Title
A Glimpse through Time and Space: Visualizing Spatial Continuity and History Making at Çatalhöyük, Turkey

Journal
Journal of Eastern Mediterranean Archaeology & Heritage Studies, 8(2)

ISSN
21663548

Authors
Lercari, Nicola
Busacca, Gesualdo

Publication Date
2020

DOI
10.5325/jeasmedarcherstu.8.2.iii

Data Availability
The data associated with this publication are available at: https://doi.org/10.6075/J0WD3XX2

Peer reviewed

Author version. The final publication is available at JSTOR or ProjectMuse

Please cite as: Lercari, N. and G. Busacca. 2020. A Glimpse through Time and Space: Visualizing Spatial Continuity and History Making at Çatalhöyük, Turkey. Journal of Eastern Mediterranean Archaeology and Heritage Studies, 8 (2): 99-122. DOI: 10.5325/jeasmedarcherstu.8.2.iii

A Glimpse through Time and Space: Visualizing Spatial Continuity and History Making at Çatalhöyük, Turkey

Nicola Lercari (corresponding author nlercari@ucmerced.edu)

Gesualdo Busacca

Abstract

The inhabitants of Çatalhöyük, a 13.5-hectare Neolithic site (ca. 7100–5900 BCE) located in central Anatolia, Turkey created material links between themselves and their past by repetitively constructing and maintaining mudbrick houses and actively retrieving skeletal remains from buried buildings. We argue that archaeological visualization is a viable tool to aid interpretation of this habituated behavior and commemorative links to the past, also known as "history making." This study employed widely adopted methods to ensure reliability, scientific rigor, and tracking of knowledge provenance in the implementation of multi-temporal 3D reconstructions of the Shrine 10 sequence, a series of superimposed buildings spanning a significant part of the site's chronology. Our results facilitate analysis of the history-making practices documented in the Shrine 10 sequence by providing unambiguous visual

representations of its complex archaeological record and enabling users to visualize the long-term history of this Neolithic built space.

Keywords: Çatalhöyük, Anatolian Neolithic, Neolithic architecture, archaeological visualization, virtual reality, 3D reconstruction, history making

The inhabitants of Çatalhöyük, a 13.5 hectare Neolithic site (ca. 7100–5900 BCE) located in central Anatolia, Turkey (Fig. 1) created material links between themselves and their past by repetitively constructing and maintaining mudbrick houses and actively retrieving skeletal remains from buried buildings (Hodder 2006: 141–49). Hodder (2018: 8) defines this strong continuity in habituated behavior and commemorative links to the past as "history making." Thus far, history making at Çatalhöyük has only been reconstructed in the form of archaeological narratives based on stratigraphic and spatial observations. We argue that archaeological visualization, the process of creating visual representation of the archaeological record based on spatial logic and inference, makes additional contributions to the understanding of history making when applied critically and with a robust archaeological focus. Here, we demonstrate how multi-temporal virtual reconstruction, or the visual superimposition of multiple discrete reconstructed phases in the history of sequences of buildings, can be implemented to facilitate analysis of the spatial and temporal links between different occupation phases, multiple rebuilds, and associated rituals.

Author version. The final publication is available at JSTOR or ProjectMuse

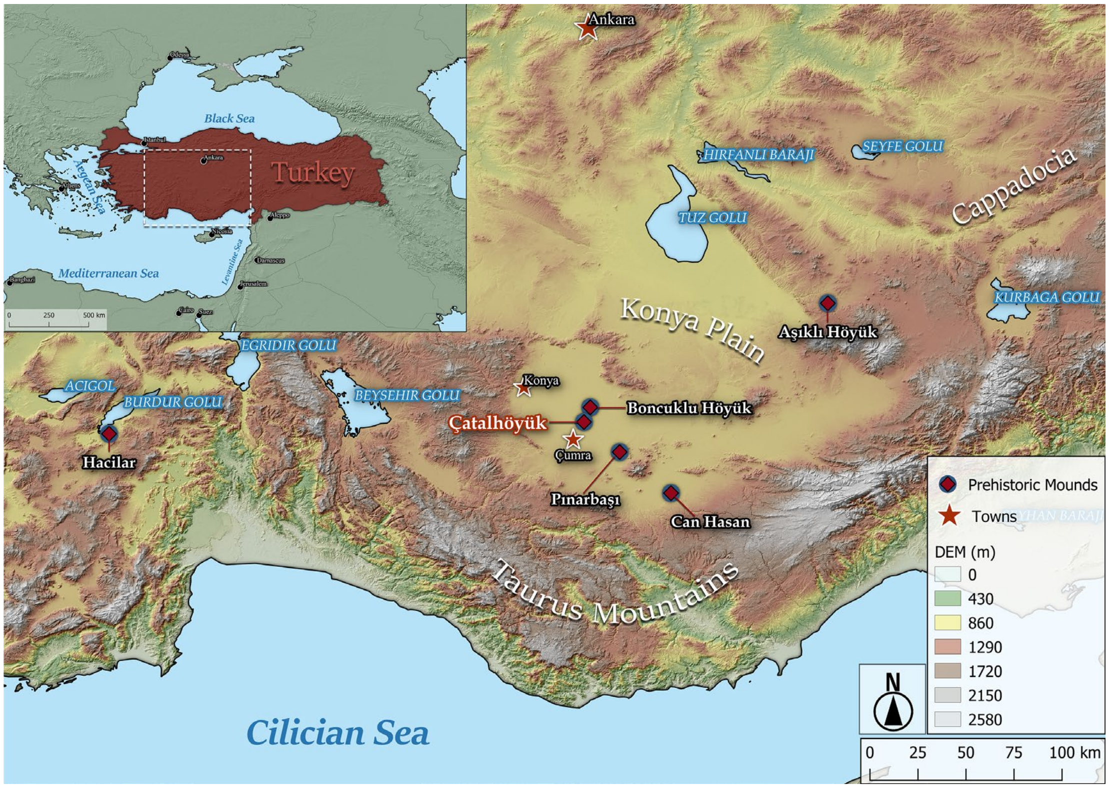

FIG. 1 Map of central Anatolia showing the location of Çatalhöyük and nearby Neolithic sites in the context of the eastern Mediterranean region. Courtesy of M. Dueñas Garcia via ESRI 2019. ArcGIS Desktop: Release 10.5. Redlands, CA, Environmental Systems Research Institute.30m NASA SRTM [Shuttle Radar Topography Mission].

Specifically, this study investigates and visualizes patterns of continuity and change in relation to the location of archaeological features and burials across superimposed Buildings 17-6-24-VII.10-VI.10, also known as the Shrine 10 sequence. We created both static and interactive 3D multi-temporal virtual reconstructions of these buildings, including 3D renders and a virtual reality (VR) application. We also discuss how widely adopted standards in knowledge visualization and representation such as the London Charter, the Seville Principles, and the CIDOC Conceptual Reference Model (CRM) ensure intellectual integrity, reliability, scientific rigor, and knowledge provenance in the implementation of multi-temporal 3D reconstructions (Beacham, Denard, and Niccolucci 2006; Lopez-Menchero and Grande 2011; Doerr 2003; Niccolucci 2012). Following recent best practices (Beacham 2012; Bruseker, Guillem, and

Carboni 2015), we put particular emphasis on recording and representing the argument-making process and reconstructive choices we made to create visualizations of our case study.

Spatial Continuity and History Making at Çatalhöyük

The repetitive use of spaces and emphasis on continuity is a widespread feature during the Neolithic of Southwest Asia that has been widely associated with increasing sedentarization and is thought to be a way in which Neolithic people created mnemonic or material links to past events or ancestors (Moore, Hillman, and Legge 2000; Hodder 2007; Baird, Fairbairn, and Martin 2017). In the case of Çatalhöyük, Hodder (2018: 7) identifies two different forms of history making: 1) "the repetition of practices within buildings is the result of habituated behavior" and 2) "commemorative behavior in which people consciously build social memories and historical links into the past." The first type is house-based, unconscious, and largely tacit. For example, the inhabitants of Çatalhöyük built the hearth in a specific location of their house "because it has always been done that way" (Hodder 2018: 7), or they repeatedly swept and plastered the northern part of their house while letting waste and charcoal accumulate near the fire installations in the southern part, also known as a "dirty area" (Hodder and Cessford 2004). The second type of history making is sodality-based, conscious, and connected to shared memory. For example, the people of Çatalhöyük created material connections with their ancestors and past events by retrieving objects and human remains from earlier phases of their house or even from earlier buildings buried beneath their dwelling (Hodder 2006: 141; Boz and Hager 2013; Pilloud and Larsen 2011).

At Çatalhöyük, houses that are rebuilt multiple times also tend to be more elaborate, both architecturally and symbolically, and frequently contain multiple burials. Hodder and Pels (2010) have termed these buildings "history houses" in recognition of the architectural ability to create meaningful connections with past events or ancestors and establish long-term memories (Hodder 2006: 143, 2016). Examples of history houses are found throughout the entire occupation of the site, including remarkable sequences such as Buildings 10-44-56-65 spanning the site's late levels (6500–6300 BCE), and the Shrine 10 sequence, encompassing early levels (7100–6700 BCE) and middle levels (6700–6500 BCE) of the Neolithic mound (Fig. 2 and Table 1).

