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Digital Çatalhöyük: A cyber-archaeological approach

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This chapter reports the results of a multifaceted research initiative that carried out digital experiments and explored the applications of three-dimensional spatial data recording, simulation and visualization of the Neolithic site of Çatalhöyük in the period 2010–2015, thanks to a collaboration between Duke University, the University of California, Merced, and Lund University. The theoretical-methodological approach adopted followed the principles of cyberarchaeology (Forte 2010a, 2015), a subdiscipline that finds its core research questions in the creation of real-time data simulations and in the interaction between users and virtual environments. Applying that logic, our initiative focused on the virtualization of the single-context method of excavation (layer by layer), on 3D geographic-information-system data, on the implementation of digital collaborative systems (teleimmersion) and on virtual-reality software for data curation.

The first half of the chapter discusses technologies of data acquisition, analysis and data modelling, while the second half focuses on technologies of visualization and data curation, including the Dig@IT software developed specifically for Çatalhöyük. In short, this chapter provides a detailed discussion of the research questions asked and results obtained by the 3D Digging Project at Çatalhöyük and how they led to a diverse digital output in the form of 3D data collections and advanced visualization systems.

Introduction

Cyberarchaeology is a domain of archaeological research devoted to the digital simulation of multimodal and three-dimensional archaeological data (Forte 2010b, 2015; Forte et al. 2015). It recalls the ecological cybernetics approach based on the informative modelling of organism-environment relationships, with the difference that the environment in this case is a virtual one. This approach requires the study of multimodal simulation models based on archaeological datasets drawing on different areas of knowledge. The 'cybernetic' factor can be measured by recording data on interaction and feedback, where the 'trigger' for data collection is the gate through which we become embodied in the cyberworld: clicking, triggering, and interacting are how we involve our minds in a digital domain. Data and models generate new data and meanings through user interaction and through collaborative activities, because different users, for example, might have different research perspectives. The study of users' interpretative code is essential for re-analysing the digital process in light of a cybernetic perspective: the feedback created by different interactors operating in the same environment or ecosystem generates further feedback and not predetermined interconnections. While virtual archaeology is mainly visual, static and graphically oriented to photorealism, tending to forestall interaction by conveying the idea of a predefined corpus of knowledge, cyberarchaeology is not purely visual but rather interactive, dynamically complex and autopoietic (Forte 2015). It focuses on the potentiality or virtuality of the interpretation as opposed to the actuality of the physical world.

Digital tools of data recording, such as laser scanners and image-based modelling, generate massive amounts of 3D data in real time both in time and space – in short, big data. In light of this fact, fundamental scientific questions arise in the archaeological domain, questions that cyberarchaeology seeks to address. Key project objectives in cyberarchaeology are 1) to apply new digital techniques of data recording to archaeological excavations and artefacts, exploring methods for handling 3D big data; 2) to create interactive analytical tools for proper data mining of 3D big data and for building realistic 3D worlds; 3) to create virtual excavation case studies based on data harvested from archaeological sites; and 4) to explore those virtual sites collaboratively in fully immersive environments. These were our objectives at the beginning of the project.

The digital work conducted in labs and in the field at Çatalhöyük between 2010 and 2015 and discussed in this chapter included several experiments in data recording ('3D digging'), collaborative visualization (teleimmersive archaeology), digital data curation and simulation in virtual reality environments (e.g., Dig@IT and the Duke Immersive Virtual Environment). This work represents a substantial effort to simultaneously coordinate and evaluate different methods belonging to the cyberarchaeology workflow (e.g., data capture, analysis, curation and dissemination) and to test innovative systems of virtual interaction and visual narration.

Because of the relatively long timeframe of our initiative, the technology used in the applications we developed at Çatalhöyük reflects the state of the art at that moment in time. Significant changes in cyberarchaeological methods and technology occurred between 2010 and 2015. This chapter discusses how this evolution in our field was reflected in our work at Çatalhöyük. The amount of digital data we produced in this period is impressive: thousands of 3D models (at micro- and macroscale), 3D geographic information systems, a dedicated teleimmersive collaborative system and a new virtual-reality software platform for data curation (Dig@IT).

Our application of digital methods for data capture and analysis focussed on the introduction of 3D techniques of data recording (Forte, 2014b; Berggren et al. 2015) and, later, on the advanced use of different simulation and visualization systems for multimodal data interaction. Therefore, our initial strategy was to choose a Neolithic house as a test case for proving that the cybermethods proposed (e.g., structure from motion, laser scanning, 3D geographic information systems) were a good fit for the documentation methodology used at Çatalhöyük. Building 89 (B.89), in the South Area, was chosen as the ideal case because of its state of preservation, intact stratigraphy, chronological sequence and spatial features.

The systematic use of both structure-from-motion photogrammetric technology (digital photogrammetry in a broad sense) and terrestrial laser scanning represents a significant innovation in how the excavation of B.89 was documented in this project. Structure-from-motion

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digital photogrammetry creates textured triangular-mesh 3D models describing the surfaces and colours of archaeological contexts, while laser scanning produces point clouds. In the first case, the 3D data can be entered into and processed by spatial technologies and virtual-reality systems with great ease; in the second case, point clouds need to be further processed to become usable in virtual-reality or geographic-information systems, as these systems only accept 3D data in the form of triangular mesh. The goal of our experiment was to field-test and compare these two methods. Digital photogrammetry can be very time-consuming for large-scale projects (unless integrated with mapping by drones), but on the other hand, it can be very effective in relatively small spatial contexts, such as a Neolithic house (see the '3D Digging' section below). Terrestrial laser scanning produces incredibly accurate data but requires time-consuming data processing in the lab.

The availability of such a large amount of 3D data enabled us to ask important research questions concerning usability, access and the modality of interactions and to achieve several different research goals. The overarching aim of our work at Çatalhöyük was not to achieve a complete standardisation of the digital workflow, but rather to experiment with new modalities of data interaction and interpretation. A particularly revolutionary aspect was the systematic 3D digital recording of all the stratigraphic units of Building 89 and the immersive visualization of the corresponding dataset. This approach shifts the study of spatial data from the usual 2D mapping to a fully 3D volumetric archive, with the ability to see strata in transparency and finds in their XYZ position.

Building 89

Building 89 (East Mound, South Area; fig. 7.1) was our main case study for the implementation of an excavation workflow coupled with 3D digital recording in the years 2011-2015. It is situated in the southeast corner of the South Area, in sequence directly under B.76. It is a large square structure, 5.80m north-south by 5.20m east-west, with platforms (and burial sequences) situated along the northern and eastern walls, hearths and dirty floors in the southern half of the central space, a possible partitioned storage zone on the western side of the structure, and a number of post scars and retrieval pits. It was originally richly decorated, since there are several traces of the removal of decorative architectural elements and red paintings (Forte et al.2015). The systematic 3D recording of all the stratigraphic layers allows a complete reconstruction of all the phases of excavation and the 3D contextualization of finds. The digital documentation, together with the study of soil samples, identified a stratigraphic sequence of about 60 plastered floors, which very likely correspond to the entire life of the house. These floors were sealed on their eastern side by a 5mm-thick compound layer of light grey silty clay and white clay plaster floor surface, which extended all the way across the east central platform of the space.

