done in helping to assemble and manage the preparation of the conference proceedings.

CHAPTER 1
Teaching and Communicating Digital Archaeology

From the Excavation to the Scale Model: a Digital Approach

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Abstract: Lyon's archaeological department took the opportunity of a recent rescue excavation to fulfil two purposes: improving (geo)archaeological knowledge of the city of Lyon while developing a set of tools for scientific mediation. The excavated site spanned 40000 years, from the Würmian period to the 19th century. Occupation from the ancient and medieval periods was the main focus points of this excavation. A 3D diachronic reconstruction was achieved for this site using a fully digital workflow. Stratigraphic and architectural data obtained from the fieldwork, or reconstructed afterwards, were integrated into GIS and modelling software to produce 3D volumes. We could produce static high-resolution renderings, a 3D printed scale model of the stratigraphy and buildings, as well as digital interactive media. This project allowed us to explore the interest of 3D both for archaeological research, as a way to develop and validate research hypotheses, and for scientific education.

Keywords: Landscape and Archaeological reconstruction, 3D printing, Virtual reality, Scientific mediation, Lyon (France)

Introduction

Our project started with the will to collaborate with the FabLab of Lyon in order to experiment with 3D printing (Wohlers 2013) applied to archaeology. Such techniques are already used for artefacts (Fantini *et al*. 2008), but we aimed at applying them to stratigraphy. We widened this initial goal to encompass other 3D methods and tools and developed an uninterrupted digital process that finally allowed us to produce several virtual and physical restitutions of an archaeological site.

Our questions were 1/ how could we, as archaeologists, adopt these innovative techniques 2/ how could they enhance our scientific practices 3/ how could they improve our educational practices 4/ could we obtain valid results with limited resources?

An emergency excavation that started at the beginning of 2014 in Lyon (France) proved to be the ideal testing ground for this experiment (Bouvard *et al*. 2015).

Salvage archaeology must adapt to several constraints that we have to overcome if we want to understand the evolution of a territory wider than the plot we dig. Time remains the first constraint, but is not the only one: urban sites for example are characterized by their confinement, fragmented nature, and stratigraphic unevenness. Therefore we need a tool that can offer the opportunity to, first fill the stratigraphic unknowns, and then help us to understand human and landscape evolution in terms of topography and sedimentology.

Moreover, sharing the cultural heritage and transmitting the knowledge to a large audience is an important part of our mission as a public institution. This is why Lyon's archaeological department involves the local community in the care of the anthropic and landscape relics that are parts of their history. For this reason, we decided to participate in a science festival ('Fête de la Science') lasting more than a week, whereby universities, museums, and other research centres offer workshops to pupils from schools and colleges, and to anyone interested in meeting scientists and learning about various scientific topics. For this event we wanted to innovate with a new and interactive education tool, associating makers and archaeologists. The goal was to create a 3D scale model of the site we excavated. We had to be able to assemble and disassemble the main stratigraphic layers and buildings, in order to explain to the general audience both the evolution of the site and the archaeological process itself. We also wanted to explore the potential of innovative human/computer interaction for archaeology and scientific mediation with various tools: contactless interaction with 3D restitutions