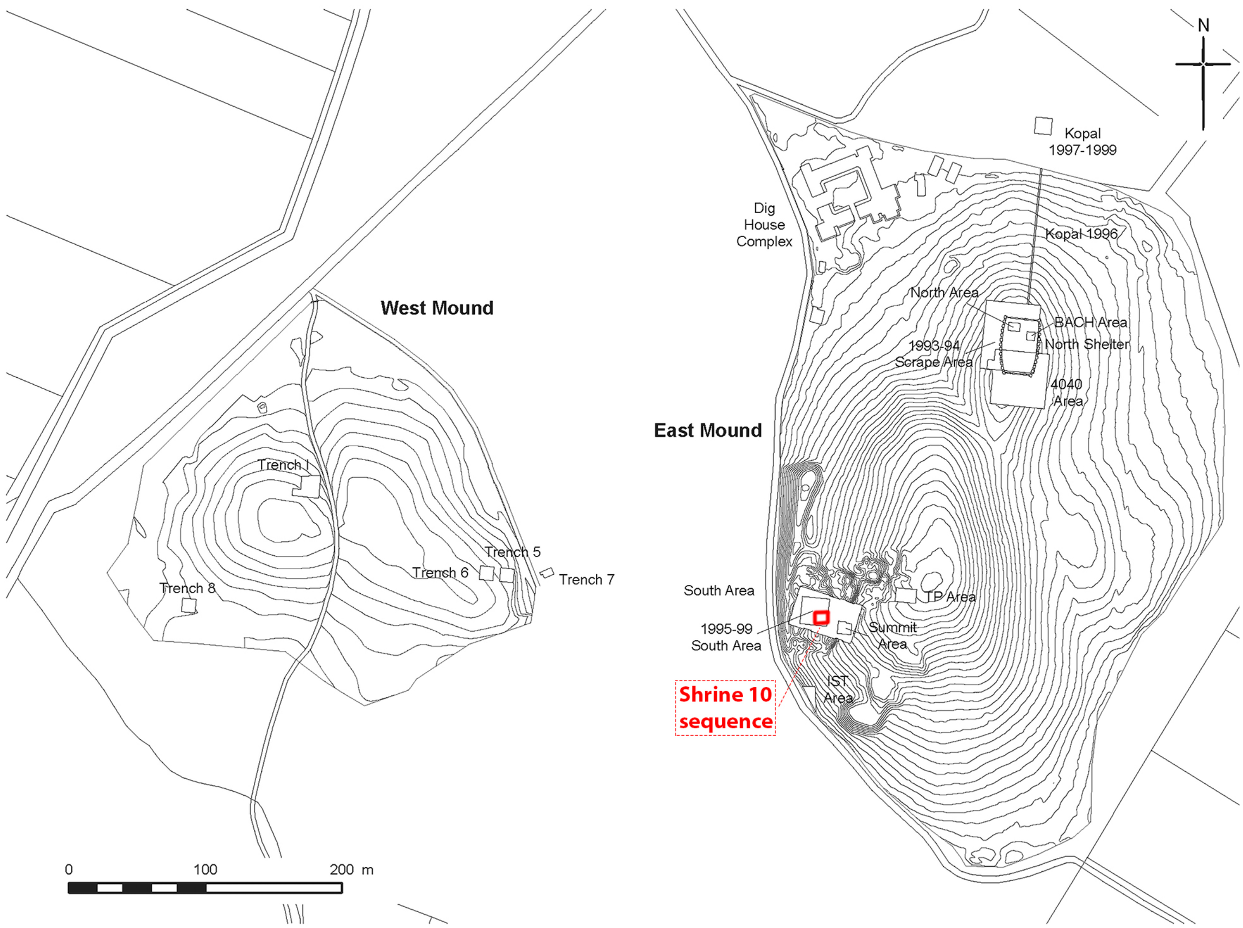

FIG. 2 Map of Çatalhöyük showing the East and West Mounds, the location of the Shrine 10 sequence (red), and the excavation areas of the Çatalhöyük Research Project (1993–2017). Courtesy of N. Lercari and the Çatalhöyük Research Project Team.

Building	Level	Temporal Group	Chronol. Range	Floor Elevation (ASL)	Floor Elevation Average (ASL)	Floor Relative Heights	No. Inhumated Skeletons
17.2.2	South K	Early	7100-6700 BC	1002.83m	1002.83m	0m (lowest level)	N/A
17.D	South K	Early	7100-6700 BC	1002.74-1002.92m (earliest floor exc. in 2017) and 1003.32-1003.63m (later floors exc. in 1999)	1003.475m	0.645m (above B17.2.2)	22
6.3	South L	Early	7100-6700 BC	1004.5-1004.68	1004.59m	1.115m (above B17.B)	10
24 / VII.10	South M	Middle	6700-6500 BC	1005.5-1005.66	1005.58m	0.99m (above B.6.3)	Not reported
VIB.10	South N	Middle	6700-6500 BC	N/A	1006.65m	1.07m (above B.24)	32 (including both phases of S.VI.10)
VIA.10	South O	Middle	6700-6500 BC	N/A	1007.25m	0.60m (above VIB.10)	

*TABLE 1 Additional information on the reconstructed buildings and phases in the shrine 10 sequence, including levels, chronological grouping, floor elevation, and numbers of inhumated skeletons. *Level column lists Hodder's classification. Comparison of Mellaart's levels with Hodder's levels is hypothetical and uncertain.*

In a sequence of history houses the regularity of the built environment is not only synchronic, but also diachronic. Internal layouts of houses were usually maintained throughout the entire duration of a building's occupation, and often even carried over into later reincarnations or rebuilds of the same house (Fig. 3).

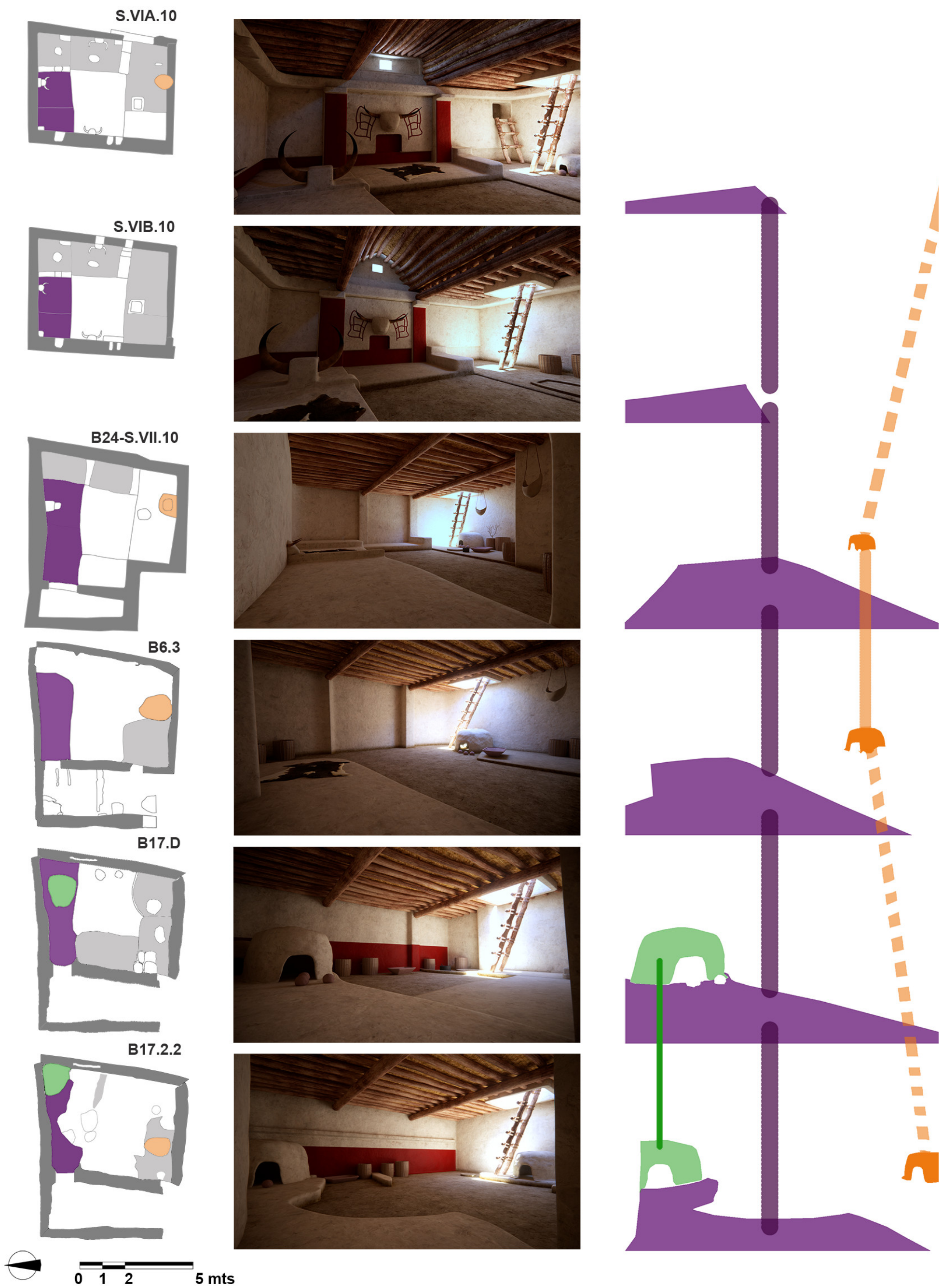

FIG. 3 Multi-temporal visualization of the Shrine 10 sequence looking southeast. Phase maps (left), 3D renders (center), and infographics (right) displaying stratigraphic, spatial, and temporal information on the repetition of the north platform (purple), northern oven (green), and southern oven (orange). Continuous or dashed lines represent respectively spatial-temporal continuity or discontinuity. Their thickness conveys quantitative information on how many times these features are repeated. Courtesy of N. Lercari, G. Cox, and A. Campiani.

In many cases, burials literally laid the foundation of a history house, especially when it was the first in a sequence. Interestingly, four skeletons of various ages also marked the foundation of Building 17, the first structure in the Shrine 10 sequence reconstructed in our study (Taylor 2017: 72) (Fig. 4). The exact location of burials within the house, for example, was highly important and likely remembered, as human remains were often retrieved and buried elsewhere, sometimes to set the foundation for a new house. The ability to discursively create these emplaced connections to the past could also be used by certain house-based social entities—households, cross-cutting networks such as religious sodalities (Mills 2014) or others—to garner respectability and status, which in turn increased the ability of the house to endure over multiple rebuilds (Hodder 2006: 143).

