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Experiencing Ancient Buildings from a 3D GIS Perspective: a Case Drawn from the Swedish Pompeii Project

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Abstract In recent times, archaeological documentation strategies have been considerably improved by the use of advanced 3D acquisition systems. Laser scanning, photogrammetry and computer vision techniques provide archaeologists with new opportunities to investigate and document the archaeological record. In spite of this, the amount of data collected and the geometrical complexity of the models resulting from such acquisition processes have always prevented their systematic integration into a geographic information systems (GIS) environment. Recent technological advances occurred in the visualization of 3D contents, led us to overcome the aforementioned limitations and set up a work pipeline in which was possible to put the 3D models not only in the context of data visualization but also in the frame of spatial analysis. The case study described is a part of the Swedish Pompeii Project, a research and fieldwork activity started in 2000 with the purpose of recording and investigating an entire Pompeian city block, Insula V 1. As an additional part of the research, a laser scanning acquisition campaign was conducted in the last few years. The resulting models were thus meant to be used to develop further research lines: Among these, a 3D GIS system was expected to be set up with the purpose to (i) collect in the same geo-referenced environment, different typologies of documentation gathered in the context of the Swedish Pompeii Project; (ii) inter-connect 3D models with the project website; (iii) use the third dimension as a further analytical field of investigation, in the form of spatial analysis and cognitive simulation.

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Introduction

In the last two decades, the evolution of spatial and visual technologies has strongly impacted archaeology. Technological development has always represented an important part of improving archaeological best practices, and the recent exponential growth of digital tools has affected archaeology at all levels. The great possibilities offered by the introduction of new instruments of documentation, such as terrestrial laser scanners, and image-based 3D modelling, create the prerequisites to experiment and introduce new methodologies to construct and use 3D models to study and analyse activities that characterized at the different phases of archaeological sites.

Despite the large number of case studies presented in the literature where texturized 3D models have been presented to further architectural documentation of ancient buildings, very few experiments have been developed with the aim of investigating how these typologies of information can be efficiently employed to study ancient buildings in the field.

Recently, several experiments have been performed in order to test the use of 3D models for the documentation of archaeological investigations that are currently in progress. Questions concerning how the use of 3D models has affected the perception of archaeological interpretation have been raised (Callieri *et al.* 2011; Dellepiane *et al.* 2012; Opitz and Nowlin 2012), and several examples have been discussed in order to demonstrate the potential of 3D models within and in support of archaeological documentation methods (Doneus *et al.* 2005; De Reu *et al.* 2014; Forte *et al.* 2012; Losier *et al.* 2007). Despite encouraging results in acquiring and generating 3D data in the framework of an archaeological field campaign—in terms of quality and sustainability—default use of 3D models in a direct spatial relation with all other information acquired during the documentation process has previously represented a flagrant limitation of the method. The problems encountered have been extensively discussed and theorized (Wheatley and Gillings 2002; Barceló *et al.* 2003; Allen *et al.* 2004; Frischer 2008), but few attempts have been made to find solutions.

An important action in this direction is represented by MayaArch3D (http://mayaarch3d.unm.edu/), a cutting edge framework focused in researching innovative approaches to make available online complex archaeological data. In the framework of this project, a prototype tool called QueryArch3D has been developed. This instrument is an online repository that brings together 3D models, geographic information systems (GIS) maps and virtual environments for visualizing architecture and landscapes (http://mayaarch3d.unm.edu/). QueryArch3D allows visualizing and linking together 3D data at different levels of details providing the users with the opportunity to perform queries and analysis using heterogeneous dataset, most of them previously combined in GIS context such as thematic maps and DTM (Agugiaro *et al.* 2011; Agugiaro and Remondino, 2014). However, this platform, to be implemented and used, requires a major input from IT professionals and computer scientists (Von Schwerin *et al.* 2011). Despite its enormous potentials, the complex workflow of data implementation prevents the use of this instrument in more "traditional" archaeological investigation campaign.

GIS have been identified as the most "natural" visualization platform to further the interconnection between all different types of data (Opitz and Nowlin 2012; De Reu *et al.* 2013; Dell'Unto 2014). GIS is currently considered one of the most influential technologies to manage and analyse archaeological information, and it is currently used in many countries as a standard for archaeological documentation (Allen *et al.* 1990; Lock and Stancic 1995; Wheatley and Gillings 2002; Chapman 2006; Conolly and Lake 2006). The importance and the potentialities in using 3D data inside GIS have been extensively discussed and theorized in the literature (Conolly and Lake 2006; Lock 2001:161; Lock 2003:182; Haklay 2002:47–57). It is the aim of the present paper to present a case study implementing such technology.