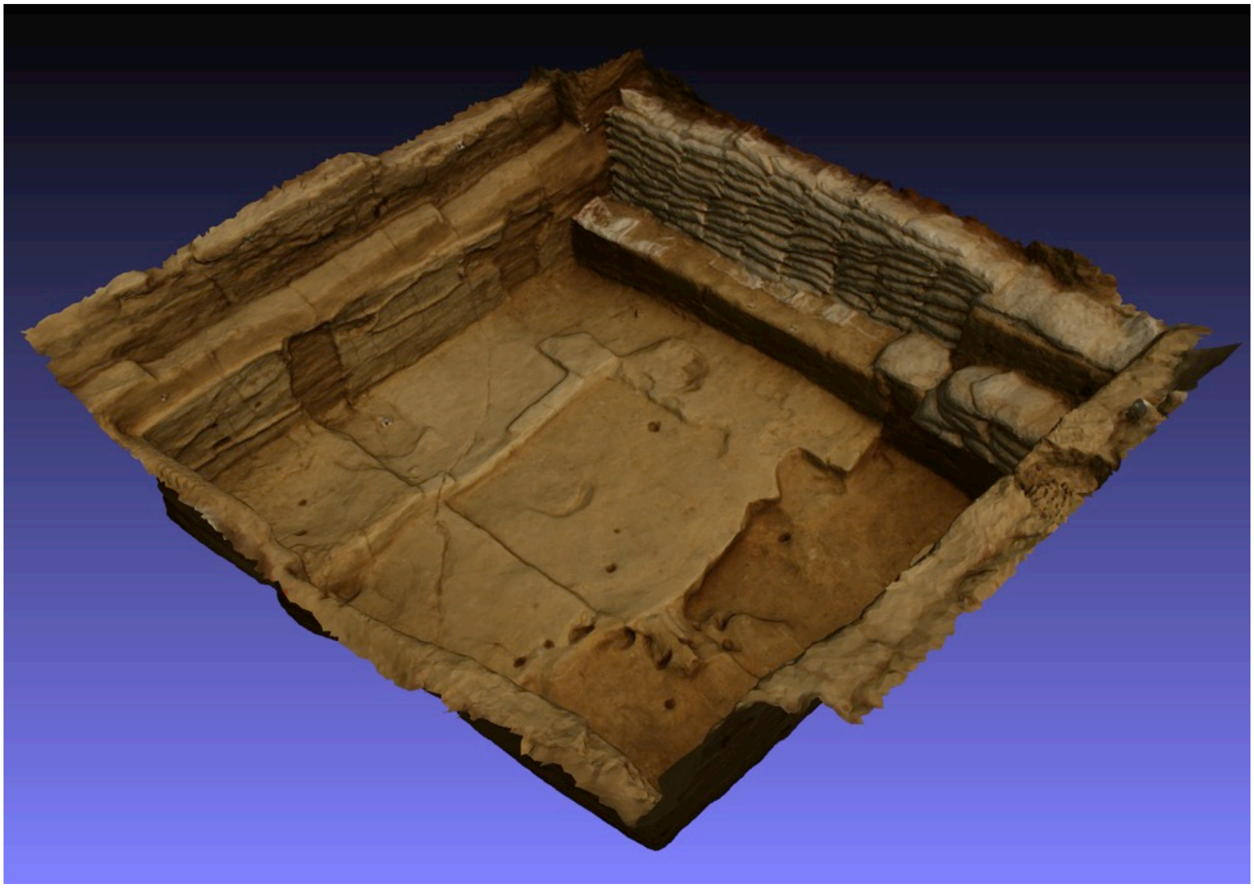

Figure 7.1. 3D visualisation of B.89 by digital photogrammetry (for 3D version, see online supplementary material).

One of the most interesting finds in this structure was a bucranium, which was found to be embedded at the western limits of the main floor sequence of the building's central space. In addition, a possible case of ritual embodiment was represented by a human mandible decorated with plaster and red pigment found in a retrieval pit near the house's northeast platform (Forte et al. 2015). The mandible was presumably attached to a similarly modified cranium and then resituated in a ritual space. This find was also digitally recorded by optical scanners and printed in 3D.

Our first experiments in virtual simulation using data from B.89 were also able to show the potential of this interpretative approach. For example, visualization of Unit 19807 (a moulded architectural element) using the computer graphics visual effect X-Ray in MeshLab shows the relationships among room infill, the walls and other architectural decorations (fig. 7.2; Forte et al. 2015).

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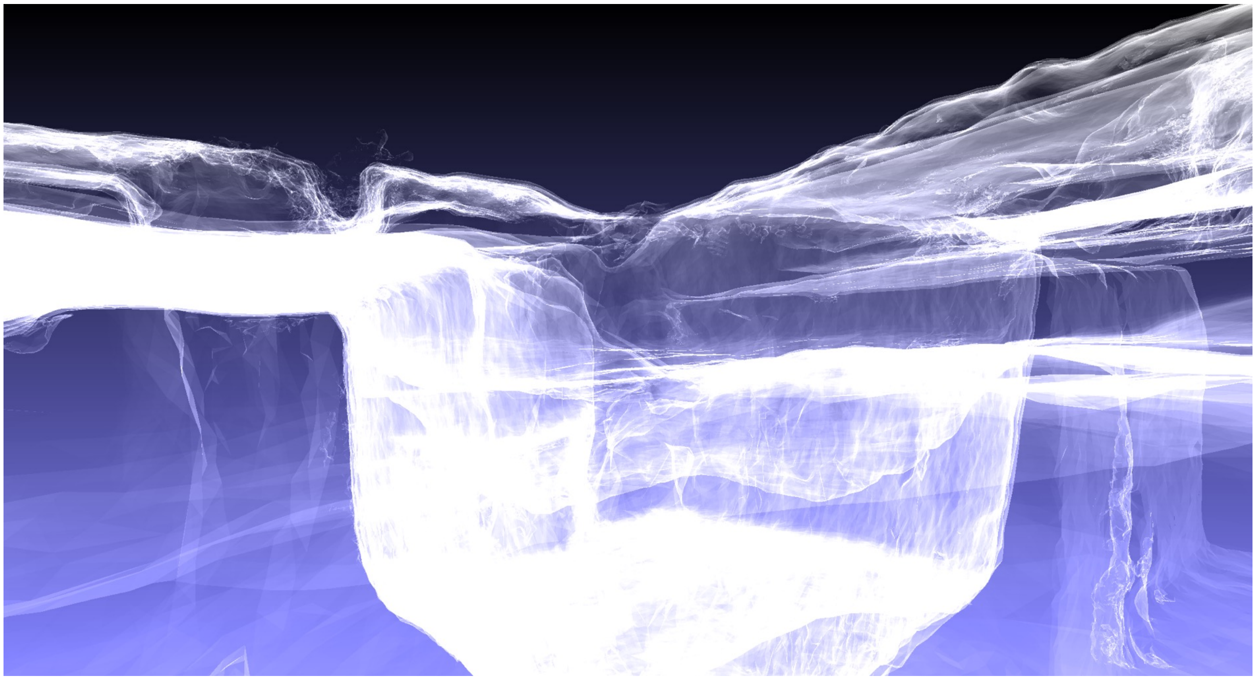

Figure 7.2. X-ray shaded view of a moulded architectural element collapsed in the middle of the stratigraphic infill.

3D Digging

The 3D Digging at Çatalhöyük Project started in 2010 with the aim of establishing a robust research protocol or workflow for recording every single phase of excavation in 3D using different technologies such as laser scanning and digital photogrammetry (image modelling, shape from motion). We mainly focussed on two case studies: a midden area (Space 376) and Building 89. We also introduced 3D stereo visualization systems during the archaeological fieldwork in order to make it possible to interact with 3D models during the excavation period itself.

In the project's initial, preliminary phase, we had to compare different kinds of laser scanners (based on different technologies with different specifications) in order to evaluate their performance in relation to the project goals (see table 7.1).

Laser scanner	**Scan range (depth of field)**	**Accuracy**	**Intended use**	**Field of view**	**Scanning speed**
Minolta 910 (optical)	0.6 to 2.5m	X:±0.22mm Y: ±0.16mm Z: ±0.10mm	Microscale data recording, microstratigraphy	TELE: Focal distance f=25mm MIDDLE: Focal distance f=14mm WIDE: Focal distance f=8mm	307,000 points per second
Trimble GX (time of flight)	350m with 90% surface reflectivity 200m with 35% surface reflectivity 155m with 18% surface reflectivity	position = 12mm at 100m distance = 7mm at 100m	Midscale data recording, macrostructures	360° x 60°	up to 5000 points per second
Trimble FX (phase shift)	1 pass: up to 60m with 50% surface reflectivity 35m with 30% surface reflectivity 2 passes: up to 80m with 50% surface reflectivity 45m with 30% surface reflexivity	0.4mm at 11m 0.8mm at 21m 2mm at 50m	Macroscale data recording, architectural structures	360° x 270°	216,000 points per second
Faro Focus 3D (phase shift)	0.6m to 120m	at 10m, raw data: 0.6mm with 90% surface reflectivity 1.2mm with 10% surface reflectivity at 10m, noise compressed: 0.3mm with 90% surface reflectivity 0.6mm with 10% surface reflectivity at 25m, raw data: 0.95mm with 90% surface reflectivity 2.2mm with 10% surface reflectivity at 25m, noise compressed: 0.5mm with 90% surface reflectivity 1.1mm with 10% surface reflectivity	Large-scale data recording, architectural structures	Vertical: 305° Horizontal: 360°	122,000 / 244,000 / 488,000 / 976,000 points per second
NextEngine (optical)	0.50m	± 0.127 mm in macro mode ±0.381 mm in wide mode	Microscale data recording, small objects	12.95 cm x 9.65 cm in macro mode 34.29 cm x 25.65 cm in wide mode	50,000 processed points per second

Table 7.1. Specifications of different laser scanners.