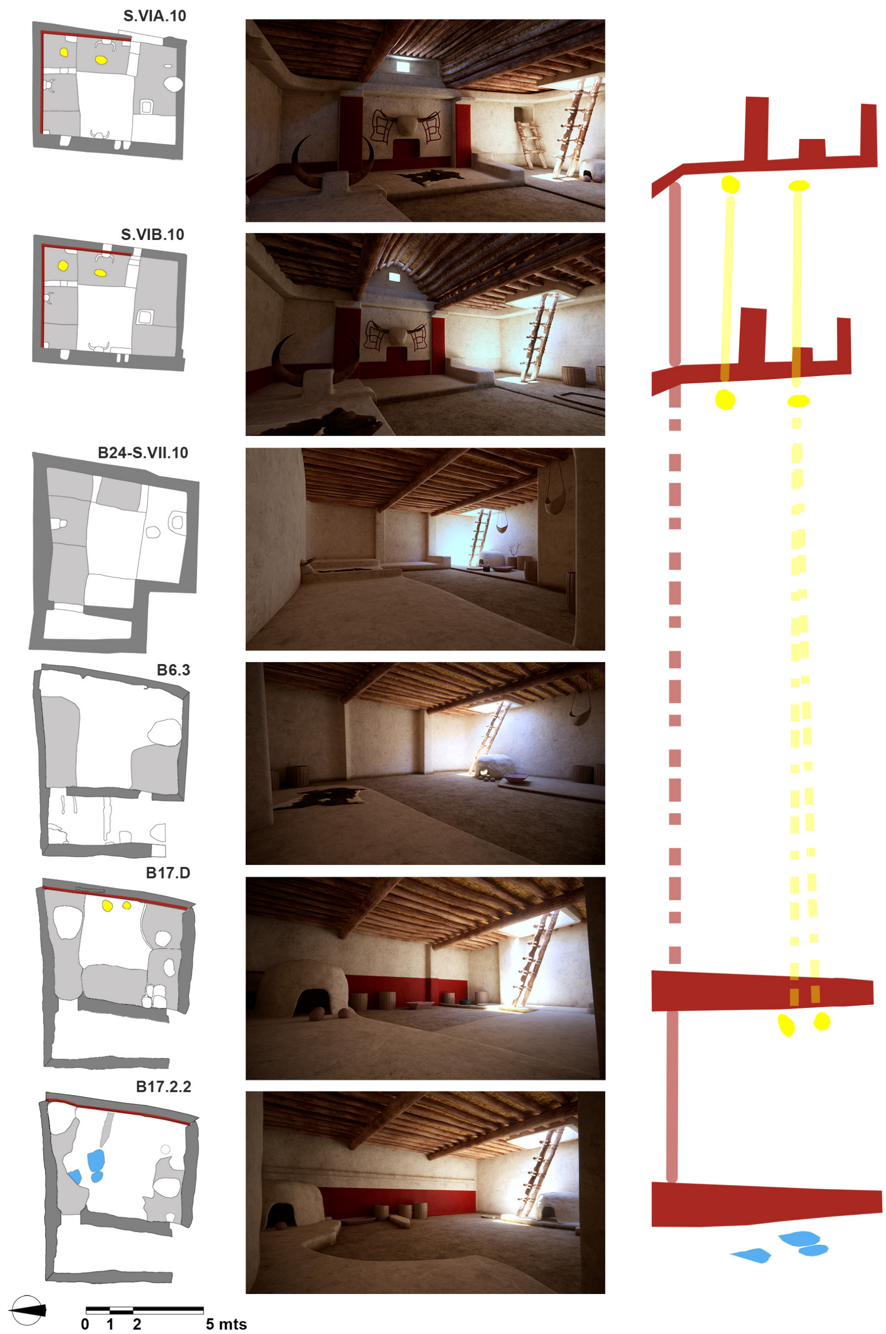

FIG. 4 Multi-temporal visualization of the Shrine 10 sequence looking southeast. Phase maps (left), 3D renders (center), and infographics (right) displaying stratigraphic, spatial, and temporal information on the repetition of burials in the northeast and east part of the house (yellow) and associated red painted panels (red). Other non-repeated burials visualized in blue. Courtesy of N. Lercari, G. Cox, and A. Campiani.

Challenges in Visualizing Çatalhöyük Archaeological Data

The archaeological data available to this study differ greatly in terms of detail, level of accuracy, and reliability owing to the profound methodological and technological differences between the first excavations at Çatalhöyük led by James Mellaart in the 1960s and recent investigation by the Çatalhöyük Research Project (ÇRP) led by Ian Hodder. Mellaart's legacy data, upon which our reconstructions of Shrines VI.10 and VII.10 are based, consist mainly of excavation plans, textual descriptions, a limited photographic corpus, and isometric "visual restorations" that heavily rely on the craft of artists and surveyors working on-site at the time (Mellaart 1998). The latter are nowadays considered highly uncertain and unreliable but, in some circumstances, they provide the only available information on buildings excavated in the 1960s. We also relied on the larger, nuanced, and diversified dataset produced by the ÇRP between the 1990s and present for the reconstruction of Buildings 6, 17, and 24. This second collection of data was generated using high-definition, single-context excavation in association with a management plan for the conservation and public presentation of the site (Hodder 2014: 2). It includes discussions and excavation diaries written by multiple archaeologists over the years, GIS-based plans, a massive archive of photographs and videos, 2D and 3D presentations, published annual reports, and final publications (Hodder 1996, 2000; Swogger 2000; Emele 2000; Morgan 2009; Ashley, Tringham, and Perlingieri 2011; Cox 2011; Forte et al. 2012).

Our capabilities to virtually reconstruct sequences of buildings at Çatalhöyük were influenced by the excavation and documentation strategies of earlier and more recent studies at the site. Following Frankland's (2012) cautionary advice regarding the representation of the archaeological record through realistic 3D renderings, we started by investigating alternative strategies to make explicit the complex processes of data integration and formulation of hypotheses that underlie our visualizations and recorded the critical arguments and reconstructive choices we made during the research and 3D modeling phases of this study. As a result, we produced transparent and replicable virtual reconstructions of the Shrine 10 sequence that also convey the uncertainty of their underlying evidence (see below, Figs. 9–14 and 6a-b).

Materials and Methods

Fitting into the general cyber-archaeological paradigm proposed by Forte (2010) and Stanish and Levy (2013), this study examines the role of archaeological visualization in helping contextualize or nuance spatial continuity and history making tied to multi-temporal 3D reconstructions. Building on recent work in this field (Lercari 2017; Lercari et al. 2018; Jones and Levy 2018), this study provides a tangible example of how to ensure sustainability of the cyber-archaeological data flow from the acquisition of field data, visualization in a VR environment, and ultimately to final curation and publication of results online and in digital collections. All the 3D models, textures, high-resolution renders, interactive reconstructions, metadata, and paradata produced in this study are available through the web portal of the University of California, San Diego Library Digital Collections that ensure long-term open access to our results beyond the lifespan of the employed digital tools (Lercari et al. 2019).

Static and Dynamic Multi-Temporal Virtual Reconstructions

In our effort to visualize house-based history making at Çatalhöyük, our virtual reconstructions of history houses represent the stratigraphic continuities and discontinuities of these buildings with a focus on the renewal process of archaeological features and burials that occurred in the Shrine 10 sequence. Our 4K realistic renderings produce a comprehensive, high-resolution representation of long-term processes both spatially and temporally by showing the repeated use and arrangement of the built space across the Shrine 10 sequence (see below, Figs. 9–14).

Our visualization of the case study also produced interactive multi-temporal reconstructions in an easy-to-navigate VR application (app) created in the game engine Unity 3D (Videos 1–3 available via Project Muse or YouTube). 3D simulations of archaeological data are uniquely capable of stimulating discussion and interpretation because the visualization effects typical of a VR environment enable users to visualize multiple strata, finds, and datasets simultaneously (W. Z. Wendrich, Bos, and Pansire 2006; Smith et al. 2012; Knabb et al. 2014; Lercari 2018). In other terms, while immersed in a VR reconstruction, the archaeologist can see through the 3D data and ponder connections which are not identifiable in a typical 2D representation, such as a plan or photograph. Our app can synchronically display all the history houses we investigated and facilitate comparison of their relative elevations and levels. By analyzing the reconstructed buildings or phases, users can dynamically explore in 3D how the archaeological record at Çatalhöyük reflects house-based history making practices documented in the Shrine 10 sequence. To ensure broader access to our app, particularly for scholars/readers who do not have access to high-end VR headsets (e.g., Oculus Rift or HTC VIVE) or find inexpensive VR cardboard options (e.g., Google Cardboard) inadequate for scientific visualization, we decided to distribute this app as a desktop VR software that works on a regular PC without the need of additional VR devices. A Windows 10 64-bit version of this app is downloadable along with all of its visual assets, metadata, and paradata from our digital collection (Lercari et al. 2019).

Interpretative Infographics

We created interpretative infographics aimed to ease analysis of continuity and history making in the Shrine 10 sequence by presenting multiple layers of information at a glance (e.g., plans, 3D renderings, and graphic spatial/temporal connectors) (Figs. 3, 4, and 5). Adapting

Tufte's (1983: 51) principles of graphical excellence to archaeological visualization, we crafted our infographics following recommendations for clarity, precision, and simplicity. We created custom-made graphical conventions able to spatially connect repeated architectural features or burial locations in superimposed buildings. For instance, we used the thickness of the graphic connectors that link repeated elements in our 3D models to quantitatively represent their temporal depth over time (Figs. 3, 4, and 5). We also employed continuous or dashed strokes to inform the readers about the continuity or discontinuity of the repetition of architectural features and burials across different buildings. A concrete example of this method can be found in the way we represented the continuous repetition, or lack thereof, of fireplace features, or hearths, in the sequence of history houses discussed below (Fig. 5).