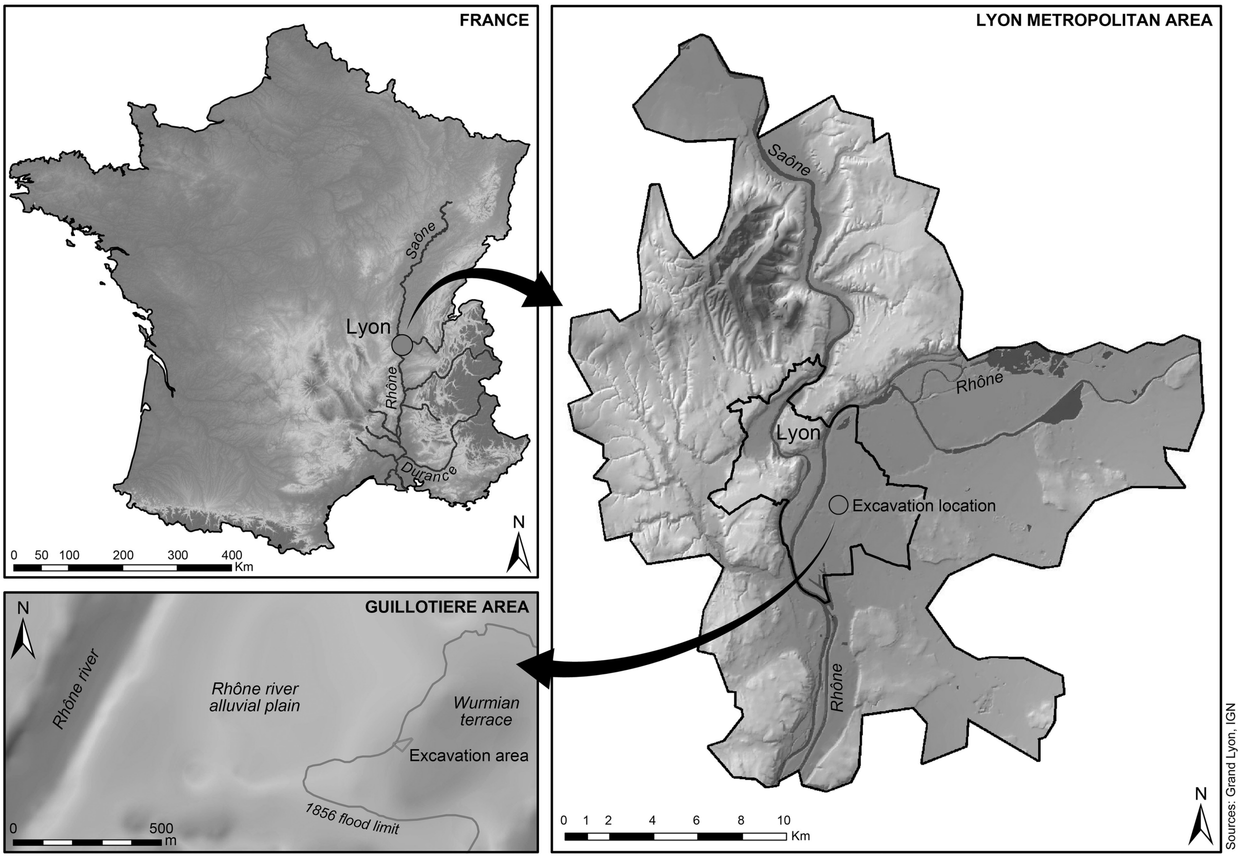

Fig. 1. Location of the archaeological site and geographical context.

of archaeological objects (using a Leap Motion controller; Spiegelmock 2013) and visit to an ancient site in virtual reality (with Oculus Rift virtual reality goggles; Knabb *et al.* 2014). These products would support a dialogue on the association between humanities and digital technologies.

One challenge of the project was the transfer of objective data from the field to a final product dedicated to education, without generating bias errors during the process. We will first present the excavation that provided the initial data. The second part of our paper will cover the end-to-end digital workflow we created to reach our objective. We will then explain the benefits we gained from the 3D restitution, from a scientific and educational point of view, and we will finally the perspectives of such an approach.

1 Archaeological context

The salvage excavation in a small plot (900m^2) took place on an *extra-muros* area around the city of *Lugdunum* (Fig. 1). We expected to find a Roman necropolis because some graves and a section of an antique road were found in the neighbourhood by archaeologists over the past twelve years (Blaizot 2010). Unfortunately this was not the case, but we did find two small settlements, one Roman and the other medieval. The site is located on the bank of the Rhône River in a district outside the Roman and the medieval town. It was a rural area in the past, but it is now an urban space. The specific topography (a moderately high terrace, a slope on the opposite side, and two large, hollow structures) allowed us to work on a stratigraphic relevant case, which seemed to be, at first, a challenge to show and to explain to non-archaeologists.