The technological limitations that characterized GIS in importing and managing 3D models have previously been witnessed by the fact that most of the case studies presenting an integrated use of 3D and GIS technology were characterized by the implementation of digital elevation models (DEM) such as triangulated irregular network (TIN) (Katsianis *et al.* 2008) and/or extruded polygons (Agugiaro *et al.* 2011). These limitations always prevented GIS from being used as an effective mean to import and manage 3D features resulting from the use of instruments such as laser scanner, photogrammetry or computer vision.

Successfully implementing this typology of data within a spatial geo-database would allow for the experience of a completely new approach to the dataset collected in the field, adding reflexivity and multivocality to the interpretation process and increasing the possibility of reaching and connecting different information through a non-linear approach (Hodder 1999:183). To achieve this goal, it is not sufficient to import 3D models as virtual replicas of the site into a GIS platform, but it is necessary to link as much as possible all of the information in order to provide researchers and scholars with the opportunity to visualize multiple patterns through different data connections.

One of the first attempts in this direction has been made in the framework of the documentation and interpretation process at the prehistoric site of Paliambela Kolindros, Greece, where for the first time, a formal data model for archaeological documentation was designed to combine the potentials of a GIS platform with large use of 2.5D raster surfaces and 3D vectors (Katsianis *et al.* 2008). Despite the limitations of GIS in managing more complex textured 3D models, this project proved how the systematic integration of 3D information in the framework of a 3D GIS platform could open up more efficient data structuring and archaeological interpretation solutions.

Another interesting project developed in this direction has been realized in the framework of the virtual interpretation of the abbacy of Niedermunster, France (Koehl and Lott 2008). This work presents an interesting review of the use of multipatch files to manage and integrate 3D data of archaeological structures in the framework of 3D GIS platforms. In this regard, multipatch files were designed for the boundary representation of 3D objects (ESRI 2012); this data format is being used more and more to manage 3D information. Despite the limitations of GIS software in editing 3D models and the impossibility at that time of importing a 3D textured boundary model, this project proved how the combination of GIS and 3D data can be efficiently employed to monitor and visualize the archaeological relations that characterized investigation of ancient buildings.

More recent implementations of multipatch files and 3D GIS visualization systems allow textured 3D models to be imported and connected with customized geo-databases. These new tools open new possibilities for further exploring the use of 3D models to create and visualize new data connections between the different typologies of information that characterize any archaeological context and therefore perform a more efficient and accurate site interpretation.

The project described in this paper has been developed with the goal of defining an efficient and robust workflow to implement geo-referenced 3D textured models (acquired by means of laser scanner and image-based 3D modelling). The development and the use of a data model of this type within the framework given by the Swedish Pompeii Project have allowed for mapping the limits and potential in using such a typology of information to document and analyse ancient structures. In particular, the 3D GIS data model has been used (i) to test its effectiveness in documenting the archaeological structures of the house of *Caecilius Iucundus*, (ii) to evaluate the efficiency of the GIS system in providing quantitative information on the conservation status of the structures and (iii) to design and test new solutions to gain more accurate information about the geometrical relations of walls shared between adjacent rooms, an important constituent in the building of all Pompeian *insulae*, which has always presented problems to the study given that the height of the preserved walls impedes overview when studied on site. In addition, the interpretative framework provided by 3D GIS will be tested as a means for simulating cognitive processes that could have occurred within the ancient space of the Roman buildings of Pompeii based on the visual analysis targeting symbolic elements located inside.

Pompeii—a 3D Revival

During autumn 2000, the Swedish Institute in Rome began a field documentation campaign with the goal of recording and studying a full Pompeian city block, *Insula* V 1. From the very beginning, different types of documentation techniques and an approach of multiple methods were tested in order to explore what was then the most accurate and least costly (in time and money) description of the relations between different features that characterize the standing structures of ancient city blocks in Pompeii.

The project aim to document an entire *insula* opened the search for a conjoint description method that would encompass as many different aspects of the ancient buildings as possible, preferably in one single visualization, which would allow researchers to consider its different constituents (houses) not as separate entities but as part of a total (Fig. 3). This approach further underscored the importance of focusing on the relation between the different types of entities that characterize Pompeian domestic architecture in order to comprehend the development of Pompeian building and social history (Leander Touati 2010; Staub 2009).

During the progression of the archaeological data collected in the field, in order to promote both detail and overview analysis, the Swedish Pompeii Project developed a digital research platform characterized by its simplicity in recording and its unique transparency. The data collected during the field campaigns are syntactically organized and published on a website (www.pompejiprojektet.se/insula.php) that allows rapid access to different levels of data, advancing from general information towards increasingly more detailed documentation, presented in photographs, texts and graphics. It includes ortho-mosaics of the ancient standing structures, ground and section plans as well as chosen floors and elevations. In addition to this visual presentation, it also contains written reports (Fig. 1).