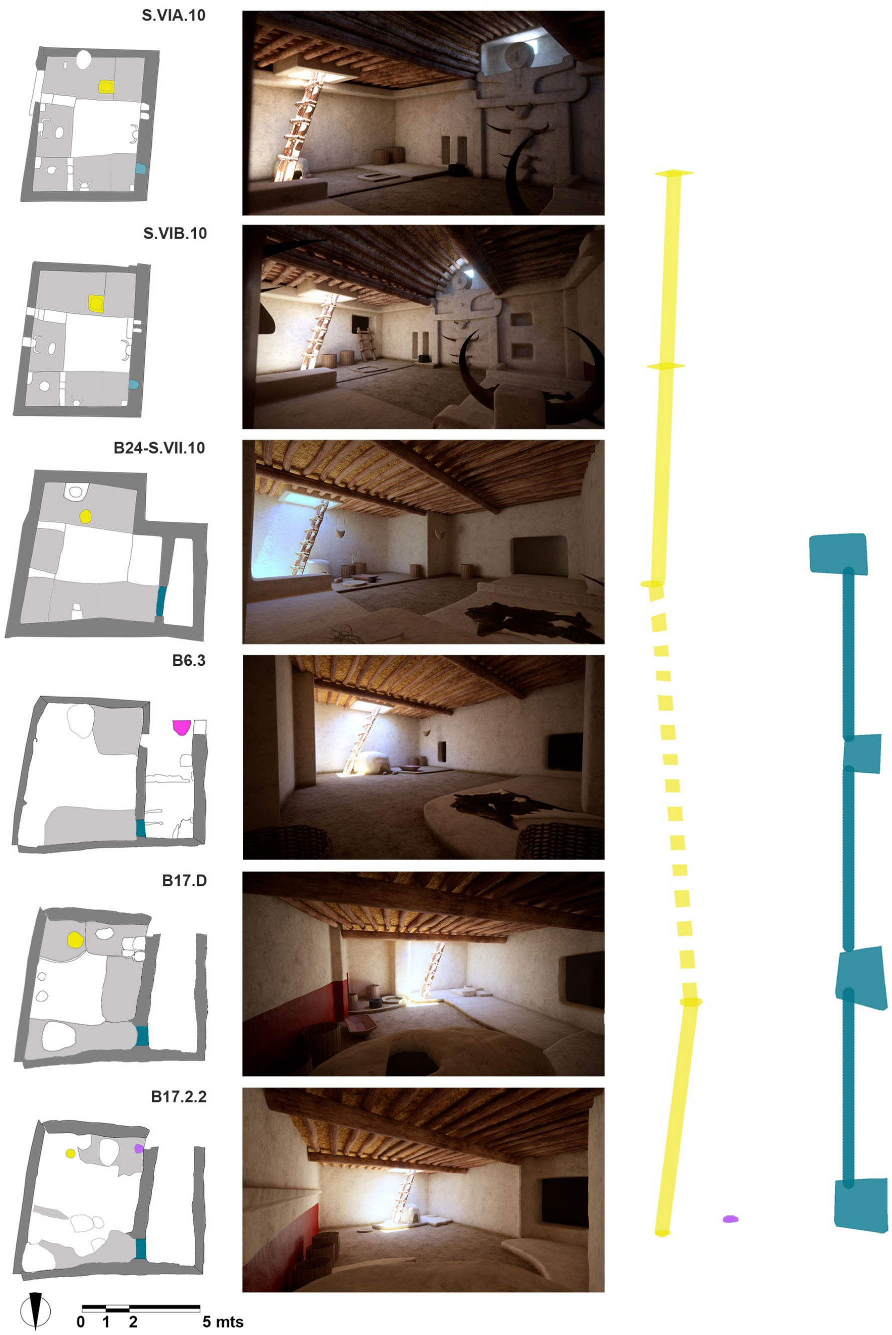

FIG. 5 Multi-temporal visualization of the Shrine 10 sequence looking southwest. Phase maps (left), 3D renders (center), and infographics (right) displaying stratigraphic, spatial, and temporal information on the repetition of hearth features in the southern part of the house (yellow) and access holes connecting main room with side rooms or other buildings (blue). Other non-repeated hearths visualized in pink. (Courtesy of N. Lercari, G. Cox, and A. Campiani.)

The overlaying view of "dirty areas" in Buildings 17-6-24-VII.10-VI.A.10-VI.B.10 portrays how the hearth occupies an almost identical location throughout the sequence (see Fig. 5), although the internal arrangement of features tends to be less structured and more mobile in the early buildings within the sequence (Buildings 17 and 6) and, more generally, throughout the site. Our 3D reconstructions visually identify the discontinuity that characterizes the "dirty areas" of the two phases of Shrine 10 by utilizing dashed lines to connect them vertically. However, in the western part of the southern wall in VI.B.10, differences in these areas are rendered mostly by the absence of an oven. The hearth documented in VII.10 shares a very similar location with the hearths excavated in the later VI.A.10 and VI.B.10. Hodder (2018: 22–26) argues that this intentional repetition of new hearths in the same location for decades or even hundreds of years, as documented at sites such as Aşıklı Höyük and Çatalhöyük, is evidence of embodied history-making practices (type 1) during the Neolithic.

Uncertainty Maps

Numerous theoretical solutions and empirical methods have been used to graphically represent scientific data (Bertin and Berg 2011; Tufte 1983; Ware 2012) or to display and quantify data uncertainty (Pang, Wittenbrink, and Lodha 1997; Potter, Rosen, and Johnson 2012; Zuk and Carpendale 2006). In the last decade, consensus has emerged among archaeologists on how to represent data uncertainty in virtual reconstructions. Multi-layered color maps, transparency, and color coding is employed to provide users with visual clues on the certainty or lack thereof occurring in specific elements of a reconstructed building or site (Aparicio Resco and Figueiredo 2017; Kensek, Dodd, and Cipolla 2004). Following these best practices, we developed a three-pronged categorization of data uncertainty based on overlaying colors for each component of our 3D models and by producing uncertainty maps (Figs. 6a-b). These maps display three degrees of uncertainty including: 1) documented elements (high accuracy), 2) hypothetical elements (medium accuracy), or 3) conjectural elements (low accuracy).

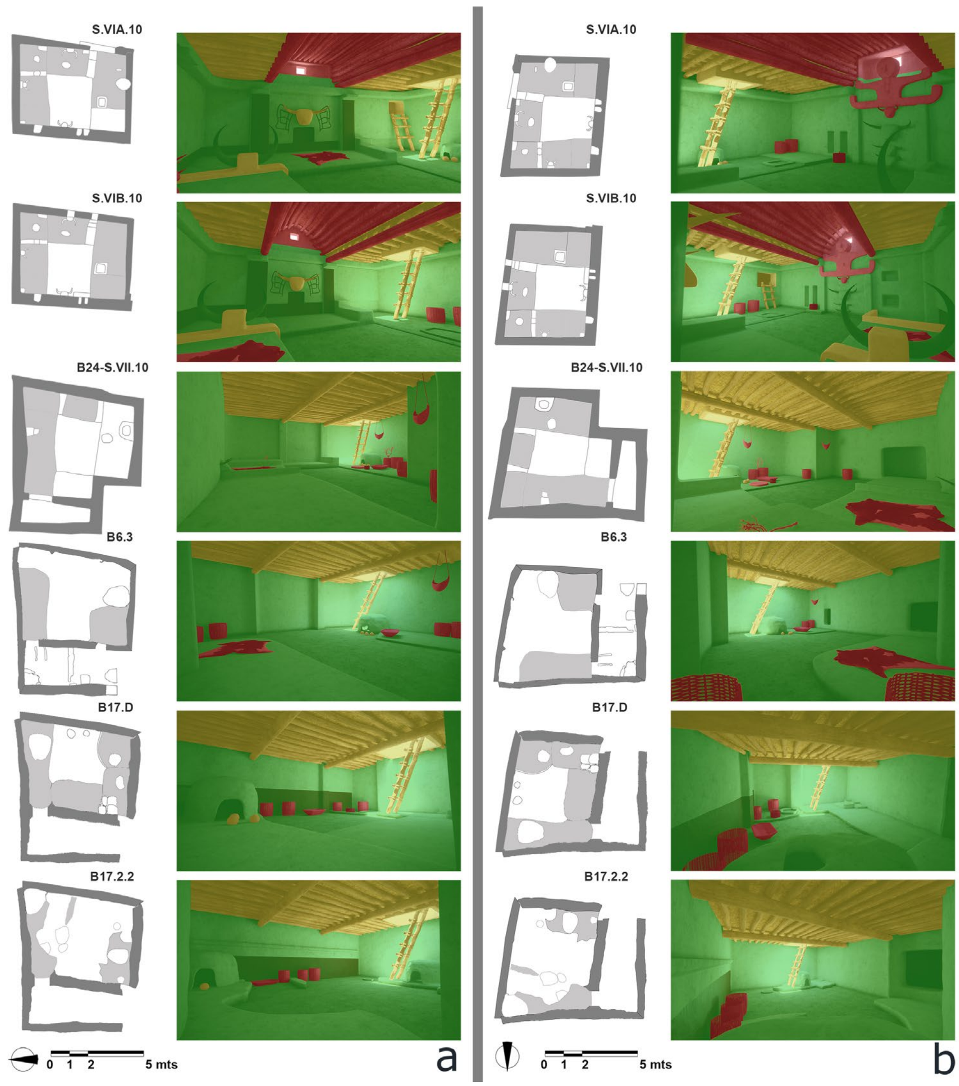

FIG. 6 Uncertainty map looking southeast (a) and looking southwest (b). Green overlay denotes high accuracy (elements documented through plans and photos). Yellow overlay denotes medium accuracy of the reconstruction (shape and location of elements are hypothetical and were inferred by analogy with similar contexts or ethnographic parallels). Red overlay denotes highly uncertain accuracy (elements were reconstructed based on Mellaart's conjecture). Courtesy of N. Lercari, G. Cox, and A. Campiani.

Elements in the first category, associated with a green overlay, were found during excavation of buildings in the Shrine 10 sequence and extensively documented through photography, plans, and other forms of documentation. Although there is always a degree of uncertainty as to how exactly these elements appeared and functioned in their Neolithic contexts, they can nonetheless be reconstructed with reasonable confidence. The second category includes elements displayed with a yellow overlay that have been found poorly preserved, or have not been found at all, but whose existence and function can be inferred from other forms of archaeological data or by analogy and comparison. For instance, the roof covering of buildings, of which little direct evidence has been retrieved at Çatalhöyük, belongs to this second tier of uncertainty. The presence of holes in the roof, used both as entrances and chimneys, is attested by ladder scars on the walls of some buildings (Hodder 2006: 120; see fig.15.5). Given the double role of these access holes as chimneys, it has been hypothesized that they were usually located immediately above fire installations such as ovens and hearths (Hodder 2006: 107). The issue, however, becomes more complicated when two of such features are present in the same occupation phases, especially when they are in different locations, as is the case with Building 17 in its early and middle phases that we reconstructed in 3D. It remains unclear whether the buildings in these phases had a second access hole or a smaller hole only used for clearing smoke. Since there is no archaeological evidence, the locations of ladders and access holes in this building and the others we reconstructed were marked as hypothetical and color coded in yellow. The basketry, containers, tool sets, and animal hides, which we used to enhance realism and sense of presence in the virtual reconstructions of the Shrine 10 sequence, are largely attested at Çatalhöyük (W. Wendrich and Ryan 2012). Given that the in-situ location of these artifacts is not certain, our uncertainty maps color code them in yellow. The third category encompasses elements displayed with a red overlay that were included in Mellaart's visual restorations of Shrine VIA.10 and VIB.10. Their accuracy is highly uncertain, since their interpretation and location are not supported by additional photographic documentation or other sources of data from the 1960s.