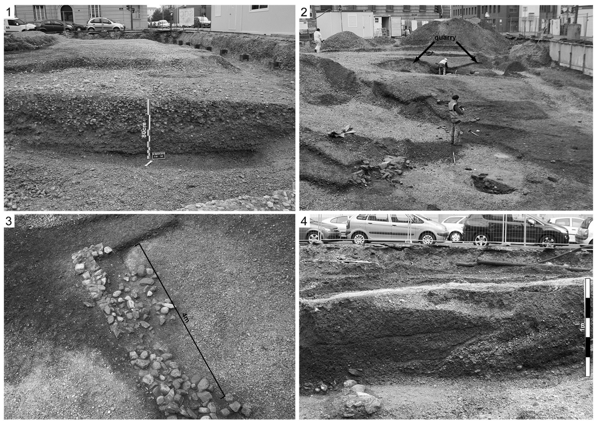

Fig. 2. Excavation: a) stratigraphic section, showing the Würmian fluvio-glacial deposits; b) gravel and pebble quarry, dug between the 1st and 3rd century AD; c) 8th-century building remains; d) late-medieval agricultural ground.

The site where the humans settled was a Würmian terrace built with fluvio-glacial deposits from the Alps, made of sands, pebbles and few silts (fig. 2a). An OSL dating, a method that proved effective in glacial contexts (Lewis *et al*. 2009) gave an age of 40,000 BP for this formation (Bouvard *et al*. 2015). It is just at the limit of the Rhône alluvial plain (Macé *et al.* 1993; Bravard *et al.* 1997), and was preserved from the floods. Indeed, one of the last big inundations in Lyon, in 1856, extended up

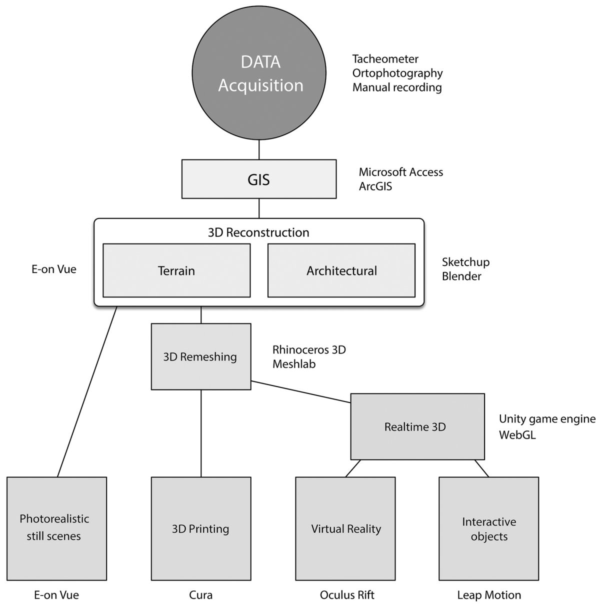

Fig. 3. Full workflow, from the field data acquisition to the multiple physical or digital outputs.

to the western limit of the plot but did not flood it (Combe 2007). The terrace was dug by human hand in two sectors of the plot (Fig. 2b). We interpreted them as two possible quarry faces made to extract building material (to make mortar, or create a road, for instance). It took place between the 1st and the 3rd century AD. Then, during the beginning of the Middle Ages, a posthole dwelling was built, quite small in scale, within the indentation made by the largest Roman quarry face (6th-7th c. AD); during the 7th or 8th century, a backfill made of funerary antique remains filled the hemispherical digging work; at the same time a second dwelling stronger than the first was built with a postament made of stones, Roman bricks and clay (fig.2c). Nothing remains from the recent periods except a thick (up to 2 m) agricultural soil made of organic earth which covers all the plot up to the 20th century ground (Fig. 2d).

2 Methods

Our initial goal was the 3D printing of each important individual stratigraphic layer and structure at one of the local FabLabs of Lyon (La Fabrique d'Objets Libres), in order to create a model that could be taken into pieces. Manipulating virtual objects and exploring the site in virtual reality were extensions of this first purpose. Unfortunately, the virtual reality application could not be ready in time for the 2014 science festival, but has been achieved since.

A complete 3D restitution of the site was needed for both purposes. This encompassed both the stratigraphic/topographic and architectural aspects, for which we used a multi-step process that we summarised in Fig. 3.

[Insert Fig. 3]

2.1 Stratigraphic reconstruction

The stratigraphic reconstruction was a complex process that could only be achieved with a combination of various pieces software and tools. Three steps can be individualized.