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Our main questions had to do with the level of accuracy and scale of representation of the different scanner models. Optical and time-of-flight scanners, in fact, have different performance and technical features. The optical ones work in a range of microns, while time-of-flight ones work in a range of mm/cm. Optical scanners are thus able to record stratigraphic surface details and micromorphologies that are not visible to the naked eye or by other means. For archaeological stratigraphy we tested the Minolta 910 (optical), Trimble GX (time of flight), Trimble FX (phase shift), Faro Focus 3D (phase shift) and NextEngine (optical).

In our first experiment in 2010 (Forte, 2010a), we used the Minolta 910 to record all the excavation layers in a midden area (Building 86, Space 344, 329, 445). Midden areas at Çatalhöyük correspond to accumulations of rubbish outside the living areas and can reflect a variety of social or collective activities with different purposes (construction, dedicated locations for rubbish disposal, etc. Shillito et al. 2011). The initial idea was to use an optical-triangulation scanner (Minolta 910) for stratigraphy in order to visualize and better study the microlayers, since they are not easily identifiable at scales below the visible. The 3D visualization of this midden area by optical laser scanning created a very detailed characterisation of the layers – perhaps too detailed. The downside of this augmented visual information was that the microscratches made by archaeological trowels were also visible, potentially compromising the identification of original anthropic micromorphologies.

Consequently, in 2011 we adopted two systems working simultaneously for data recording: a new phase-shift scanner (Trimble FX) and a suite of camera-based digital-photogrammetry and image-modelling software (PhotoScan, Stereoscan and Meshlab; see the 'Digital Photogrammetry and 3D Geographic Information Systems' section below). The Trimble FX is a phase-shift scanner able to generate 216,000 points per second and with a 360° x 270° field of view, and it proved to be a very fast and effective scanner with the capacity to generate meshes during data recording. Every data-capture session was very quick and effective: about 15 to 20 minutes for digital photogrammetry, laser scanning and drawing by tablet. By the end of the season, we had recorded eight different phases of excavation using both methods.

In addition, the systematic use of structure-from-motion photogrammetric technology for data recording of burials was extremely successful for the osteologists' team. For example, it was possible to reconstruct complicated sequences of multiple burials under the house floor and skull-retrieval pits (Haddow et al. 2013). 3D data recording and visualization were able to show hidden connections among the skeletons, which are not visible in 2D maps. Indeed, in 2012 it was possible to record and reconstruct in 3D 21 burials, in addition to the related 2D drawing of the skeletons and other features. In this case, the digital workflow involved digital photogrammetry for the generation of 3D models, 2D and 3D georectification, 2D drawing of the burials in CAD and finally their implementation in ArcGIS as digital maps (raster-vector) and 3D models (3ds).

This new ‘3D digging’ approach also introduced new research questions: Are we able to identify additional or different stratigraphic relationships? Does the Harris Matrix also work successfully in a 3D visual sequence of data (fig. 7.3)?

Can we successfully replicate the excavation in a digital environment? What do we learn from a virtual excavation? For example, a stratigraphic structure might manifest relationships and affordances in its original context (the ancient one) but also in the sphere of excavation where archaeologists operate (the empirical one). The interpretative challenge in this process is the comparison between the graphic realism of 3D data (stratigraphy, monumental structures, finds) and the schematic layout of vector and spatial georeferenced data.

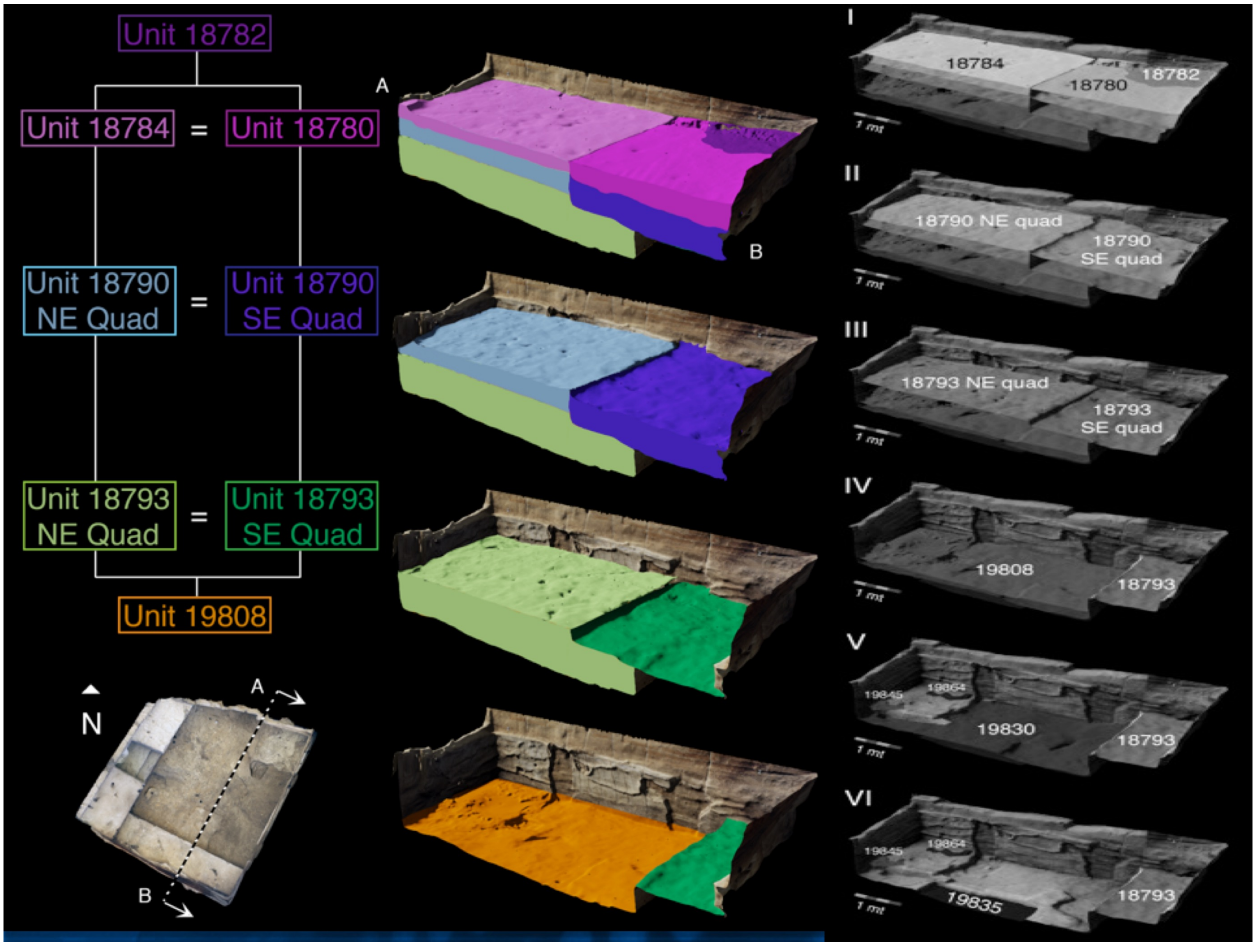

Figure 7.3. Three-dimensional visualisation of the archaeological stratigraphy of B.89 and related Harris matrix.

In the first case, the simulation is finalized for gaming engines or virtual-reality devices (head-mounted displays); in the second case, for spatial analysis and digital image processing. The main purpose of generating multiple digital simulations of an archaeological excavation is to study the relationships between information units (layers and structures) and empirical observation (traditional photos, videos, field notes). In other words, the goal is to study the

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interaction between the empirical experience of digging and the interpretative postprocessing work (documentation, description, reconstruction).

This approach was able, in a relatively short time, to change the documentation methods on site, by standardising a template of digital recording and ultimately by the introduction of a complete paperless system (on tablet PCs) on site (Berggren et al. 2015). 3D data recording on site combined different technologies such as optical, time-of-flight and phase-shift laser scanning and camera-based digital photogrammetry. Image-based modelling techniques were used at the intrasite or microscale level for data recording of buildings, layers, units, features and burials, while 3D laser scanning was used for large-scale excavation areas (the South, North, TPC, and GDN Areas) (Lercari 2019; Campiani et al. 2019).The bottleneck in this giant effort of digital recording, on the other hand, is ensuring the full accessibility of the datasets (big data) and metadata and the long-term sustainability of the project. On top of all that, a key question is the impact of different technologies, tools and devices on the interpretation and communication process. However, in 2015 the project was able to organise a 3D exhibit at the Stanford University Archaeology Center with the first examples of 3D data visualization and 3D prints of a selection of archaeological finds and human remains.