Argument Making and Knowledge Provenance

This study considers archaeological visualization as a visual-analytical practice able to successfully render and reconstruct places of the past. Building on previous work on visual-knowledge representation in Near Eastern archaeology (W. Wendrich, Simpson, and Elgewely 2014: 2; Sullivan, Nieves, and Snyder 2017), we also believe that the significance of a virtual reconstruction depends on how the underlying cognitive processes and interpretative choices are recorded and made available to other scholars. For these reasons, we used the recommendations of the London Charter and Seville Principles to guarantee the intellectual integrity, reliability, and scientific rigor of our multi-temporal reconstructions and compiled an extensive collection of associated metadata and paradata (Lercari et al. 2019). More specifically, we employed the framework proposed by Bruseker, Guillem, and Carboni (2015: 36–37) based on the CIDOC CRM 6.2.1 ontology and CRMinf 0.7 extension, to capture the critical arguments and inference choices we made during all the phases of the study (Fig. 7).

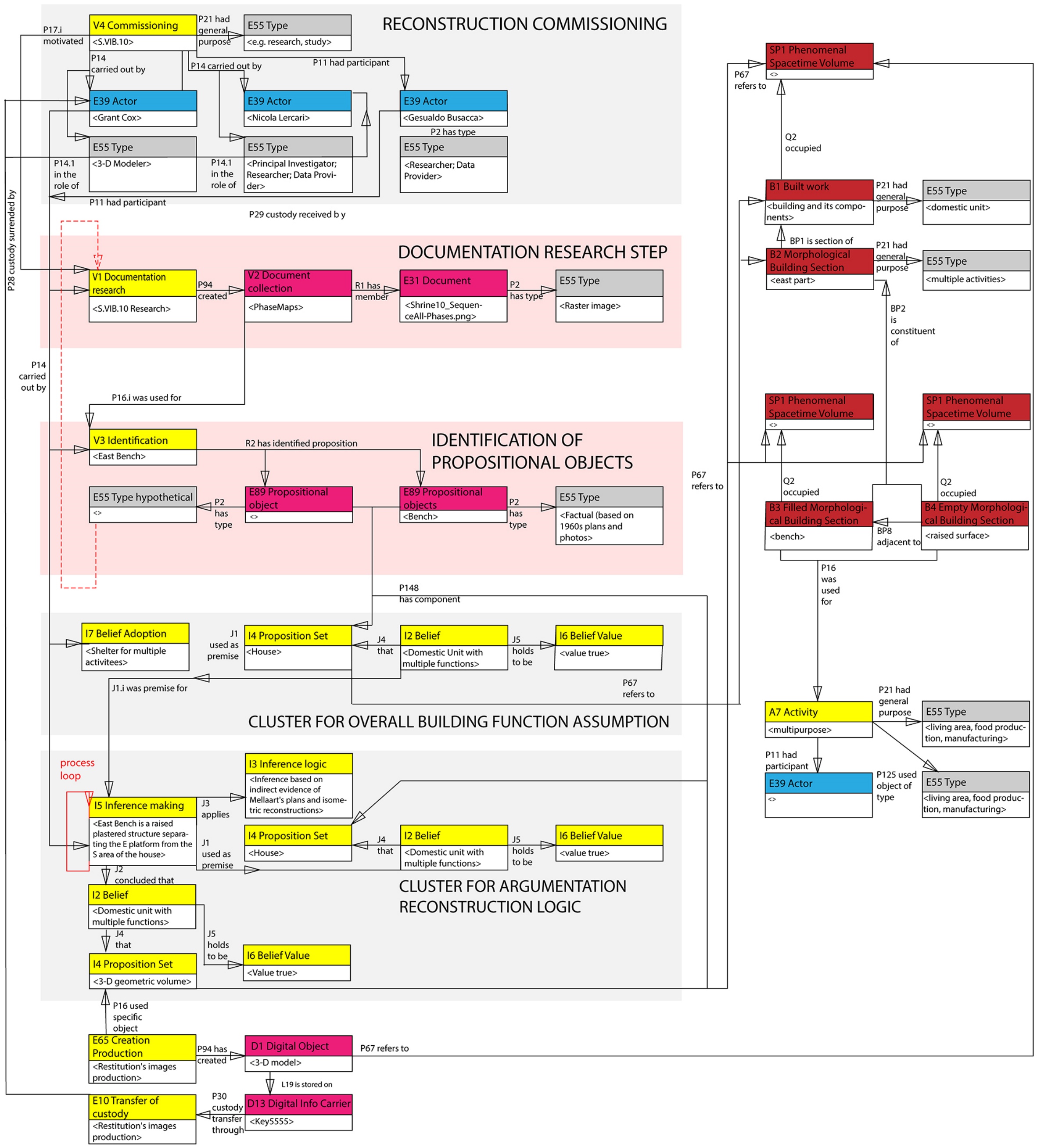

FIG. 7 Graphical presentation of the virtual reconstruction process and argumentation model based on CIDOC CRM used in this study. Courtesy of A. Guillem; adapted from Bruseker, Guillem, and Carboni 2015.

The CRMinf 0.7 extension expands the capability of the CRM, providing additional tools for capturing and curating the 3D-modeling argumentation paradata and their sources. To ensure transparency and track provenance in the data and argumentation knowledge used in this study, we recorded precise information in each of the following phases: 1) reconstruction commissioning; 2) documentation research; 3) identification of propositional objects; 4) functional argumentation cluster; 5) geometric argumentation cluster; and 6) results of argument. Each phase has been described in detail in our paradata as a discrete set of events whose outcomes determine the subsequent activities.

Results and Discussion

In this study, our visualizations of the Shrine 10 sequence are meant to amplify user perception of spatial relationships and enhance interpretation of data. For instance, Figure 4 facilitates immediate perception of direct spatial relationships between the ritual red-painted panels found in the east part of some of those houses and also their temporal connections with buildings that were constructed centuries later (see Fig. 4: Building 17 phases 2.2 and D and Shrine VIB.10 and VIA.10). Similarly, Figures 3 and 5 highlight patterns of continuity in the location of superimposed features (e.g., ovens, hearths, platforms, access holes), thereby allowing scholars to identify new relationships among them (see Figs. 3 and 5). These visualizations combine several visual forms of archaeological information (e.g., GIS phase maps, 3D models, spatial-temporal continuity schematics) into a series of infographics that aim to transcend the "snapshot effect" given by other non-multi-temporal visualization techniques, and they convey interpretative information on the complex archaeological record of Çatalhöyük.

We argue that the visualizations created in this study allow scholars to identify, analyze, discuss, and interpret history making practices in the Shrine 10 sequence with greater ease compared to traditional forms of data curation including printed books, photo collections, or databases (Llobera 2011; Perry 2015; Perry and Johnson 2014). Future research will provide an even more thorough interpretation of history houses by integrating visualized data with additional archaeological information that is less amenable to this kind of visualization, including the human and animal remains that were deposited across the buildings within the sequence and actively retrieved from buried houses.

The Shrine 10 Sequence

Shrine 10 is a series of four superimposed buildings—or five, depending on whether VI.A.10 and VI.B.10 are considered two separate buildings or two phases of the same structure. Based on the preliminary chronological grouping of its stratigraphic levels, the estimated life use of Shrine 10 is approximately 300 years, spanning a significant part of the site's chronology (Fig. 8, Video 1, and Table 1). In view of the high number of rebuilds and burials and their degree of architectural and symbolic elaboration, buildings in this sequence are categorized as history houses (Hodder 2014: 3).

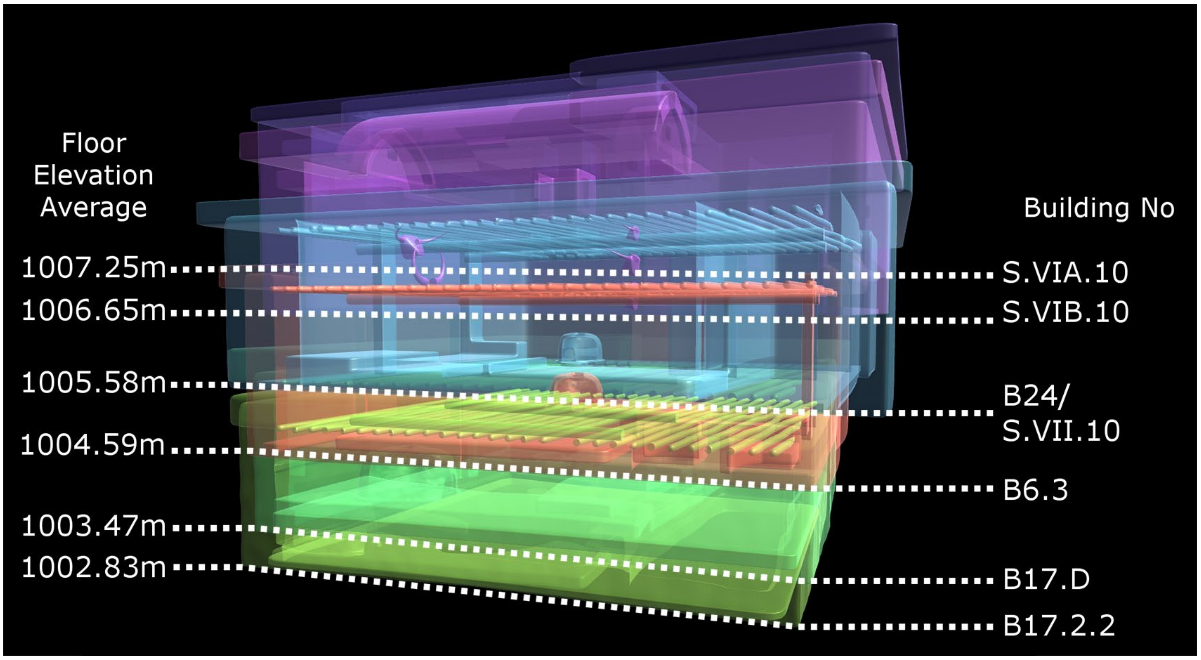

FIG. 8 Snapshot describing the interactive visualization of the Shrine 10 sequence created in Unity 3D. It shows the four reconstructed buildings (total of six phases) and their relative heights. (Courtesy of N. Lercari.)