2.1.1 Terrain data acquisition

The first step was the acquisition of terrain data. An extensive set of control points was needed in order to create altitude isosurfaces (digital elevation models, DEM) for each stratigraphic layer. We chose not to represent each individual layer, but instead to focus on the most significant ones according to the following criteria: on the one side the periods with the greatest layers (the ancient topography and its gravel quarry, and the topography at the beginning of the modern period, which is characterized by a very thick layer of agricultural soil), and on the other side the less obvious features that had, however, significant meaning in this precise excavation (the natural landscape before the anthropic impacts, which is a state that could not be observed directly, and the medieval infill of the 8th century AD that contained ancient cremation remains).

A microtopography survey was conducted during the excavation. At every noticeable stripping phase, numerous control points were acquired, using a total station. Each point was defined both by its xyz position and by its corresponding stratigraphic layer. Since a stratigraphy is also in a way chronological information after it has been interpreted, control point attributes in fact contained 4D data (localisation + deposition period). This set of microtopography points was completed afterwards with additional control points extracted from the stratigraphic section drawings that were georeferenced in ArcGIS. Our final dataset contained about 300 control points, with a varying density according to the complexity of the terrain (the more complex the stratigraphy in an area, the more points were acquired and processed for this area).

2.1.2 Topographic restitution

The restitution of each period's topography was made with the 3D analysis module of the GIS software ArcGIS. At this step corrections had to be made several times. We had to add further control points to refine the digital elevation models. This additional data was obtained from the stratigraphic sections. We were particularly careful about the areas where the stratigraphy had not changed between two periods. For instance, the 8th century topography only differs from the ancient topography in the quarry area, whereas the remainder of the topography had to be identical. The parameters we provided to the kriging engine were thus critical in obtaining correct interpolations. The three elevation models (ancient, 8th century and late medieval/modern) that we obtained were extremely close to what we observed in the field and in the stratigraphic sections drawings.

The pre-anthropic landscape was the most difficult part of the restitution. Since it had been deeply incised by the quarry, its original shape could not be observed and measured directly. We thus had to reimagine its potential configuration. For this, we used the ancient topography dataset and removed from the interpolation all the control points that could only have been the result of direct human impact. The geomorphological expertise allowed us to discriminate features that could have been the result of natural processes (streams, erosion) from the anthropic-exclusive processes (i.e. quarry diggings). The result was an altitude surface that was the likely topography before human occupation, which was the last elevation model needed for our work (Fig. 4). Obviously this remains a hypothesis that cannot be proven with absolute certainty, but the resulting DEM

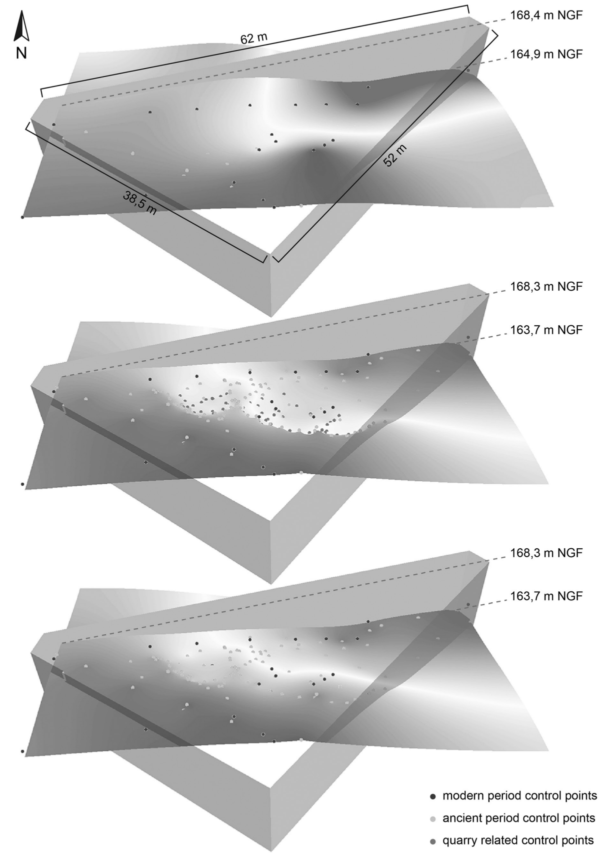

Fig. 4. GIS palaeotopographic modelling: a) topography at the beginning of the modern period; b) ancient topography; c) reconstruction of the pre-anthropic topography.