Since the fall of 2011, Lund University (Institute of Archaeology and Ancient History together with the Humanities Laboratory), in collaboration with the National Research Council of Italy (Institute of information Technology and science “A.Faedo”), began a project of digital acquisition by means of integrated spatial technologies, such as phase shift laser scanners and image-based 3D modelling of the *Insula* V 1 (Dell’Unto *et al.* 2013b).

The aim of this work was to acquire a high-resolution model of the entire city block in order to (i) provide a more accurate documentation of the structures that characterize the *insula* and (i) use the 3D dataset to increase the possibilities for studying relationships between the different constituents that characterize Pompeian domestic architecture. The virtual structures developed so far have been used as a geometrical reference to interpret several parts of the city block (Dell’Unto *et al.* 2013a). Post-processed, it has been added to and combined with the documentation previously produced by the project.

The material developed in the framework of this project has been employed to design a new data model for the archaeological documentation of *insula* V 1, which combines a 3D GIS platform with the use of textured 3D models of the ancient structures previously acquired by means of laser scanner and image-based 3D modelling techniques.

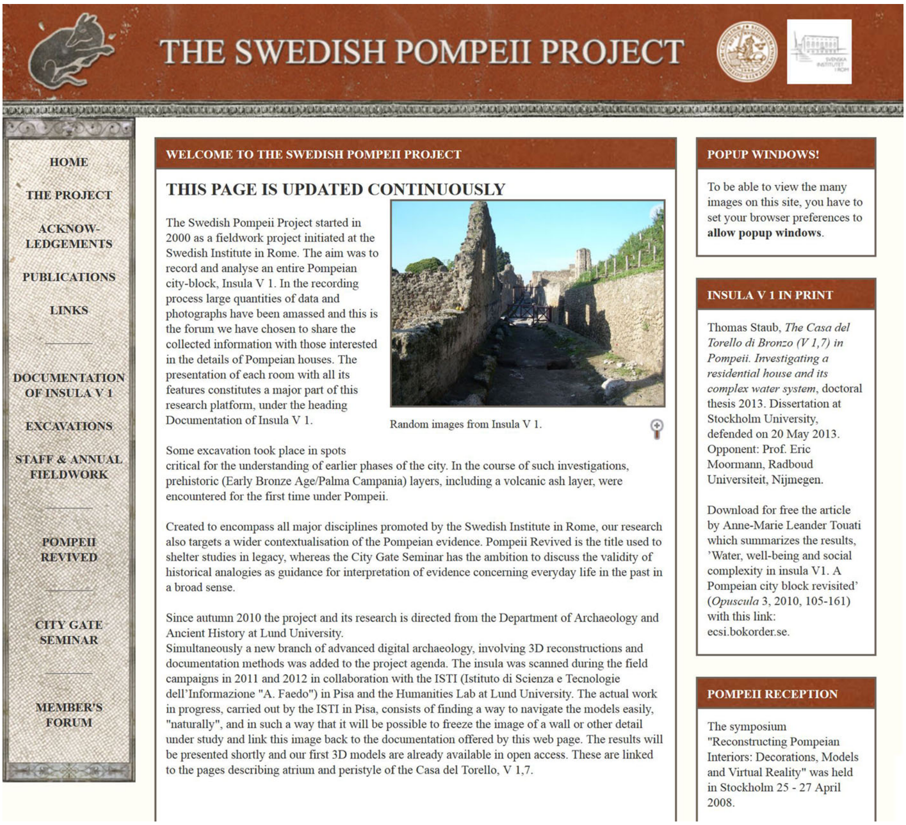

Fig. 1 Website of the Swedish Pompeii Project. For the archaeological dataset, visit Documentation of Insula V 1

For the reason that the maximum transparency should also include the 3D data, we experimented with using WebGL to visualize the gathered 3D data directly through web browsers, in order to connect this new experimental approach with the classic documentation disseminated during these years through the internet.

The development of such web access to visualize the 3D data would provide anyone interested in studying *insula* V 1 an opportunity for direct access to the information elaborated by the project team.

Acquisition Campaign

The acquisition campaigns took place during the fall of 2011 and 2012; a team of six people was employed (three from Sweden—Department of Archaeology and Ancient History—and three from Pisa—CNR). Two phase shift scanners (a Faro Focus 3D and a Faro PHOTON 120) were used in parallel to cover the whole surface (1,330 m^2) of the *insula*.