Digital Photogrammetry and 3D Geographic Information Systems

Structure-from-motion (SfM) photogrammetric technology (digital photogrammetry in a broad sense) is now recognised as a revolutionary tool in the field of 3D documentation in archaeology. Due to its versatility and low cost, SfM has been tested within the framework of several field investigation campaigns, being used most often to create georeferenced bidimensional orthoimages, 3D surface-textured models, and high-resolution dense point clouds. The introduction of this recording method in support of archaeological practice has made it possible to explore and analyse aspects of the information gathered that was previously impossible to be considered (Callieri et al. 2011; Forte et al. 2012; Dellepiane et al. 2013; De Reu et al. 2014; Optiz, Limp 2015; Dell’Unto 2016; Dell’Unto et al. 2017), opening up new scenarios in the field of spatial analysis (Dell’Unto 2020).

Starting in 2011, we carried out experiments within the framework of the 3D Digging Project to test the quality of these techniques for recording archaeological evidence. Initially, the main challenge was assessing the efficiency of these tools in generating sufficiently accurate 3D models within the framework of the excavation (Forte et al. 2012). The use of digital photogrammetry techniques for the documentation of such complex stratigraphy was not an easy task. If on the one hand it was possible to document – in three dimensions and with high accuracy – the complex stratigraphic relations that characterised Building 89, it was on the other hand no simple matter to manage such large 3D datasets. It was necessary to define rigid guidelines for their production and implementation.

Significant results were finally achieved during the 2013 field campaign, when the 3D textured models produced by SfM were imported into and visualized within the geographic information system in use on site. For the first time, it was possible to use the 3D models within the context of their spatial relations with the rest of the documentation produced during the field investigation. In the 3D Digging Project, we used ArcGIS, a geographic information system developed by ESRI for managing spatial data. Among the different GIS platforms available, ArcGIS was one of the first to allow users to manage and visualize georeferenced 3D textured models. This platform takes advantage of a fast rendering speed to make it possible to review the archaeological data recorded in the field in a 3D environment. Through this 3D geographic information system, it was possible to create real-time simulations combining contexts and features detected and exposed across different investigation campaigns. This provided the team with the opportunity to gain an overview of the actions undertaken over the years and keep reasonable control of the diachronic sequence of the contexts detected during the field campaign. In addition, despite the limits of 3D geographic information systems in editing the 3D information, it was possible to test a system for annotating directly onto the models the observations made during the field investigation.

The results of these experiments encouraged different specialists to adopt a similar documentation approach, producing material which could be merged directly into our datasets through the geodatabase. The 3D space available through the geographic information system provided the team with the opportunity to experience new ways of approaching archaeological datasets. The system proved to be a very efficient tool in support of field investigation, during which real-time simulations were created in aid of several discussions. Following our first experiments in Building 89, SfM techniques were adopted by the Çatalhöyük Research Project excavation team for documenting buildings, spaces and features investigated across the site. Several protocols were developed, and within a short time, a vast archive of georeferenced 3D models was created (Taylor et al. 2018).

Since their creation, the 3D models stored in the geodatabase have been employed by the team members in a wide variety of ways. An interesting example of their use occurred during the 2015 field season when a painted plastered head was retrieved in Building 132 (North Area). Due to its fragility, the head was removed before it could be analysed in spatial relationship with the rest of the building. For this reason, the excavation team used the archive of 3D models to identify old 3D versions of the building in which the feature was still visible. Among the different available versions, one model which contained the plastered head still in situ was found. The record was then imported into the 3D geographic information system and visualized in spatial relation with the 3D data produced after the removal of the feature. This operation made it possible to identify the correct orientation of the plastered head in relation to the contexts that were later identified by the excavators (Lingle et al. 2015). On several occasions, as well, the 3D geographic information system proved to be an excellent instrument for examining information in a nonlinear way, making the excavation process more reflexive (Berggren et al. 2015).

Laser Scanning for Stratigraphic Documentation

Terrestrial laser scanning (TLS) is a well-established non-contact metric survey technique that delivers high-fidelity 3D data about archaeological surfaces and built structures (Andrews et al.

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2009; Mills, Andrews 2011; Lercari 2016). One of the main goals of the 3D Digging Project was to assess the viability of TLS as a 3D documentation method able to enhance the stratigraphic record of a building. Although previous geomatics work involving TLS had been conducted at Çatalhöyük (Lees 2003; Forte 2010a), it was only in 2011 that a Trimble FX phase-shift laser scanner proved successful in the documentation of every stratigraphic layer of Building 89. Between 2011 and 2014 each layer excavated in B.89 was scanned several times from different positions to enable the generation of high-accuracy dense 3D point clouds (fig. 7.4). Additionally, the most significant phases of occupation of B.89 were also scanned in 2015 to provide final documentation of this building prior to the end of its excavation.

Given the positive results we obtained using the Trimble FX scanner in 2011, we continued documenting the stratigraphy of B.89 using a newer and more powerful FARO Focus 3D S120 scanner starting in 2012. The S120 is a powerful, portable, accurate non-touch measurement device suitable for midrange outdoor surveying, with a ranging error of ±2mm at 10m and 25m, each at 90% and 10% albedo. At the one-quarter resolution and one-eighth quality settings, this equipment produced coloured point clouds of about 11 million points per scan. The colours of the stratigraphic layers were acquired via the built-in coaxial camera (70 megapixels parallax-free colour overlay) and then applied to the recorded X, Y, Z points during postprocessing to facilitate identification and analysis of materials directly in the 3D data (fig. 5 and table 1).

As part of the TLS workflow developed for the 3D Digging Project, all point clouds documenting stratigraphic units or phases of B.89 were automatically aligned using FARO Scene software and later georeferenced in the local grid using ground control points provided by the total station survey team.

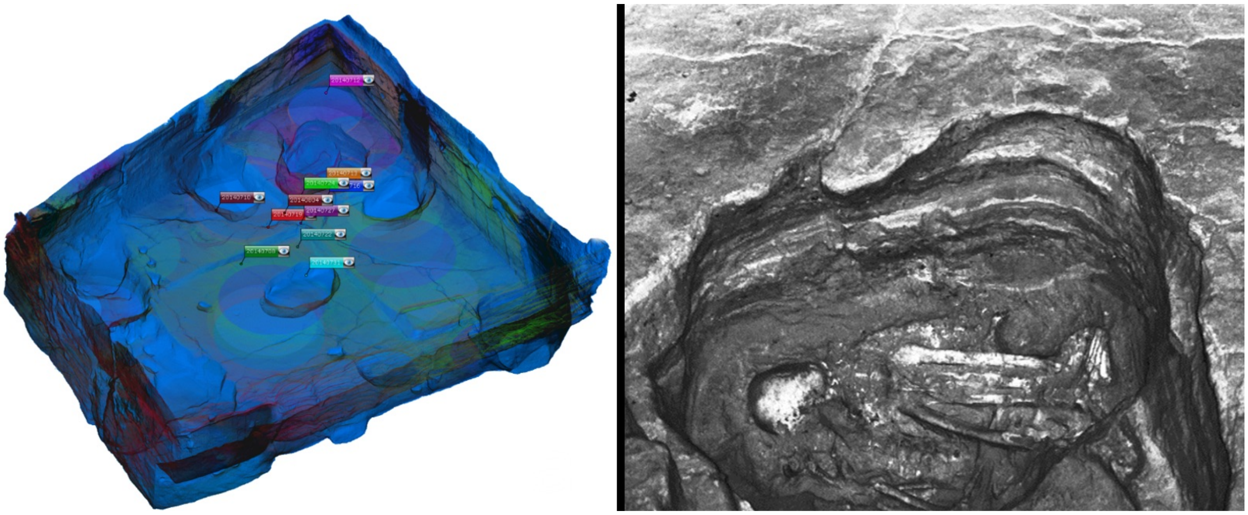

Figure 7.4. (a) All scans of B.89 captured in 2014; (b) Point cloud of skeleton (30928).

Figure 7.5. Terrestrial laser scanning units used at Çatalhöyük between 2010 and 2015, from left to right: Minolta Vivid 910; Trimble GX; Trimble FX; FARO Focus 3D S120.