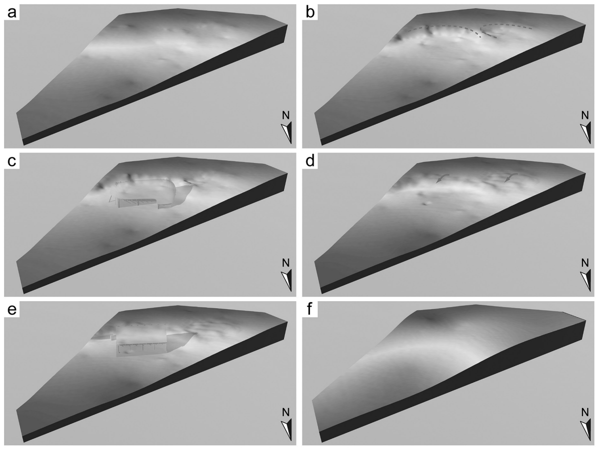

Fig. 5. Period by period volumetric restitution, incorporating the buildings: a) pre-anthropic topography; b) alteration of the landscape during the ancient period caused by quarrying (underlined in red); c) first medieval settlement (7th century); d) filling of the quarries by ancient cremation remains; e) second Middle Age settlement (8th century); f) end of Middle Age/beginning of the modern period: formation of agricultural soils.

is highly plausible. From a methodological standpoint, this process is also a shift from the restitution to the reconstruction.

2.1.3 Volumetric modelling

However, the 2.5D digital elevation models we obtained were insufficient for our purposes, which included computing the volume of gravel that had been extracted from the reconstructed natural landscape by the quarriers, as well as producing 3D prints of the stratigraphy.

The elevation models were thus imported in 3D modelling software (E-on Vue Studio), where they were used as displacement maps on special 2.5D planes ('terrains'). These terrains were converted into 3D polygonal meshes in order to create actual three-dimensional bodies (Fig. 5). The 3D software we used did not manage georeferenced data, and we therefore had to drop this spatial information. However, we preserved the size and relative positioning of objects (stratigraphical layers in our case), allowing us to keep working in a 1:1 scale environment.

Boolean operations were then conducted on the meshes to obtain a series of 3D volumes, each representing one stratigraphic unit. E-on Vue proved to be the most efficient software at our disposal to manage these computations on complex meshes. Another advantage of Vue was its 'ecopainter' and vegetation engines. This module allows the constitution of realistic ecosystems in a minimal time, an aspect we needed in order to produce a few realistic still images for the posters that would accompany the workshops. The manifoldness and 'normals' alignment of our meshes were checked and adjusted in Meshlab and Rhinoceros 3D to ensure their proper export to 3D printers.

2.2 Architectural reconstruction

The reconstruction of the two houses was closer to a regular 3D modelling process. Since several kinds of products were envisioned with different requirements in terms of resolution, file size, etc., we had to produce different models with varying degrees of details. We chose to first create high-resolution buildings, aimed at being textured in E-on Vue for photorealistic rendering. These models would then be degraded for the other applications (3D printing and real-time rendering).

2.2.1 High-resolution reconstructions

The few archaeological insights we had (some postholes for the 7th-century building, and remains of the stone base for the 8th century one) were imported as a 1:1 floor plan in Sketchup. We then built the elevations from this plan. We referred to existing literature about constructions of the early Middle Ages (Faure-Boucharlat 2001; Gentilli and Lefevre 2009), as well as remaining wood and mud traditional housing to build our houses. Several hypotheses were tested for the 7th-century building, as we were trying for the most realistic configuration: on one hand we were not certain if some postholes belonged to the house, and on the other it was clear that some other postholes had obviously not been discovered during the excavation.