Building 17

The earliest house in the sequence is Building 17. A sondage conducted below its foundation revealed that this building was constructed on midden deposits, therefore ruling out the existence of underlying buildings (Taylor 2016 67–71). In total, Building 17 contained as many as 22 burials. Its walls, especially in the eastern part of the building, were painted multiple times with monochromatic red or black panels as well as with geometric motifs (Fig. 9).

FIG. 9 3D render of Building 17.2.2 showing simultaneous presence of ovens in both the northeast (left) and south areas (right) of the house and red panel and geometric motif on the east wall (center). Courtesy of G. Cox.

Since burials were sealed by thick, white plaster during the occupation of a house at Çatalhöyük, we decided not to make these features directly visible in the 3D renders and real-time reconstructions of the reconstructed buildings. Nonetheless, this crucial information is represented in our infographics to include the location and pit size of burials excavated in the sequence (see Fig. 4 above).

We argue that our infographics enhance interpretation of history making in the Shrine 10 sequence as these visualizations show the direct spatial correlations between the burials and painted panels in the eastern part of Building 17, further demonstrating their temporal links with paintings found in Shrine VI.10. Additionally, our virtual reconstructions and related paradata facilitate better understanding of how history making was enacted across the site by highlighting the great degree of spatial continuity in the arrangement of features used for food production in Building 17 and overlying structures, particularly its ovens. The earliest versions of the building

FIG. 10 3D render of Building 17.D showing only one oven in the north part of the house and red panel along the east wall. The "dirty area" in the south only includes the hearth and a basin (southwest corner). Courtesy of G. Cox.

Building 6

The next house in the sequence is Building 6, which was built directly on top of the scoured walls of its predecessor. As displayed in our reconstructions, its internal layout underwent a similar progression as Building 17. During an earlier occupation phase (B6.2), not reconstructed in this study, two ovens were located in the northeastern corner of the main room and the northern wall was lined by basins and bins, while a platform and a hearth were located in the southern area. During a later phase (B6.3), the oven was moved to the southern area, while a new platform was built in the northern area of the room (Fig. 11).

FIG. 11 3D render of Building 6.3 showing an oven located in the "dirty area" in the south (notice the absence of the hearth, which was instead located in the side room) and multiple access holes to access the storage room. Courtesy of G. Cox.

The perception of continuity in the delineation and use of space along the base of the north wall in Building 6 becomes apparent in our infographics, wherein a continuous purple line spanning the four reconstructed buildings highlights the repeated layout of the raised northern platform across the Shrine 10 sequence (see Fig. 3). Without the graphic information provided by our visualizations, scholars would only be able to understand the direct spatial and temporal correlations among these buildings' features by conducting complex queries in the ÇRP online database. This advancement demonstrates that our virtual reconstructions and infographics, along with the related paradata, are well suited to aiding interpretation and visualization of the mobility of ovens and "dirty areas" across generations of use.

Building 24–Shrine VII.10

Shrine VII.10 lies directly on top of Building 6 and was excavated almost completely by Mellaart in the 1960s, except for its walls and parts of two small side rooms excavated in the

1990s as Building 24. According to Mellaart (1966: 108–10), no paintings were present, but the building included a series of plaster reliefs and silhouettes depicting bulls and a “stag on a rock.” These features, with the exception of a plastered cattle head, were later reinterpreted as simple “irregularities in the wall plaster” and therefore were purposefully omitted from our 3D model of Shrine VII.10 (Farid 2007: 331) (Fig. 12).

FIG. 12 3D render of Building 24-S.VII.10 showing a bucranium hanging from the north wall, platforms arranged along the western, northern, and eastern walls, and the oven located in the “dirty area” in the south part of the house. Courtesy of G. Cox.

Comparing Building 24–Shrine VII.10 with underlying Buildings 6 and 17, our multi-temporal reconstructions and infographics show a high degree of continuity in the arrangement of their northern platforms, ovens and hearths (south area), and access hole to a side room to the west. The number of burials excavated in this building and their location are not reported by Mellaart and therefore were not included in our infographics. As in the case of other buildings reconstructed in this study, our visualizations of Building 24–Shrine VII.10 also include hypothetical features (second category of data uncertainty), modeled using indirect archaeological evidence from other Çatalhöyük buildings or ethnographic parallels. These features include the access hole and a ladder above the oven, along with additional artifacts including cow hides, baskets, and clay balls (see Figs. 6 a-b above).

Shrine VI.10

Shrine VI.10, the last building in the sequence, was subdivided into two main phases of continuous occupation: VI.B and VI.A. Mellaart (1967: 125-127) identified them as two distinct buildings, but this categorization was then changed by the ÇRP. As shown in our virtual reconstructions, during the later VI.A the main floor was elevated by approximately 60 cm, and an oven was added to the southern wall (Fig. 13).

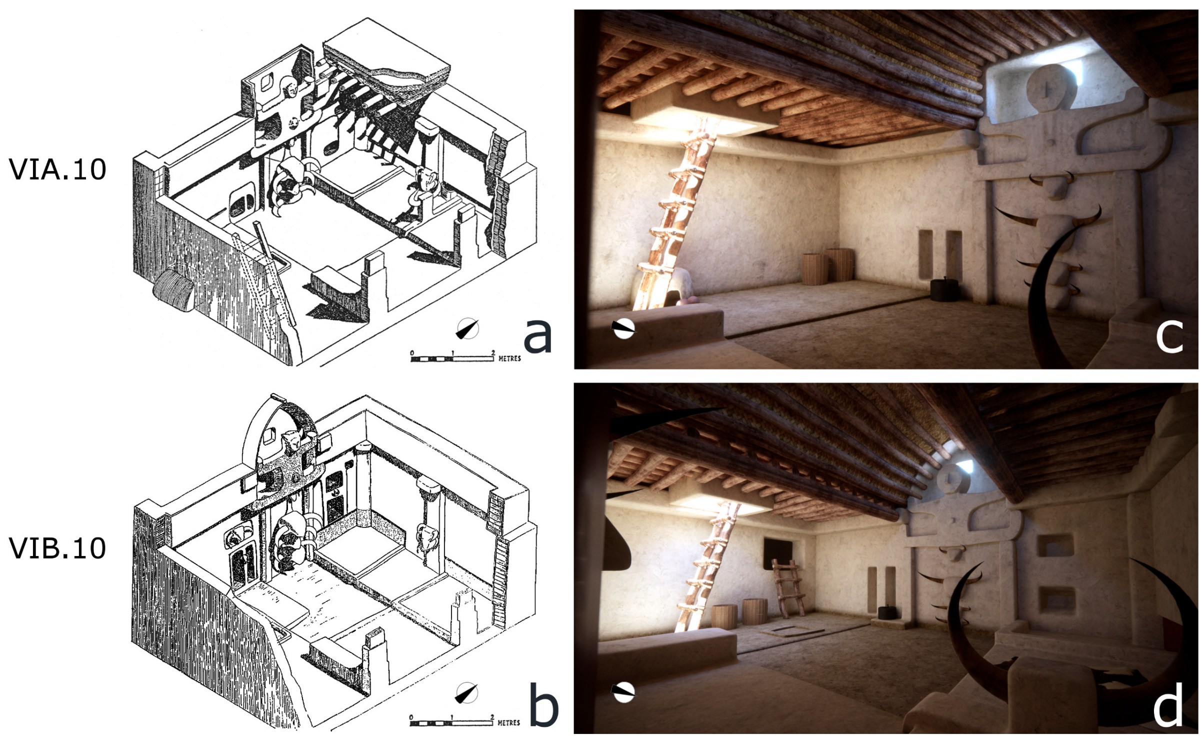

FIG. 13 Comparison of Mellaart's isometric visual restoration of S.VIA.10 (a) and S.VIB.10 (b) and virtual reconstruction of S.VIA.10 (c) and S.VIB.10 (d). Similarities between the two phases are shown in terms of artwork hanging from the east wall and also differences, including dissimilarities in floor levels, the oven missing in phase VIB, and a crawl hole missing in the south wall of VIA. Fig. 13a–b courtesy of G. Huxtable and N. Alcock [Mellaart 1967]; Fig. 13c–d courtesy of G. Cox.

A major discontinuity between VI.B and VI.A is the reconfiguration of the access holes that connected them to adjacent buildings. These access holes were located along the south wall in phase VI.B.10 and in the southern part of the east wall in phase VI.A.10 (Fig. 14a–14c). Other noticeable differences in VI.A are the reduction in size and number of niches cut in its west wall (see Fig. 13c–13d and Video 3).

FIG. 14 Shrine VIA.10 east wall as interpreted by Mellaart (1963, plate XIII) in his isometric restoration (a) and in our virtual reconstruction (b). Fig. 15c is a view of our virtual reconstruction of Shrine VI.B east wall showing discontinuity with later phase VI.A. Fig. 14a courtesy of G. Huxtable and N. Alcock; Fig. 14b–c courtesy of G. Cox.

Building upon Mellaart's virtual restorations and narrative descriptions (1963, plate XIII), our 3D models of both phases of Shrine VI.10 illustrate the similarities of their northern platforms with almost identical features in all three underlying buildings. Our visualizations also emphasize the intense ritual activities performed in this mid-level history house as embodied in ritual structures decorated with plastered animal heads and horns (e.g., bull pillars, bucrania) and painting that we reconstructed in the central part of the east and north walls and especially in the west wall (Mellaart 1963, plate XIII).