The automatic alignment of 3D scans was enabled by manual or automatic recognition of white sphere targets that were placed around the perimeter of B.89, along with a paper checkerboard target taped to the concrete foundations of the South Shelter. High-resolution textures of each layer of B.89 were also recorded using DSLR cameras (18 megapixels) with the aim of adding more precise and vivid texture colours (RGB information) to the point clouds. These photos were eventually added to the registered and edited point clouds using texture parameterization tools in two software programs, the open-source MeshLab and the commercial 3D Reshaper. Additional textures were also recorded using the FARO Focus scanner's built-in coaxial camera starting in 2012. In addition, in the 2010, 2011 and 2012 field seasons, optical laser scanners were also used to digitise a number of Çatalhöyük artefacts. The digitisation of B.89 finds such as figurines, pottery, stone and bone tools and, more generally, small finds was carried out using a Next Engine HD scanner (table 7.2).

Unit	**Type**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
NextEngine	Structured light	X	X	X			
Konica Minolta Vivid 910	Structured light	X					
Trimble GX	Time of flight	X					
Trimble FX	Phase shift		X				
FARO Focus 3D S120	Phase shift			X	X	X	X

Table 7.2. Terrestrial laser scanners used by the 3D Digging Project between 2010 and 2015.

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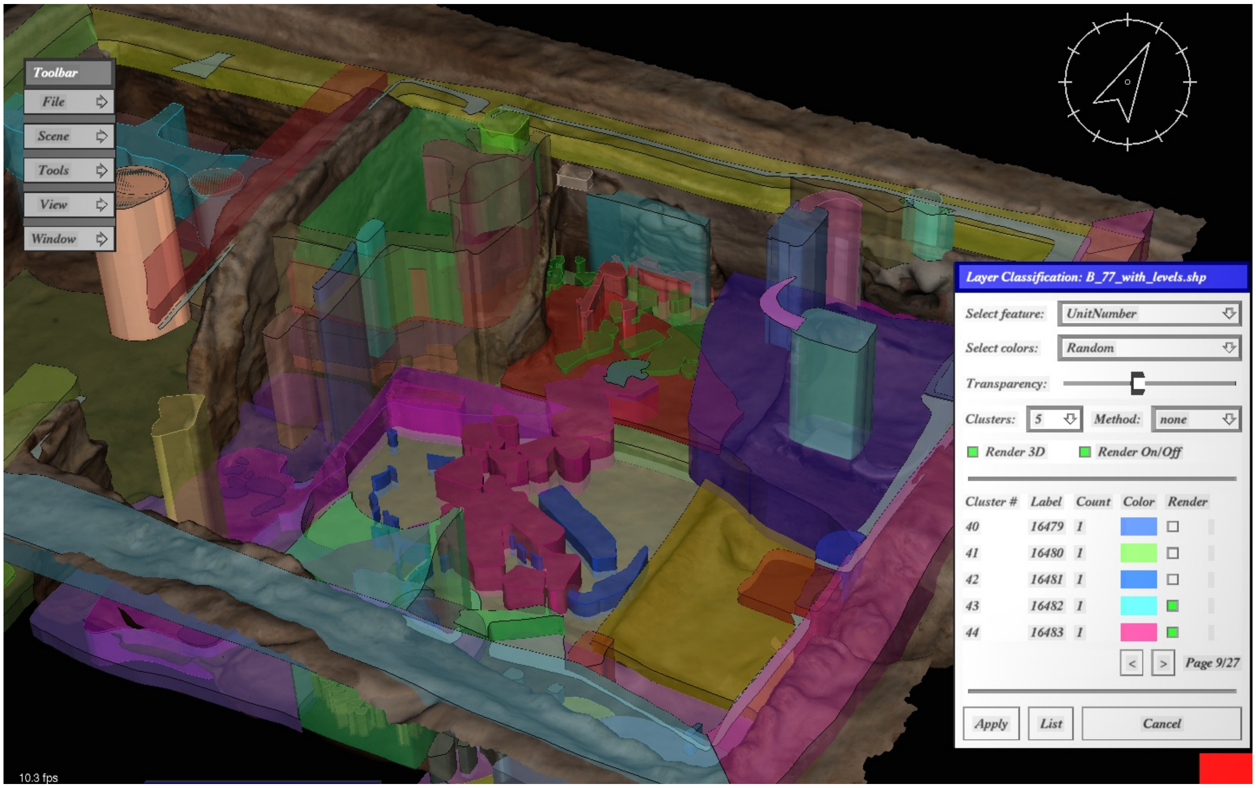
Teleimmersive Collaborative Archaeology

Collaborative research represents one of the most important challenges in scientific communication and interpretation. Minds at work simultaneously with continuous feedback and interaction, able to share data in real time, can co-create new knowledge and open up different research perspectives. The involvement at Çatalhöyük of a large multidisciplinary and international team, as well as the importance of continuing the discussion on data interpretation after the excavation, made this site the perfect case study for collaborative research in digital domains. Therefore, in 2013, thanks to a collaboration with the University of California, Berkeley, we decided to create the first teleimmersive system (Forte, Kurillo 2010; Forte 2014b) for archaeology. A teleimmersive system is a visualization system that uses stereo cameras and kinect haptic systems for visualization and for combining user avatars and 3D models in immersive remote participatory sessions. In short, these systems are aimed at the integration of different data sources for the real-time collaborative interaction of geographically distributed scholars (for example, at different universities). These tools allow the data decimation, analysis, visualization, archiving, and contextualisation of any 3D database in a collaborative space. Berkeley's teleimmersive platform consisted of several stereo clusters connected to a quad-core server, able to perform 360-degree stereo reconstruction. 3D data were streamed in each location via multiple streams (i.e., one stream for each view or cluster). The renderer plug-in received the data from the gateway and rendered it in the same virtual space in connection with other remote users. A tracking system (TrackIR by NaturalPoint) integrated the position and orientation of a Wii Remote (Nintendo) and active shutter glasses for a 3D TV (Panasonic). As the user moved his or her head, the rendered image corresponded to the user's location.

Our Çatalhöyük teleimmersive experiments used data from Buildings 77 and 89 and were mainly focussed on spatial and editing tools: measurements, lighting, shading, virtual digging and data mining (fig. 7.6). These two buildings were chosen because of their architectural features and the accuracy of the digital documentation available. The 3D visualization included both 3D models and geographic-information-systems spatial databases and was able to simulate stratigraphic layers, finds and metadata in the virtual space.



Layer Classification: B_77_with_levels.shp

Select feature: UnitNumber

Select colors: Random

Transparency:

Clusters: 5 Method: none

☑ Render 3D ☑ Render On/Off

Cluster #	Label	Count	Color	Render
40	16479	1	🟦	☐
41	16480	1	🟩	☐
42	16481	1	🟦	☐
43	16482	1	🟦	☑
44	16483	1	🟪	☑

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Figure 7.6. Building 77 in the teleimmersive system. Visualisation of different categories of stratigraphic layers and archaeological finds.

A possible scenario for the real-world use of this kind of application might be the following: diggers discuss a site with pottery experts, geoarchaeologists, physical anthropologists, conservation experts, geophysicists and other specialists in the same virtual space. Their discussion is based on data interaction, embodied actions and virtual annotations and comments; we can describe this process as kinesthetic learning. In fact, this form of learning and communication is created by interactive gestures and articulated embodied activities in virtual environments. In particular, the interaction of human avatars in the virtual space augments the level of digital embodiment and the capacity to coordinate sophisticated actions and achieve collaborative goals in real time (Forte et al. 2010). In archaeology, this kind of application highlights the importance of engaging in collaborative activities in order to promote a critical approach to digital archaeological reconstruction and its context, to share data and interpret them during a simulation session in virtual reality (fig. 7.7).