The complex structure of the area needed careful acquisition planning, where different features of the scanners (in terms of flexibility and portability) were taken into account. The total time for acquisition was 7 days (3 days in 2011 and 4 days in 2012), for a total of 326 scan positions (Fig. 2). The average sampling rate was of 1 cm at a 10-m distance, and the total number of acquired points was more than 1 billion.

The fast acquisition time and the amount of scan positions obtained in a few days were a consequence of the choice to not use markers. Given the amount and overlapping of scans, it was decided to apply the markerless alignment procedure (see below).

In addition, Image-based 3D modelling was also used to acquire details: The more interesting structures, like some portions of the hydraulic system, were carefully acquired using images.

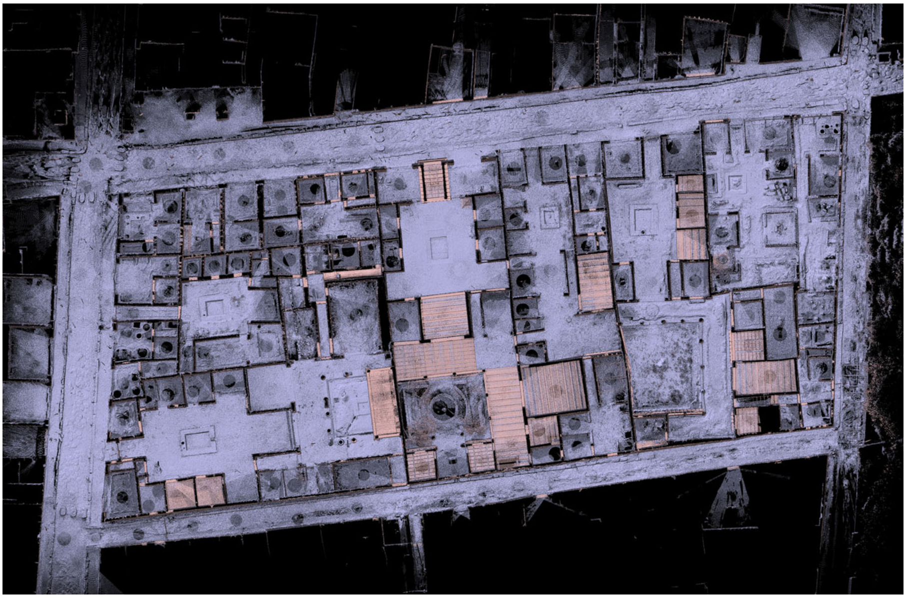

Fig. 2 This image shows the complete aligned dataset of point clouds realized to document the insula

Data Post-processing

While the scanning campaign was successful and very good coverage of the surface was obtained, the data processing represented a challenge. This was mainly due to the size of the acquired area and to the amount of data to handle (Dell'Unto et al. 2013b).

Moreover, the absence of markers brought on the need to align the scans by finding an initial alignment through the indication of a few correspondences among them.

Hence, after a cleaning phase where unwanted data were eliminated from the scans, the alignment process was organized as follows:

- The entire area was divided into blocks (roughly following the organization of the houses in the *insula*).
- The scans describing each area were aligned independently with an attempt to keep the alignment error as low as possible.
- The areas were then aligned by taking advantage of the overlapping surfaces.
- Finally, a global alignment was calculated for the whole area.

Even though the amount of data was massive, it was possible to perform a global alignment that resulted in an average registration error of less than 1.5 cm (Fig. 2).

The global aligned point cloud was then used to generate several 3D models of the *insula* (Fig. 3). All of them were obtained through a Poisson surface reconstruction. In addition to the model of the whole *insula* (which resulted in a 25 million triangles mesh), other models at higher detail were produced for sub-portions of the *insula*, like the house of *Caecilius Iucundus* (Fig. 4).

The entire geometry processing was performed using MeshLab (Cignoni *et al.* 2008), an open source mesh processing tool.

Once the 3D meshes were available, the colour information was added. In this process, the already extant image dataset, documenting every portion of the *Insula* was used. The meshes were processed using MeshLab and Blender, the images were aligned on the meshes