As highlighted in our infographics, a low red-painted panel ran along the eastern and northern walls to denote extensive ritual activities in this part of the building associated with at least 32 burials, the highest number in a single building ever recorded by Mellaart (1967: 205) (see Fig. 4 and Table 1 above). Significantly, our multi-temporal reconstructions and infographics show these burials and associated painted panels were built in the same location as in underlying Building 17, constructed hundreds of years earlier. Therefore, we argue that our visualizations allow scholars to better understand the magnitude of this long-term continuity and how the repeated use of space contributes to the creation of house-based history making in this sequence of houses. Conversely, due to the lack of reliable data on skeletal remains and objects retrieval in the history houses excavated by Mellaart, our visualizations cannot represent sodality-based history making practices in the reconstructed buildings.

We also reconstructed a monumental splayed figure, known as "goddess relief," located above the stacked bucrania on the west wall, although not clearly identifiable from Mellaart's photographs (1963). Based on the uncertain interpretation of this monumental plaster feature with an estimated height of more than three meters, our 3D reconstructions display a raised "clerestory," an arched or rectangular roof structure similar to the upper part of the nave in medieval churches (see Figs. 14c–14d and 15b–15c), able to accommodate its in-situ location on the west wall as proposed by Mellaart (1963, plate XIII–XV). Our related uncertainty map necessarily uses a red overlay to reflect the highest level of uncertainty of the clerestory's visualization (see Figs. 6 and 7 above). Finally, our 3D renders and interactive reconstructions clearly show the elaborated bucrania and wall painting that adorned the west, north, and east walls of VI.B.10, maintained in situ and renewed in VI.A.10 even though the southern part of the house was modified.

Significance of the Proposed Multi-temporal 3D Virtual Reconstructions and Infographics in Visualizing History Making at Çatalhöyük

Extensive archaeological evidence from excavations led by both Mellaart and Hodder document continuity in the repeated use of space, habituated practices, and rituals at Çatalhöyük. This diverse corpus of information provides a solid basis for understanding different types of history making within the social landscape of the Neolithic site.

Along with the necessary discussion and evaluation of all available data sources, the archaeological visualization, argument-making, and knowledge-provenance tracking methods discussed in this study provide a more precise representation of the spatial and temporal continuity of architectural and ritual elements in an approach that is well suited for application at archaeological sites worldwide.

Our approach uses a multi-temporal 3D reconstruction, enabling users to glimpse through time and space to visualize the long-term history of a built space. In doing so, our visualizations facilitate analysis and interpretation of repeated building practices and rituals at Çatalhöyük, especially for what concerns the house-based history-making practices (type 1) identified by Hodder. Furthermore, this study successfully applies concepts codified in the London Charter and Seville Principles to the virtual reconstruction and visualization of the complex archaeological context of Çatalhöyük's Shrine 10 Sequence. We ensured the sustainability of our results by structuring and presenting our 3D-modeling argumentation paradata using CIDOC-CRM and conveyed the varying level of accuracy of our virtual reconstructions through uncertainty maps and color coding.

Finally, we made available to other scholars all the results produced in this study, including metadata and paradata, through an online open-access collection that ensures sustainability of our findings and data beyond the lifespan of this project.

In conclusion, the multi-temporal 3D virtual reconstructions and related infographics presented in this study demonstrate that the Shrine 10 sequence is a clear example of the practice of history making based on the repetition in the use of space and the renewal of ritual artworks and features across multiple history houses. Our visualizations are significant as they achieved this goal by providing an unambiguous representation of the complex archaeological record of the Shrine 10 sequence and by visually linking the continuity that exists across these history houses to the habituated building practices, deliberate creation of memories, and shared histories documented at Çatalhöyük.

Acknowledgments

This work is funded by a UC President's Research Catalyst Award (CA-16-376911) and Stanford IRiSS Seed Grant Program. We thank Grant Cox, Jad Aboulhosn, Arianna Campiani, Anaïs Guillem, Ho Jung Yoo, and Ryan Johnson for contributing to the creation of our virtual reconstructions, figures, paradata, and online data collection. We are particularly grateful to Gina Palefsky for editing the manuscript and the Çatalhöyük Research Project team for providing feedback on data collection and visualization.

About the Authors

Nicola Lercari is an Assistant Professor of Heritage Studies at the University of California, Merced. His research focuses on the fields of digital cultural heritage and digital archaeology and is directed towards understanding spatiality (i.e., space, place, and mapping), place-making, and urbanism in ancient cities, using digital methods and technology as a lens to explore these topics with a novel perspective. Lercari has participated in the Çatalhöyük Research Project from 2011–2018 where he examined the role of archaeological virtual reality (VR) and 3D reconstructions in promoting public audience engagement for the understanding of ancient civilizations. At Çatalhöyük, he also investigated how remote sensing and Geographic Information Systems (GIS) can be used to develop new site monitoring and conservation strategies to preserve the fragile earthen architecture of large-scale and complex prehistoric sites. (Nicola Lercari, Ph.D., Assistant Professor of Heritage Studies, Dept. of Anthropology and Heritage Studies, University of California, Merced, nlercari@ucmerced.edu)

Gesualdo Busacca received his PhD in anthropology from Stanford University and his MA in archaeology from the Scuola Superiore di Catania (University of Catania, Italy). Busacca has conducted extensive archaeological research in Sicily, Turkey, and Israel. His PhD dissertation project focuses on the practice and experience of architectural paintings at the Neolithic site of Çatalhöyük, Turkey, using a theoretical approach influenced by the anthropology of craft and practice, "new materialisms," and the archaeology of the senses. Busacca specializes in using GIS to investigate the temporal modifications of paintings, and in performing lighting analysis in 3D environments aimed at exploring the experience of paintings within their original contexts. (Department of Anthropology, Stanford University, Department of Anthropology Main Quad, Building 50 450, Serra Mall, Stanford, CA 94305; gbusacca@stanford.edu)

Cited References

Aparicio Resco, Pablo, and César Figueiredo. 2017. "El Grado de Evidencia Histórico-Arqueológica de Las Reconstrucciones Virtuales: Hacia Una Escala de Representación Gráfica." *Revista Otarq: Otras Arqueologías*, no. 1: 235–247.

Ashley, Michael, Ruth Tringham, and Cinzia Perlingieri. 2011. "Last House on the Hill: Digitally Remediating Data and Media for Preservation and Access." *Journal on Computing and Cultural Heritage (JOCCH)* 4 (4): 13.

Baird, Douglas, Andrew Fairbairn, and Louise Martin. 2017. "The Animate House, the Institutionalization of the Household in Neolithic Central Anatolia." *World Archaeology* 49 (5): 753–776.

Beacham, Richard. 2012. "Defining Our Terms in Heritage Visualisation." In *Paradata and Transparency in Virtual Heritage*, edited by Anna Bentkowska-Kafel, Hugh Denard, and Drew Baker, 7–12. Farnham, UNITED KINGDOM: Taylor & Francis Group. http://ebookcentral.proquest.com/lib/ucm/detail.action?docID=834080.

Beacham, Richard, Hugh Denard, and Franco Niccolucci. 2006. "An Introduction to the London Charter." In *The E-Volution of Information Communication Technology in Cultural Heritage: Where Hi-Tech Touches the Past: Risks and Challenges for the 21st Century*, edited by Marinos Ioannides, 263–89. Budapest: Archaeolingua.

Bertin, Jacques, and William J Berg. 2011. *Semiology of Graphics: Diagrams, Networks, Maps*. Redlands, Calif.: ESRI Press : Distributed by Ingram Publisher Services.

Boz, Başak, and L. D. Hager. 2013. “Living Above the Dead: Intramural Burial Practices at Çatalhöyük.” In *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, 413–40. Cotsen Institute of Archaeology.

Bruseker, G., A. Guillem, and N. Carboni. 2015. “Semantically Documenting Virtual Reconstruction: Building a Path to Knowledge Provenance.” In *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*. Vol. II-5/W3. Taipei.

Cox, Grant. 2011. “Photo-Realistic Reality: Focusing on Artistic Space at Çatalhöyük.” MSc, Southampton: University of Southampton. 2011.

Doerr, Martin. 2003. “The CIDOC Conceptual Reference Module: An Ontological Approach to Semantic Interoperability of Metadata.” *AI Magazine* 24 (3): 75–75. doi:10.1609/aimag.v24i3.1720.

Emele, Martin. 2000. “Virtual Spaces, Atomic Pig-Bones and Miscellaneous Goddesses.” In *Towards Reflexive Methods in Archaeology: The Example at Çatalhöyük*, edited by Ian Hodder, 219–228. Cambridge: McDonald Institute for Archaeological Research.

Farid, Shahina. 2007. “Level IX Relative Heights, Building 2, Buildings 22 & 16 and Building 17.” In *Excavating Çatalhöyük: South, North, and KOPAL Area Reports from the 1995–99 Seasons*, edited by Ian Hodder, 139–226. McDonald Institute for Archaeological Research / British Institute of Archaeology at Ankara.

Forte, Maurizio. 2010. “Introduction to Cyber-Archaeology.” In *Cyber-Archaeology*, edited by Maurizio Forte, 9–14. BAR International Series 2177. Oxford: Archaeopress.

Forte, Maurizio, Nicoló Dell’Unto, Justine Issavi, Lionel Onsurez, and Nicola Lercari. 2012. “3D Archaeology at Çatalhöyük.” *International Journal of Heritage in the Digital Era* 1 (3): 351–78. doi:10.1260/2047-4970.1.3.351.

Frankland, Tom. 2012. “A CG Artist’s Impression: Depicting Virtual Reconstructions Using Non-Photorealistic Rendering Techniques.” In *Thinking beyond the Tool: Archaeological Computing and the Interpretive Process*, edited by Angeliki Chrysanthi, Patricia Murrieta-Flores, Constantinos Papadopoulos, and Jeremy Huggett. Oxford: Archaeopress. https://eprints.soton.ac.uk/203059/.

Hodder, Ian, ed. 1996. *On the Surface: Çatalhöyük 1993-95*. Cambridge: McDonald Institute for Archaeological Research / British Institute of Archaeology at Ankara.

———. 2000. “Developing a Reflexive Method in Archaeology.” In *Towards Reflexive Method in Archaeology: The Example at Çatalhöyük*, edited by Ian Hodder, 3–14. Cambridge: McDonald Institute for Archaeological Research / British Institute of Archaeology at Ankara.

———. 2006. *The Leopard’s Tale: Revealing the Mysteries of Çatalhöyük*. London: Thames & Hudson.