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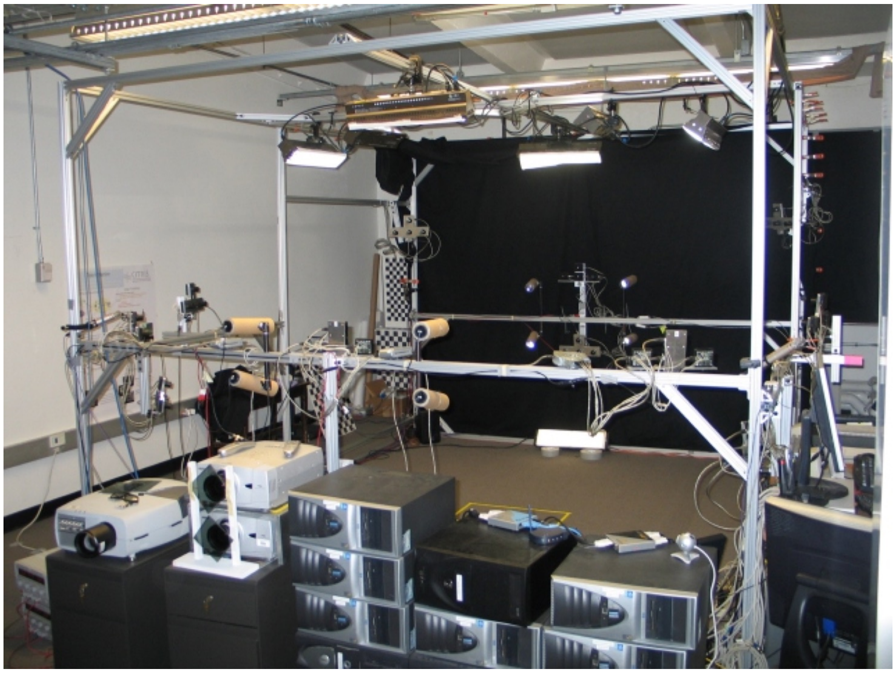

Figure 7.7. The teleimmersive system at the University of California, Berkeley (2015).

Dig@IT: Virtual-Reality Software Developed for Çatalhöyük

Building on the 3D documentation workflows developed and the archaeological data collected by the 3D Digging Project, a virtual-reality application was created at Duke University between 2014 and 2016 to tackle the challenge of curating our searchable 3D stratigraphic field documentation of B.89 in an immersive and interactive visualization platform (Lercari 2014; Lercari et al. 2014). Dig@IT is a multi-platform, scalable virtual-reality tool able to foster archaeological data analysis, interpretation and curation in a realistic and highly interactive immersive virtual environment connected via Structured Query Language (SQL) to the Çatalhöyük Database server (Lercari et al. 2018). Dig@IT was developed in the programming language C# in Unity 3D, a state-of-the-art game development ecosystem able to build multi-platform applications using MiddleVR, a platform-agnostic plugin that enables virtual-reality interaction (e.g., the manipulation of 3D models via a Razer Hydra two-handed wand controller) and immersive visualization capabilities (e.g., via an Oculus Rift headset). This custom-made app enables the interactive curation and visualization of the spatial and 3D data we collected at Çatalhöyük over multiple field seasons, with two goals: (a) to reconstruct the single-context stratigraphic excavation process and (b) to provide users with capabilities that are not available in existing software.

In order to achieve these aims, we designed and developed the following features and tools: (i) a 3D visualization of B.89 stratigraphic layers and 3D models of nearby houses in the South Area; (ii) free-roaming navigation of the South and TPC Areas; (iii) interaction with B.89 single-context layers based on triangular-mesh selection techniques; (iv) a measuring-tape tool able to calculate the linear dimensions of stratigraphic layers and buildings; (v) an import feature able to add artefacts and other archaeological objects to the simulation at run time (.obj file format only); (vi) an in-app georeferencing script that ensures that all simulated layers and buildings maintain real-world coordinates (Çatalhöyük local grid); (vii) a timeline tool to explore buildings and layers through years of excavation; (viii) real-time querying (via SQL connection) of the Çatalhöyük Database to retrieve metadata about stratigraphic layers directly in the virtual environment; and (ix) in-app metadata visualization through a 'virtual tablet' (fig. 7.8).

The archaeological documentation and 3D data we curated in Dig@IT include hundreds of 3D stratigraphic layers and features recorded in B.89 from 2011 to 2014 using the digital-photogrammetry workflow discussed above. Consequently, Dig@IT allows users to visualize and query the stratigraphy of this building from its post-depositional phases (e.g., the interface between the latest infill level of B.89 and the overlaying B.76, partially excavated in the 1960s and completely excavated in the 2000s) down to the earlier phases of occupation excavated in 2014, including numerous plastered floors, burials and dirty areas. To ensure the sustainability and preservation of the digital documentation and 3D data beyond the lifespan of Dig@IT (such apps usually have a lifespan no longer than five years), we also published all of the 3D models of B.89, source images, digital-photogrammetry project files, processing reports and related metadata on the UCSD Library Digital Collections portal (Lercari et al. 2017). Due to the technical limitations of virtual reality at the time of development, Dig@IT is not capable of connecting directly to our online digital collection, because it requires specialized input/output devices (e.g., Oculus Rift and Razer Hydra) for interacting with the virtual scenario and browsing the 3D data, but nonetheless, it can interface seamlessly with the Çatalhöyük Database server. The most recent version of Dig@IT can be downloaded free of charge from our repository on GitHub (Zielinski, Shiferaw 2018).

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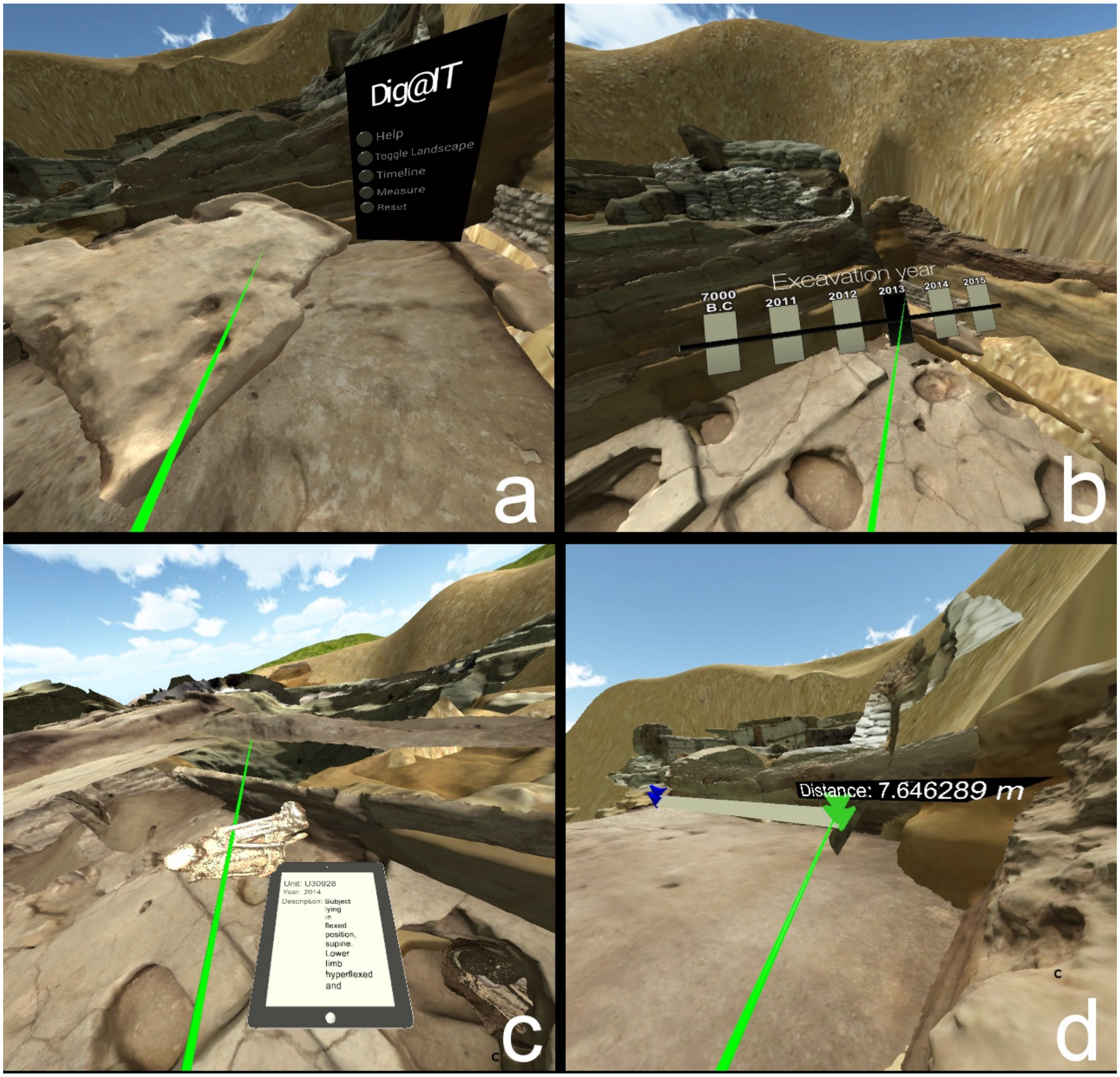

Figure 7.8. Dig@IT. View of (a) in-context menu; (b) timeline; (c) virtual tablet; (d) measuring-tape tool.