Since both dwellings were extremely simple structures, advanced architectural techniques such as architectonics or material resistance were deemed not necessary. The

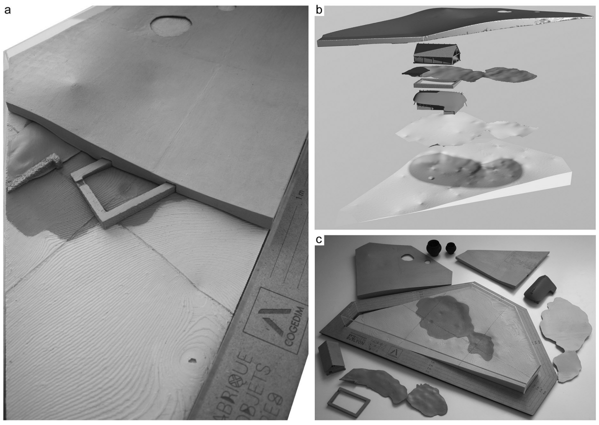

FIG. 6. 3D PRINTED 1:100 SCALE MODEL: A) ASSEMBLED STRATIGRAPHIC CROSS-SECTION; B) DIGITAL RENDERING OF THE PIECES AS AN EXPLODED VIEW; C) COMPLETE SET OF PRINTED PIECES.

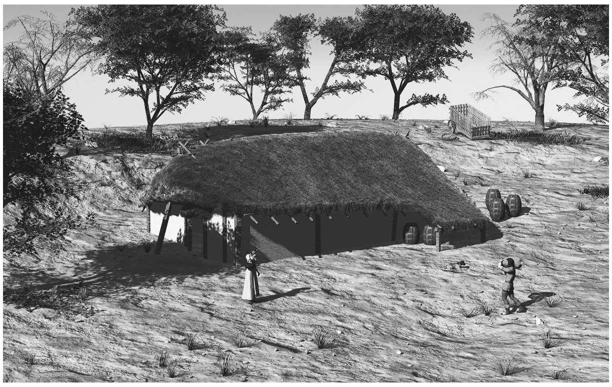

FIG. 7. HYPOTHETICAL RENDERING OF THE 7TH-CENTURY DWELLING AND LANDSCAPE.

simple Sketchup models were imported in Blender for some enhancements (for example the thatched roofs could not be modelled properly in Sketchup).

2.2.2 Low-resolution reconstructions

The file size of the high definition buildings, as well as its many small elements and complex shapes, made it difficult to render in real-time on low-to-middle end hardware. We decimated this model in Blender in order to obtain a more manageable file that could be used in WebGL applications or in game engines.

2.2.3 Creating a 'printable' file

Creating a printable file proved to be another challenge. Since we wished to print our houses at a 1:100 scale, many elements would prove too small for the printer's resolution. The walls themselves would have been only 2mm thick, resulting in a very flimsy model, a problem considering that it was supposed to be handled by the public. We had to increase slightly the thickness of the walls and roofs to get clean and sturdy prints. Also, because we could not rely on displacement or bump maps to simulate the details of the stone walls or of the roof straw, we needed to add real three-dimensional reliefs to the buildings. The details that we wanted to see on the real-life model had to be there in the mesh. Voronoï filters were applied to the basement walls of the 8th-century building to simulate the individual stones, and gaussian noise was added to the roofs. Finally, all the separated pieces of the buildings were merged into a single mesh for each house, to ease the exporting in the 3D printer software.

2.3 Realistic rendering, 3D printing and virtual simulations

Printing a scale model was the main goal, but we were confronted with a basic obstacle: the size of the model. We settled on a 1:100 scale model of the site, which was large enough for people to gather around and have a good view of the items and still allow its easy transport and storage. We had to split the larger stratigraphic layers into several blocks, since the low-cost 3D printers we had access to did not allow us to produce parts larger than a 20 cm cube. This in turn led to a further series of controls and adjustments of the meshes. This part of the work saw a close collaboration between the makers of the FabLab and the archaeologists. The cleaned objects were imported into the Cura software used to interface with the Ultimaker 3D printers. Five full days were needed for the printers to complete the production of the pieces. Some of them were then glued back together to ensure easy handling. The finished product comprised four stratigraphic layers which adjusted within each other, the few archaeological remains of the houses that we discovered, and the reconstruction of these dwellings. Each block has a distinctive colour, one for each period (fig. 6). Finishing the model also implied a few small manual interventions (sanding, paint touch-ups) and finally adding an MDF and Plexiglas base.