———. 2007. “Çatalhöyük in the Context of the Middle Eastern Neolithic.” *Annual Review of Anthropology* 36 (1): 105–120.

———. 2014. “Introduction and Summary of Summaries.” In *Integrating Çatalhöyük: Themes from the 2000-2008 Seasons*, edited by Ian Hodder, 1–22. Ankara: British Institute at Ankara.

———. 2016. “More on History Houses at Çatalhöyük: A Response to Carleton et Al.” *Journal of Archaeological Science* 67 (March): 1–6. doi:10.1016/j.jas.2015.10.010.

———. 2018. "Introduction: Two Forms of History Making in the Neolithic of the Middle East." In *Religion, History, and Place in the Origin of Settled Life*, edited by Ian Hodder, 1–32. Boulder: University Press of Colorado.

Hodder, Ian, and Craig Cessford. 2004. "Daily Practice and Social Memory at Çatalhöyük." *American Antiquity* 69 (1): 17–40.

Hodder, Ian, and Peter Pels. 2010. "History Houses: A New Interpretation of Architectural Elaboration at Çatalhöyük." In *Religion in the Emergence of Civilization: Çatalhöyük as a Case Study*, edited by Ian Hodder, 163–186. Cambridge: Cambridge University Press.

Jones, Ian W. N., and Thomas E. Levy. 2018. "Cyber-Archaeology and Grand Narratives: Where Do We Currently Stand?" In *Cyber-Archaeology and Grand Narratives*, 1–17. One World Archaeology. Cham: Springer. doi:10.1007/978-3-319-65693-9_1.

Kensek, Karen M., Lynn Swartz Dodd, and Nicholas Cipolla. 2004. "Fantastic Reconstructions or Reconstructions of the Fantastic? Tracking and Presenting Ambiguity, Alternatives, and Documentation in Virtual Worlds." *Automation in Construction*, Conference of the Association for Computer Aided Design in Architecture, 13 (2): 175–86. doi:10.1016/j.autcon.2003.09.010.

Knabb, Kyle A., Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy. 2014. "Scientific Visualization, 3D Immersive Virtual Reality Environments, and Archaeology in Jordan and the Near East." *Near Eastern Archaeology* 77 (3): 228–32. doi:10.5615/neareastarch.77.3.0228.

Lercari, Nicola. 2017. "3D Visualization and Reflexive Archaeology: A Virtual Reconstruction of Çatalhöyük History Houses." *Digital Applications in Archaeology and Cultural Heritage* 6 (2017). doi:10.1016/j.daach.2017.03.001.

———. 2018. "Virtually Rebuilding Çatalhöyük History Houses." In *Religion, History and Place in the Origin of Settled Life*, edited by Ian Hodder, 263–82. Boulder: University of Colorado Press.

Lercari, Nicola, Gesualdo Busacca, Grant Cox, Jad Aboulhosn, Anaïs Guillem, and Arianna Campiani. 2019. "Data from: A Glimpse through Time and Space: Visualizing Spatial Continuity and History-Making at Çatalhöyük, Turkey." UC San Diego Library Digital Collections. https://doi.org/10.6075/J0WD3XX2.

Lercari, Nicola, Emmanuel Shiferaw, Maurizio Forte, and Regis Kopper. 2018. "Immersive Visualization and Curation of Archaeological Heritage Data: Çatalhöyük and the Dig@IT App." *Journal of Archaeological Method and Theory* 25 (2): 368–392. doi:10.1007/s10816-017-9340-4.

Levy, Thomas E. 2013. "Cyber-Archaeology and World Cultural Heritage: Insights from the Holy Land." *Bulletin of the American Academy of Arts & Sciences* 66: 26–33.

Llobera, Marcos. 2011. "Archaeological Visualization: Towards an Archaeological Information Science (AISc)." *Journal of Archaeological Method and Theory* 18 (3): 193–223.

Lopez-Menchero, Victor Manuel, and Alfredo Grande. 2011. "The Principles of the Seville Charter." In *CIPA Symposium Proceedings*, 2011:2–6. http://congressgate.com/cipa/proceedings/pdfs/B-2%20Seville%20charter/Lopez%20Menchero.pdf.

Mellaart, James. 1963. "Excavations at Çatal Hüyük, Second Preliminary Report, 1962." *Anatolian Studies*, no. 13: 43–103.

———. 1966. "Excavations at Çatal Hüyük, Fourth Preliminary Report, 1965." *Anatolian Studies*, no. 16: 165–191.

———. 1967. *Çatal Hüyük: A Neolithic Town in Anatolia*. London: Thames and Hudson. http://journals.cambridge.org/abstract_S0003598X00033998.

———. 1998. "Çatal Hüyük: The 1960s Seasons." In *Ancient Anatolia: Fifty Years' Work by the British Institute of Archaeology at Ankara*, edited by Roger Matthews, 35–41. London: British Institute of Archaeology at Ankara.

Mills, Barbara. 2014. "Relational Networks and Religious Sodalities at Çatalhöyük." In *Religion at Work in a Neolithic Society: Vital Matters*, edited by Ian Hodder. Cambridge: Cambridge University Press.

Moore, Andrew Michael Tangye, Gordon C. Hillman, Anthony J. Legge, and J. Huxtable. 2000. *Village on the Euphrates: From Foraging to Farming at Abu Hureyra*. Oxford: Oxford University Press.

Morgan, Colleen L. 2009. "(Re)Building Çatalhöyük: Changing Virtual Reality in Archaeology." *Archaeologies: Journal of the World Archaeological Congress* 5 (3): 468–87. doi:10.1007/s11759-009-9113-0.

Niccolucci, Franco. 2012. "Setting Standards for 3D Visualization of Cultural Heritage in Europe and Beyon." In *Paradata and Transparency in Virtual Heritage*, edited by Anna Bentkowska-Kafel, Hugh Denard, and Drew Baker, 23–36. Farnham, Surrey, England; Burlington, VT: Ashgate. http://public.eblib.com/choice/publicfullrecord.aspx?p=834080.

Pang, Alex T., Craig M. Wittenbrink, and Suresh K. Lodha. 1997. "Approaches to Uncertainty Visualization." *The Visual Computer* 13 (8): 370–90. doi:10.1007/s003710050111.

Perry, Sara. 2015. "Crafting Knowledge with (Digital) Visual Media in Archaeology." In *Material Evidence: Learning from Archaeological Practice*, edited by Robert Chapman and Alison Wylie, 189–210. New York: Routledge.

Perry, Sara, and Matthew Johnson. 2014. "Reconstruction Art and Disciplinary Practice: Alan Sorrell and the Negotiation of the Archaeological Record." *The Antiquaries Journal* 94: 323–352.

Pilloud, Marin A., and Clark Spencer Larsen. 2011. "Official and Practical Kin: Inferring Social and Community Structure from Dental Phenotype at Neolithic Çatalhöyük, Turkey." *American Journal of Physical Anthropology* 145 (4): 519–30. doi:10.1002/ajpa.21520.

Potter, Kristin, Paul Rosen, and Chris R. Johnson. 2012. "From Quantification to Visualization: A Taxonomy of Uncertainty Visualization Approaches." In *Uncertainty Quantification in Scientific Computing*, edited by Andrew M. Dienstfrey and Ronald F. Boisvert, 226–49. IFIP Advances in Information and Communication Technology. Springer Berlin Heidelberg.

Smith, Steve, Steve Cutchin, Alyn Rockwood, Adel Saad, Neil G. Smith, and Thomas E. Levy. 2012. "Demo Paper: Virtual and Immersive Experience Presentation of Cultural Heritage Sites." In *2012 18th International Conference on Virtual Systems and Multimedia*, 645–48. doi:10.1109/VSMM.2012.6365998.

Sullivan, Elaine, Angel David Nieves, and Lisa Snyder. 2017. "Making the Model: Scholarship and Rhetoric in 3-D Historical Reconstructions." In *Making Things and Drawing Boundaries*, 301–16. Experiments in the Digital Humanities. Minneapolis: University of Minnesota Press. http://www.jstor.org/stable/10.5749/j.ctt1pwt6wq.38.

Swogger, James. 2000. "Image and Interpretation: The Tyranny of Representation?" In *Towards Reflexive Method in Archaeology: The Example at Çatalhöyük*, edited by Ian Hodder, 143–52. Cambridge: McDonald Institute for Archaeological Research.

Taylor, James S. 2017. “Excavations in the South Area.” Archaeological excavation report. Çatalhöyük Archive Report. Stanford, CA: Stanford University.
Tufte, Edward R. 1983. *The Visual Display of Quantitative Information*. Cheshire, Conn. (Box 430, Cheshire 06410): Graphics Press.
Ware, Colin. 2012. *Information Visualization: Perception for Design*. Boston: Morgan Kaufmann. http://www.books24x7.com/marc.asp?bookid=51036.
Wendrich, W. Z., JEMF Bos, and K. M. Pansire. 2006. “VR Modeling in Research, Instruction, Presentation and Cultural Heritage Management: The Case of Karanis (Egypt).” In *The Evolution of Information Communication Technology in Cultural Heritage. Where Hi-Tech Touches the Past: Risks and Challenges for the 21st Century, Nicosia*, edited by Marinos Ioannides, Franco Niccolucci, and Katerina Mania, 225–30. Proceedings of the 7th International Symposium on Virtual Reality, Archaeology, and Cultural Heritage (VAST 2006). Geneve, Switzerland: Eurographics Association.
Wendrich, Willeke, and Philippa Ryan. 2012. “Phytoliths and Basketry Materials at Çatalhöyük (Turkey): Timelines of Growth, Harvest and Objects Life Histories.” *Paléorient* 38 (1/2): 55–63.
Wendrich, Willeke, Bethany Simpson, and Eiman Elgewely. 2014. “Karanis in 3D: Recording, Monitoring, Recontextualizing, and the Representation of Knowledge and Conjecture.” *Near Eastern Archaeology* 77 (3): 233–37. doi:10.5615/neareastarch.77.3.0233.
Zuk, Torre, and Sheelagh Carpendale. 2006. “Theoretical Analysis of Uncertainty Visualizations.” In *Visualization and Data Analysis 2006*, 6060:606007. International Society for Optics and Photonics. doi:10.1117/12.643631.