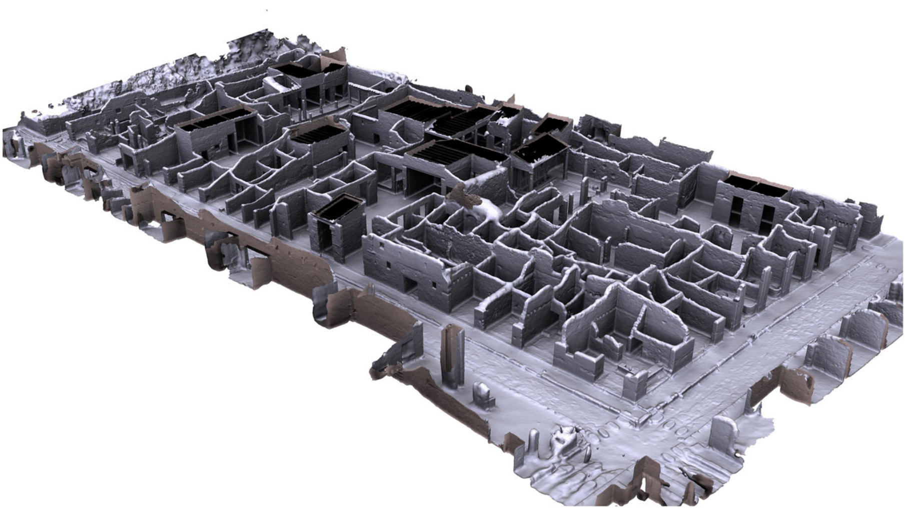

Fig. 3 This image shows the entire dataset aligned and meshed

Fig. 4 This image shows triclinium O of the house of *Caecilius Iucundus*. Ortho-mosaics to the *left*, imported into the meshed 3D model to the *right*

using an approach based on mutual information (Scopigno *et al.* 2012) and the colour was projected in order to obtain a high detail description of colour information (Fig. 4).

A 3D GIS for *Insula* V 1

Structuring the 3D GIS Dataset

As mentioned above, one of the aims of the present project was to investigate the use of 3D models previously acquired as a means to improve the documentation strategies of a complex archaeological site. Accordingly, one of the most challenging parts of the work was to set up a fully functioning 3D geographic database to manage the archaeological documentation collected by the Swedish mission in *insula* V 1. This was basically achieved through the integrated use of digital tools enabling users to work with different types of files (3D, raster, vector, pictures). At the core of the system, a GIS platform was required to manage and interconnect diverse typologies of information such as 3D models, vector and raster files. As previously mentioned, the potentialities provided by GIS in the documentation process of an archaeological record are well known and should be further enhanced with the addition of 3D data. As Llobera (2003) stresses, traditional, bi-dimensional GIS have strong limitations, as they do not allow archaeologists to investigate the cognitive framework that related the ancient inhabitants with their environment (landscape/building). Part of the research related to finding new techniques of documentation methodology in the study of *insula* V 1 was aimed at overcoming these limitations by testing an integrated approach to load 3D models derived both from laser scanner acquisition and image-based 3D modelling techniques on a GIS platform. ESRI ArcGIS software appeared to be the best suited for the purpose.

Combined with ESRI ArcGIS software, the structure of the geo-database makes it possible to build up a system of geographical datasets where basic data storage functions are implemented along with a set of tools aimed at maintaining data integrity, defining topologies and setting relationships between features. In addition, the recent technical improvements made on the already existing 3D Analyst extension make ArcGIS one of the best suited environments to manage 3D geo-spatial content. Among these improvements, it is worth mentioning a high-quality data visualization experience, a general speed up of rendering and better performing memory allocation settings (ESRI 2010). Furthermore, it is even possible to perform more complex 3D editing operations, which can allow users for example to digitize features straight on the models. In brief, the adoption of such software is intended to provide expert users with a complete environment not just to visualize 3D models but to put them into the wider context of traditional GIS analysis, which is usually performed on 2D/2.5D features. Another important aspect to be stressed is the fact the ArcGIS suite is relatively user-friendly compared to other GIS products, which often require an extensive IT background to use. In this way, archaeologists involved in the Swedish Pompeii Project can easily interact with the 3D GIS, performing most of the different tasks enabled (switching through the layers, querying, digitizing, measuring, etc.). In this sense, the development of a visual platform that allows researchers and scholars to explore the data without receiving any technical support increases aspects of multivocality and reflexivity.

As a first step in data implementation, a spatial database management system (Geo-DBMS) was designed to collect all of the available documentation related to the *Insula* V 1. To verify the feasibility of this project pipeline, the southernmost of the two parts constituting the double atrium house of *Caecilius Iucundus* (south house) was chosen as a test case.

According to the scheme presented above (Fig. 7), the general mapset was given by, respectively, (i) a ground plan, (ii) the 3D models and (iii) the digitized features derived from the topographical survey. As for the ground plan adopted and, in general, for the overall system, the Italian datum Rome 1940 Gauss Boaga (EPSG 3004) was chosen because it is the standard format currently in use by the Archaeological Superintendence of Pompeii (Foss and Dobbins 2007). A raster dataset of maps spanning in scale from 1:1000 to 1:20 was added; a general plan of Pompeii's archaeological area was completed with the recently established plan drawn in the field during the work of the Swedish Pompeii Project and verified by comparison with the scanned data, in particular, with a detailed plan of *Caecilius Iucundus*' South House. A digital elevation model (DEM) of the house was obtained by extracting elevation values from vector points digitized over the scanned house plan. On a larger scale, a less resolute DEM (one spot per 20 m) provided us with the topography of the Pompeii area.