The Duke Immersive Visualization Environment (DiVE)

In addition to the development of Dig@IT, the 3D Digging project also used the Duke Immersive Visualization Environment (DiVE) facility to conduct new experiments in 2015 including data from the entire excavation of B.89 (fig. 9). These experiments consisted of simulating data and archaeological context from B.89 and enabling users to virtually excavate all the layers recorded by digital photogrammetry in the DiVE.

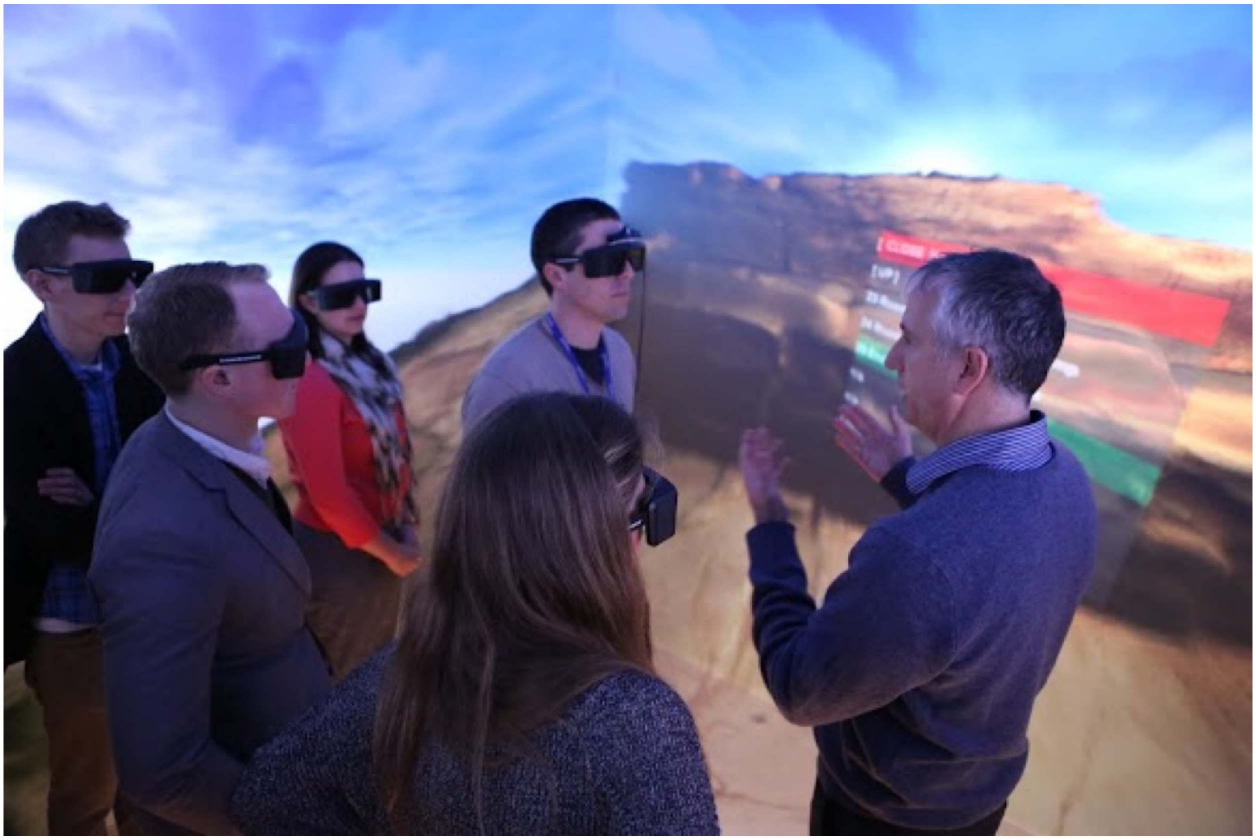

Figure 7.9. Virtual-reality session on B.89 in the DiVE (Duke Immersive Virtual Environment).

The DiVE is a research facility dedicated to exploring techniques of immersion and interaction: it is the fourth six-sided CAVE-like system built in the United States. It is a 3m x 3m x 3m stereoscopic rear-projected room with head and hand tracking and real-time computer graphics. All six surfaces – the four walls, the ceiling and the floor – are used as screens on which computer graphics are displayed. The user wears stereo glasses to interact in the visual space, while a handheld wand controls navigation and virtual object manipulation. The wand allows the user to browse through and interact with layers, models and artefacts in 3D, using a 3D menu, and the tracking system connected to the stereo glasses drives the visualization according to the position of the user's head. In this way, the user's virtual exploration augments his or her sense of presence in the virtual environment.

In our case, the entire B.89 sequence was virtually reconstructed, including all the stratigraphic layers excavated between 2011 and 2015, and as we were pleased to find in our first experiments, undertaken in 2014-15, the six-sided CAVE correctly rescaled the virtual building, giving users a truly embodied spatial perception of the excavation 'pod'. The interaction with different layers and datasets 'from inside' and in transparency stimulates new discussions on stratigraphy and the formation processes of the archaeological deposits. The virtual reconstruction of the building in its original context includes its plaster floors, decorations, roof and interior architecture. The computer model overlays the original structures of the building

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recorded by laser scanning, so it is possible to compare the original architectural settings with the structures explored during the excavation. In addition, since the DiVE can host as many as six or seven people simultaneously, we experimented with digital classrooms on Neolithic archaeology and some preparatory seminars before our summer fieldwork.

3D Archaeology and Spatial Embodiment

The visual inspection of a confined space, like a ritual platform, a burial or an altar, or a special artefact, implies the activation of a performative level of experience through the triggering of embodied simulation in the brains and bodies of the beholders. Embodied simulation is also triggered by the experience of spatiality around our body, the situated experience of physical space and proprioception (in the broader sense of 'self-perception'), and by the contemplation of objects. The functional architecture of embodied simulation seems to constitute a fundamental capacity of our brain, making possible our rich, diversified and even empathic experiences of space and the other individuals and objects therein.

In a recent contribution, Forte and Gallese (Forte, Gallese 2015) have discussed the relationships between cognitive neuroscience and 3D archaeology and the important role played by the cortical motor system and bodily action in visual and nonvisual perception. In fact, the cognitive information we process through material culture is based on real or potential actions: for example, when we are looking at objects, we simulate some of the actions they afford and perform. In this way, we build spatial maps as a consequence of our bodily motor potentialities. The trigger is in the 'empathy' we develop through objects and spatial interactions. For example, just observing an architectonic 3D space implies the embodied simulation of the actions we could perform in a similar space. The perception of a limited space like a Neolithic house assumes the activation of a performative level of experience of that space, enabled by the embodied simulation this space is able to trigger in our brains and bodies (Forte, Gallese 2015). In addition, mirror motor neurons activated when observing someone else perform an action are able to map the actions of others onto the observers' motor representation of the same activity (Rizzolati et al. 2002).

In other words, cognitive observation is a proactive 'virtual' performance with a clear impact on embodied spaces. Does this happen in virtual space as well? In the future, the neuroscientific study of virtual environments could reveal new ways to understand ancient sites and artefacts by studying their virtual affordances. Exploring this possibility is one of the goals of a new research project on neuroscience and virtual archaeology now underway at Duke University's Dig@lab and involving the use of EEG and eye-tracking systems in virtual reality and in empirical spaces.

A Neolithic house in Çatalhöyük is a multitasking environment because it entails domestic performances mixed with hyper-real and ritual aspects (Forte, Gallese, 2015; Hodder, Pels, 2010): a "memory making" environment (Hodder, 2018). The building is a performative space for its entire life and perhaps even after; it is a social and ritual unit, within which behaviour is governed by different levels of embodiment and virtual triggers. The triggers draw out the affordances among objects and environment, humans and objects. Such embodied relations have specific neurophysiological correlates in the parieto-premotor cortical networks that map space. This context requires a virtual environment to explore and interact with. The virtual simulation of this visual and sensorial paradigm could give us new insights about the cognitive meaning of Neolithic artefacts and increase our awareness of the centrality of performative aspects of sociality and culture.