The high definition architectural reconstructions were imported and textured in Eon-Vue. Since our objective here was realism and not real-time rendering, we used advanced procedural textures, many of them incorporating displacement maps (for example for the stone walls of the dwellings, or for the roofing, for which we used vegetation to simulate the thatched roofs). Vegetation was added using the 'ecopainter' engine of the software. We then created a few realistic still images in high resolution of the potential landscapes at the 7th and 8th centuries (fig. 7). Unfortunately, we were not able to produce quality videos because of the time needed to render a single full frame on consumer grade hardware (6 to 8 hours).

The terrains produced by E-on Vue were also imported, in combination with the low definition architectural reconstructions in the Unity Engine, in order to develop a basic virtual reality application (Fig. 8). Textures were added, this time using techniques closer to what is used in game design to ensure good real-time performances, such as normal mapping (more precisely bump mapping), so as to simulate details on the walls and roofs of the buildings. Only the largest vegetation elements (trees) were 3D objects. We used bill-boarded textures for the grass. Wind was added to enliven to the scenes and animate the moving objects (vegetation, smoke). The Oculus SDK allowed us to implement a FPS-like ('first person shooter') control scheme that would be compatible with Oculus Rift VR goggles (DK2). Our application also allows the player to switch at anytime during the simulation between the four historic periods we chose to represent to experience the site's evolution: pre-anthropic landscape, ancient quarry, 7th-century

Fig. 8. Real-time rendering of the 8th-century house in the Unity engine: a) the original landscape before human intervention; b) the landscape modified by the quarry; c) the 7th-century posthole dwelling at an early construction stage; d) the 8th-century house, built on its strong base.

settlement, 8th-century settlement. It is also possible to use the application on screen, like a regular virtual visit, without VR goggles.

Finally, the low definition architectural models, an exploded view of the scale model, as well as some 3D models of archaeological objects, like medieval cooking pots that were found on the site and reconstructed from their shards, were converted to be used in conjunction with the Three.js WebGL javascript library in a web browser. We also used the Leap.js, a library that interfaces the Leap Motion (an infrared motion sensor) with WebGL content.

3 Results

3.1 The archaeological research perspective: what does 3D bring?

One of the archaeological results relates to the quarry: thanks to GIS and the 3D volumetric meshes, we could calculate the amount of sand and pebbles extracted from the Würmian terrace during the beginning of the Roman period. Because we were manipulating real-size volumes after the reconstruction, we could find the amount of gravel (118 m^3) extracted from the quarry by simply querying the software. This gravel is similar to the one used to construct the Roman road recognized near our plot. If we imagine that we have discovered one of the places where the Romans stockpiled gravel it is possible to calculate the length of road they could have laid. Our figures revealed that they could have built 100m of road, 5.80m wide and 0.20m thick.

Moreover, we could visualize how anthropic settlements evolved in the landscape, adapting themselves to the special topography of the terrace, the slope and the quarry. The medieval dwellings, the remains of which were very scarce (22 holes for the oldest, and a fragment of a rectangular stone base for another), needed 3D reconstructions to check our configuration hypotheses. And indeed, the 3D approach brought out several discrepancies that we could correct. These would have remained unseen with a standard 2D perspective drawing. It also helped us in choosing between several configurations for the buildings.

3.2 The educational perspective: workshop unrolling

Audiences (groups or individuals) were invited to discover not only the history of the archaeological site through the scale model, but also to understand how we created it. The use of 3D tools applied to archaeology was as important as the site itself. For many of the people who visited us, 3D printing and 3D modelling were completely new. This is why the workshops were designed from the beginning to be dialogues between ‘makers’ and archaeologists, and it was this feature that made the events successful (around 350 people and pupils came to the workshops over 3 days).

Posters and an informative booklet were provided to help in understanding the evolution of the settlement, as well as the restitution process, and archaeologists and makers were also on hand to answer questions.