The following step was the 3D model GIS implementation. As previously mentioned, few attempts have been made thus far to include such complex 3D models into a GIS project. Among these, it is worth mentioning a pioneering work carried out by Koehl and Lott (2008), which illustrates an integrated approach of 3D acquisition techniques and GIS implementation. More recently, Opitz and Nowlin (2012) described a work pipeline for implementing photogrammetrically derived meshes into a GIS. Nevertheless, our experiment still constitutes one of the few examples of integrating geometrically complex 3D data in a geo-referenced system in which analysis and interpretation can be applied. In the context of the Swedish Pompeii Project, the attempt was to push forward this research line by implementing a novel pipeline to manage 3D data in a fully functioning GIS environment. At a first stage of the process, 3D models previously optimized and textured using high-resolution images acquired in the framework of the Swedish Pompeii Project were scaled based on a scale factor of 0.001, which corresponds to the difference in measurement units used in data acquisition (millimetres) and GIS data visualization (metres). Subsequently, data were imported as COLLADA files into the ArcScene 3D Analyst extension, where the previously geo-referenced maps provided the basis for locating the 3D models at their absolute coordinates (Fig. 5).

The 3D Analyst extension of ArcGIS was used to import and transform the imported COLLADA file into a multipatch file. Each model was then moved along the *x*- and *y*-axes by using editing tools enabling roto-translation operations. With the plan of *Caecilius Iucundus*' house as a reference map, the model of each room was set at its actual location. Moreover, the snapping tool allowed the models to be matched together with a degree of accuracy less than 1 mm, resulting in the exact alignment of *Caecilius Iucundus*' south house at its actual, absolute *x* and *y* coordinates. A further issue addressed was the actual alignment along the *z*-axis; in order to get it, additional information had to be implemented based on the elevation dataset related to the house. For this purpose, a set of height points was digitized over the 1:20 scale scanned map in order to provide the references needed for the 3D building alignment. Next, a digital elevation model was produced based on the interpolation of those vector points. The DEM provided the base level for the house plan which was located at its exact absolute *z* coordinates. Finally, the multipatch feature of the house was "lifted up" to match its ground floor according to the DEM plan (Fig. 6).

The final step of this project pipeline was the linkage between the 3D models and the database structure of the Swedish Pompeii Project website (http://www.pompejiprojektet.se/insula.php). The design of the metadata architecture was based on the original framework featured by the project website, which has the room as the basic database entity. Thus, its structure was related both to the 3D object (one-to-one relationship) and to other entities, such as architectural remains, photographs and drawings (one-to-many relationship), storing information connected to the room. The relational structure was then completed by importing all of the tables into the geo-