Conclusions

This contribution summarizes the main digital applications developed and experiments performed in connection with 3D data recording as part of the archaeological excavation of Çatalhöyük in the period 2010–2015, initially by a small group of scholars and students and, later, by the entire team working on site as part of the Çatalhöyük Research Project. Photogrammetry, laser scanning, remote sensing, virtual reality, computer graphics, geographic information systems and teleimmersive systems constituted a particularly challenging set of different technologies, methods and tools. Certainly, Çatalhöyük was the ideal case study for this innovative cyberarchaeological research, because of the multidisciplinary teams involved, the multivocal mission of the project and the general attitude of its leadership.

Our intensive and extensive use of cyberarchaeology methods and digital data in different domains was the result of endless meetings and methodological discussions on and off site. This debate was mainly focussed on the role of the digital in relation to the reflexive methods employed by the Çatalhöyük Research Project, especially in connection with the excavation process and the final interpretation and representation of data. For instance, previous studies evaluating the evolution of reflexive methods at Çatalhöyük have highlighted how the design, development, and application of the cyberarchaeology methods and technology discussed in this chapter have directly contributed to a shift on how reflexivity may be achieved directly within the excavation and recording methods (Berggren et al. 2015, 434; Berggren and Nilsson 2014). In addition, we also considered the impact of the digital on the local community of diggers and, in a broader sense, on the archaeological community as a whole. Our finds show how quickly and widely the adoption of digital documentation and analysis methods such as structure from motion digital photogrammetry, 3D GIS, and virtual reality-based data visualization systems have changed the way archaeologists and students have to rethink the ways they record, discuss, and interpret archaeological information at Çatalhöyük and at many other sites in the Near East (Forte el al 2015; Jones and Levy 2018). Despite all the advances discussed in this chapter, we are aware that the implementation of a ‘sustainable’ digital workflow is still a highly debated topic in archaeology and entails technological and methodological questions: how to make digital data accessible? how to use and share 3D information and related metadata?

The 3D Digging Project and, more generally, our 3D data recording, analysis, and modelling have demonstrated over several years of experiments that it is possible to integrate different tools and methods during excavation, achieving important results in terms of standardisation, information quality, virtual interaction and reliability of the digital workflow. A correct approach to data acquisition and spatial archiving has also allowed the long-term use of these datasets in different forms and domains, such as geographic information systems, 3D modelling, virtual reality and collaborative systems. For example, in the current research period (2020) we are in the process of testing several 3D models of the excavation and virtual reconstruction of history houses on highly portable head-mounted displays (Oculus, HTC Vive) with excellent results.

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The next step is to improve the spatial accuracy of 3D models in real time in order to use virtual reality as a scientific tool and not just as pure visualization.

The cyberarchaeological workflow and 3D documentation system we developed and tested at Çatalhöyük proved very effective, producing high-resolution models perfectly georeferenced with the excavation grid and compatible with the geographic information system the very same day the data were recorded. The ‘mediated experience’ of digital documentation devices (laser scanners, digital cameras, geophysical devices and tablets) was always accompanied by the empirical observation of data on site. Since the 3D models were ready and visualizable within a very short time, the interaction between empirical observation and mediated experiences supported new forms of knowledge. In addition, the use of tablet PCs during the excavation of Building 89 complemented the transformation of the entire documentation into digital formats.

More importantly, the entire documentation system was completely digital and paperless, without any mediation like paper maps, notebooks and other analogue supplements. In line with the cyberarchaeological principles for data interaction, all data migrations were from digital to digital, from the site to virtual reality and data archiving. It is important to recall that the architecture of the entire site is made of mud bricks that are extremely fragile once they are excavated and exposed to new environmental conditions (very hot in the summer and cold in winter). It is in fact very difficult and expensive to restore and preserve these structures for a long period (Lingle 2014), and therefore digital preservation is the best and the most sustainable approach available today.

All the 3D data from B.89 and a selection of other buildings were linked and georeferenced with layers and datasets recorded in the past, reconstructing at the end a complete 3D map of the site and of the entire stratigraphic context. Another important achievement was in Building 77, where our cyberarchaeology approach made it possible to recompose in 3D the entire sequence of paintings documented in this building, relying on digital data collected over four years of excavation. This entire sequence is no longer visible on site, since the paintings are very fragile and cannot be preserved in situ. Thus, the only way to study them is in a virtual environment with all the links to their metadata and stratigraphic contexts. The project also released and designed specific software for collaborative research (teleimmersive archaeology) and the virtual simulation of the archaeological excavation (Buildings 89 and 77). Both platforms are conceived for real-time interaction and immersive environments.

Given the experimental nature of some pioneering applications (i.e., teleimmersive archaeology) and the lack of resources for further developments, it was impossible to integrate all the tools and methods in a single workflow. However, geographic information systems and photomodelling and photogrammetry applications achieved a high level of standardisation on site. In fact, within less than two years, all the excavation pods adopted the same methods of 3D data capture in different trenches and fieldwork contexts. Every pod had the chance to experience 3D data visualizations on portable tablet computers and notebooks for comparing empirical information (on site) and digital documentation.

Some of our datasets are migrating to the Çatalhöyük Living Archive project at Stanford (http://catalhoyuk.stanford.edu), while others are still processed and archived in different labs at Duke University, Lund University and the University of California, Merced (Lercari 2017 et al.). Our ongoing discussion is focused on how and where to deposit a large amount of 3D data and a large number of models for public access. At Duke University we are developing a new open-source platform called Morphosource (https://www.morphosource.org) where we can archive 3D models and metadata.

In addition, our virtual simulations involved in a first stage an immersive CAVE (the Duke Immersive Virtual Environment), then, in a second stage, virtual headsets (Oculus, Oculus Go, Oculus Rift Oculus Quest, HTC Vive) and holographic augmented reality screens (Z-Space). The multiplication of the same visual content across distinct devices was able to generate different research questions and to enable comparative analyses of the archaeological stratigraphy and finds. The most important achievements of this combination of virtual reality, immersive reality and augmented reality were the perception of depth, a new digital embodiment and kinesthetic realism. It is also quite interesting to notice, so many years after we began, that our approach still allows for new interpretations through virtual simulations. The new generation of headsets are able to create a new sense of embodiment and to stimulate a more advanced sense of presence in the virtual space. This could potentially improve our capacity for learning and interacting with spatial models.

All the tools, devices and methods we have mentioned have been part of a consistent effort towards the creation of a robust digital workflow, but at this stage of research we are far from a real standardisation of protocols, systems and data models. It is difficult to deal with different formats and still more difficult to migrate them to stable platforms. The long-term sustainability of the technologies, data migrations, data integration and open-access repositories we have used is still an unsolved issue, at least on a larger scale. At this stage of research we need to move the discussion forward from data standardisation, repositories and data migration to data circulation and beyond. In other words, the elaboration of different digital ontologies creates several categories of data that can survive by virtue of their capacity to play in separate platforms and databases, rather than in one single standardised system. These data don't migrate, they circulate. For example, some 3D data can be visualized in a 3D geographic information system, in a game engine, in a procedural modeler, in a web browser or on specific hardware or devices, such as head-mounted displays (Oculus, HTC Vive and equivalent). As a result, the circulation of data is based on their use, on the multiplication of users and on the manipulation and re-elaboration of the content. It is not a standardised process, of course, but the survival of data depends on the speed of their co-evolution.

In a broader cyberarchaeological perspective (Forte 2015), the differentiation of knowledge in distinct ontologies stimulates and propagates the idea of a potential past and its relativistic interpretation. A simulation becomes a catalyst for the generation of multiple realities and multiple interpretations. We could say that the interpretation of digital models is at the 'trigger's edge', because digital triggers set the parameters for human interaction with digital data and the way we access such complex information. One of the consequences of this data 'explosion' is a

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general concern about the use or abuse of mediated tools versus empirical interpretations. In fact, we think that there is no opposition between digital tools and empirical data, because both are part of the same human-enriched experience. The digital experience is augmented by different media, but it does not annihilate the empirical one. Human vision itself is a mediated experience, since the brain classifies environmental information according to different biocultural frameworks, for example, the classification of colours and textures, physical engagement and embodiment. More generally, 'the analysis of archaeological records, particularly when acquired in 3D and enabling a true immersive interaction, naturally lends to a "performative" study of the acquired evidence, enabled by the possibility to empirically document the relationship between a given object, be it a wall, a depiction, a vase or a Neolithic house, and the body activity, practices, and habits it evokes by means of the embodied simulation triggered by its vision or exploration' (Forte, Gallese 2015: 50).

Supplementary material

For supplementary material related to this chapter, please visit https://doi.org/10.18866/BIAA/e-15. It comprises a colour and 3D version of figure 7.1 and colour versions of figures 7.2–7.9.

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