The ‘historical’ component of the workshop revolved around the scale model that was exhibited and available for manipulation. When school classes visited, the archaeologists and teachers handled the model themselves. The model could be used by the public in two ways. Disassembling the layers one by one, the subsoil could be explored as an archaeologist does during an excavation. Alternatively, if one starts to assemble the scale model from the first layer, it is possible to apprehend the evolution of the landscape from the Würm to the current period. Moreover, it is possible 'to dig' (i.e. remove), only half of a layer so we can see the stratification between sedimentary and anthropic deposits (fig.6a). This allows an easy understanding of the main principles of stratigraphy: why are the older layers below, what is sedimentary accretion, why are the remains of ancient buildings buried, etc. Of course, these are all aspects that are obvious to archaeologists, but not so easily interpreted by the general public and school children.

The 'computing' component of the workshop, undertaken in collaboration with the makers of the FabLab, presented the reconstruction of a medieval cooking pot in real time: a shard found in the excavation was presented; its profile was then drawn on a laptop before being imported, reconstructed and converted into a virtual object in 3D software (Blender). A 3D printer then reproduced it at a scale of 1:20 in real time, while the finished virtual reproduction could be manipulated contactless thanks to the Leap Motion controller. All school classes, as well as a few other visitors, would then keep the small printed pottery reproduction as a souvenir along with the workshop's booklet.

4 Discussion

'Archaeology in plastic' was the title of the workshop, intended as a dialogue between past and present, false and true relics. It was a way to bridge the gap – associating new technologies and human sciences can sound like forced marriage to many. However, we demonstrated that this association can be beneficial for both archaeological research and cultural mediation. The fact that a single initial set of data can be converted into several media, both digital and physical, while preserving their scientific objectivity, is remarkable.

3D printing has taken a long time to reach archaeological studies and museums. It is 30 years old now (Hull 1986; Lipson & Kurman 2013) – and it is time for humanities to give it a try. This tool, invented to make industrial prototypes (Chua *et al*. 2003), is now being used for many more purposes, including cultural education, especially to produce replicas of archaeological artefacts, and in general for museography (Chaumier and Françoise 2014). It is definitely a do-it-yourself approach, because it is now low-cost and readily available. Much software is now open-source, and tutorials are easy to come by (Schelly *et al.* 2015).

Concerning the interactive virtual media, many enhancements have to be made to this first experiment to provide a better educational experience. The Leap Motion controlled objects were, in the case of the dwellings, very simplified models of real houses. More detailed models are needed (a compromise has to be found between realism and performance) and they have to be completed by informative conventional media (texts, pictures, etc.). During the science festival, no other content or explanation was provided with it. Thus, the presence of an archaeologist was needed to provide relevant information to the public. As it was, the application was more of a technological demonstration than a complete, standalone educational product. This was also the case for the Oculus Rift VR simulation, which has not been widely tested yet. We also have to remember that these kinds of human/computer interaction systems are still nascent. The ease of implementation of these tools is getting better every day, and we are convinced that they will have a huge impact on scientific mediation. Improving the quality of the simulations by adding more realistic textures and interactive characters is also becoming easier thanks to more powerful hardware. A realistic soundscape can also hugely enhance the virtual simulations (Pardoen 2015). Finally, the development of APIs (i.e. WebGL), allows content as rich as this to be hosted online.

The integration of 3D within the archaeological research process can also bring benefits: better understanding of complex stratigraphy, testing and validating hypotheses, etc. One of the limits of our approach was the disappearance of all metadata when we transferred from GIS to 3D modelling software. A fully 3D GIS would solve this issue, but, at the moment, we could not find a single piece of software encompassing all the features we needed, despite this being a long running issue (De la Losa and Cervelle 1999). Geologic modelling software, on the other hand, does provide full capacity for 3D stratigraphic modelling, but it is harder to integrate with archaeological research workflow (Apel 2006).

Setting up this project took approximately 40 days (to which we must add the printing phase, an additional 5 days, but most of it being purely machine time). Considering that this was a first experiment, we advanced a lot by trial and error. The process has since been established, tested and validated, and even if further refinements are needed, we could now probably reduce this time by a considerable amount. We also must not forget that the scale model can be reused for further exhibitions, and that the digital media can be improved, thus increasing their value.

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