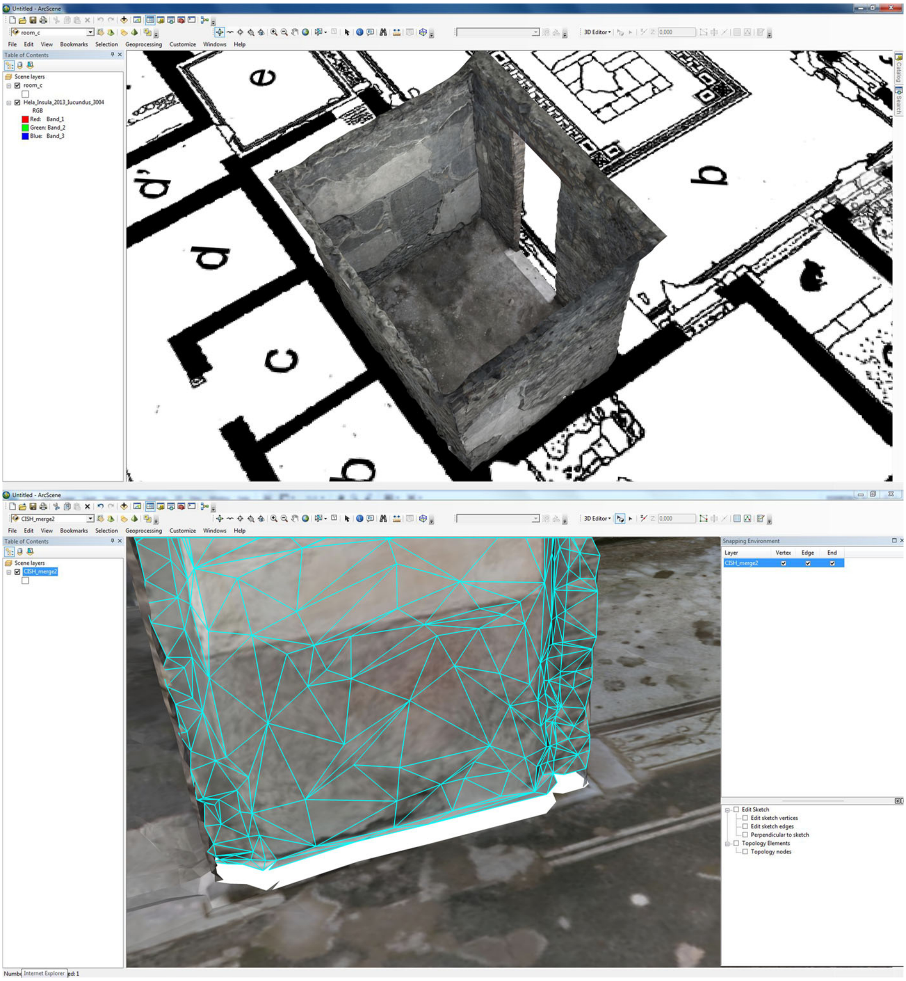

Fig. 5 The upper part of the image show the multipatch feature edited in ArcScene and geo-located, using Caecilus Iucundus' house raster as a reference map. The bottom image exemplifies how all the 3D objects were matched using the snapping tools

database and defining all of the relationships necessary to connect each single entity. This operation allows specific rules to be set up enabling retrieval operations, such as spatial and table queries. Each 3D object was thus connected to its own "room table of attributes", linked to different sets of architectural structure entities (i.e. north wall, east wall, floor, etc.) based on the documentation provided by the website. Additional information was then provided by the photographs, drawings and tables, featuring most of the documentation collected by the Swedish mission. Additionally, table entities were provided with a specific hyperlink field to connect each record to its corresponding webpage available on the Swedish Pompeii Project website (Fig. 7).

The final result is a 3D environment providing a direct link to the documentation currently available, with the possibility for users to interrogate the objects, query the database and retrieve information from the website (Fig. 8).

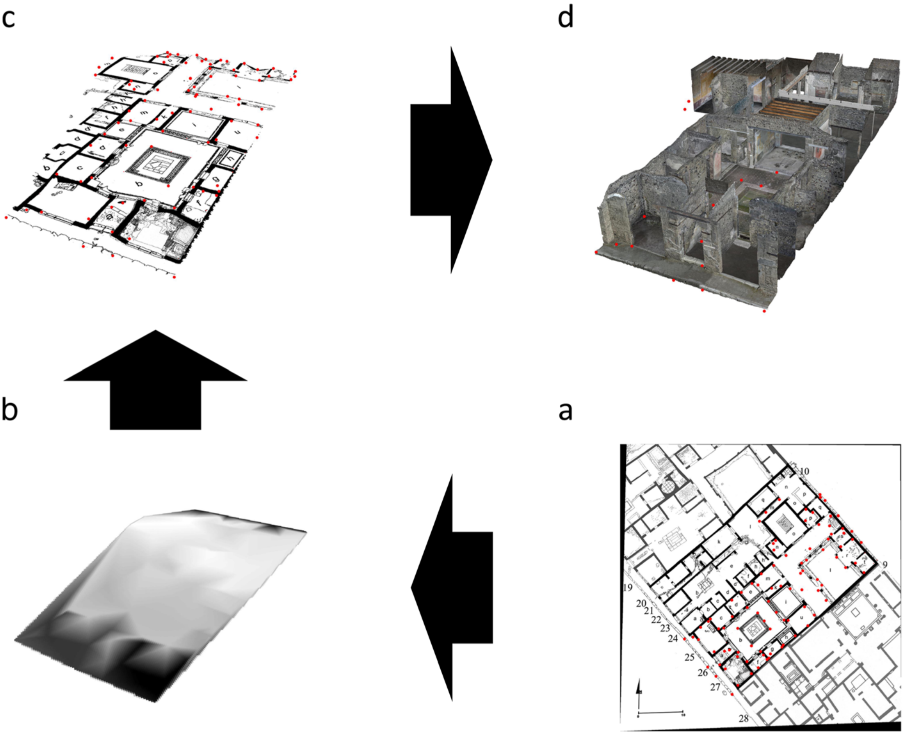

Fig. 6 This pipeline illustrates the steps followed when geo-referencing *Caecilius Iucundus*' south house along the *z*-axis. First, all of the elevation points based on the values derived from total station survey were drawn on a reference map (**a** after Ezequiel Pinto-Guillaume). Next, a DEM based on this point dataset was obtained (**b**) and used to set the reference map at its actual height (**c**). Finally, all of the 3D models of the house were 'lifted up' and placed on the reference map (**d**)

Results

This project allowed a robust workflow of data implementation to be defined, through which it is possible to explore, analyse and measure all the elements that characterize the structures of the house and their actual spatial location. Moreover, it opens the possibility for editing all of the elements recognized during the building investigation in 3D, thus enabling researchers and scholars to report the results of their analysis directly on the 3D GIS using the models as a geometrical reference. This framework can be developed in operations of post-excavation analysis or during the investigation campaign itself (using a tablet PC). The possibility to record information directly in the field allows researchers to keep a direct visual relation with the monument providing the opportunity to verify the quality of the information observed in real time. The use of such a method makes it possible to have access to the entire dataset of spatial information previously stored in the geo-database. It provides archaeologists with the opportunity to benefit (already during field investigation) from interpretation and analysis already performed in this same area by other team members or in earlier scholarship. This new way to approach the data in the field represents an important opportunity to contextualize and validate with greater accuracy hypotheses and intuitions gained during work in progress in the field.

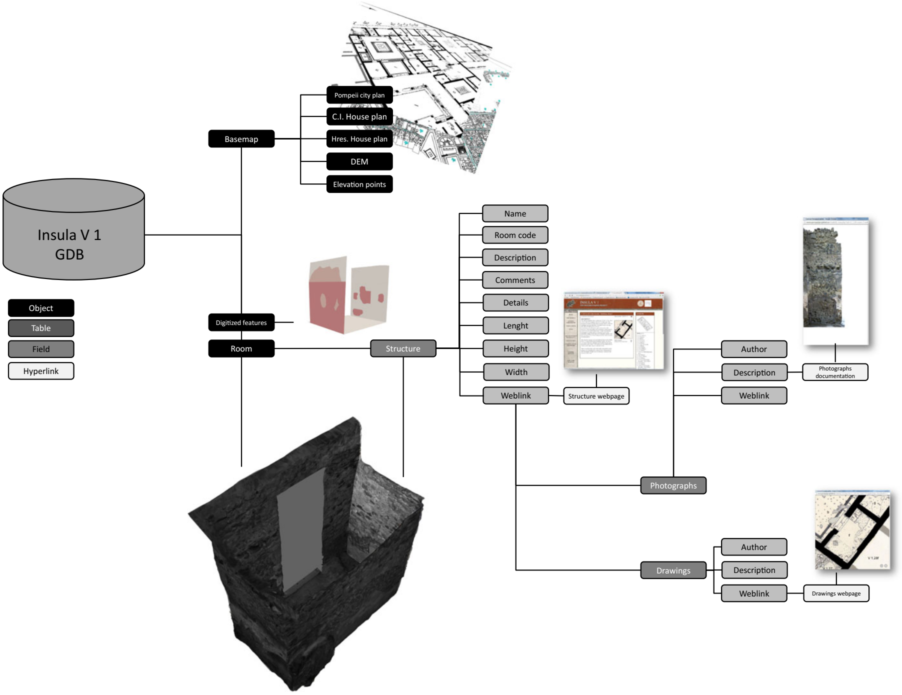

Fig. 7 Geo-database architecture developed in the framework of the project. At the core of the system is the 3D model representing the 'room' entity, related to the Swedish Pompeii Project database and linked to the project website. Further geo-database layers are represented by the vector drawings and the ground plan providing the geo-reference based on the Italian coordinate system

The development of such a system allows (i) importing, storing and visualizing all of the data previously realized in the framework of the project, putting different typologies of data recorded in different years into a direct spatial relation (Fig. 9), (ii) introducing the systematic 3D documentation of the stratigraphic relations that characterize the ancient structures, and (iii) visualizing plans and elevations in a same geo-referenced space and with high accuracy of details, providing a "real" 3D representation of the archaeological relations detected in the field. With this regard, as shown in Fig. 10, a newly developed 3D editing tool allowed us to draw directly on the models of the house, so as to obtain a 3D representation of the main features observed, with the possibility to better discern and highlight contexts pertaining to different chronological phases. Unlike traditional bi-dimensional drawings, such a method provides the opportunity to enhance our understanding of the physical relations which occur among the various "actions" detected in the fields and recorded during the digital acquisition process. Additionally, this methodological approach fosters the connection and measurement of stratigraphic units belonging to different sides of a same wall (Fig. 11). In particular, such a function provides archaeologists with the opportunity to investigate and analyse spatial relations and structural connections which would not be detectable during the field activity. As an example, the alcove located in the south-western corner of *cubiculum* (room p) was possibly a passage door to the *triclinium*, which was finally bricked up and covered with plaster. To better test this hypothesis, it is possible to digitize the boundaries of this alcove and move them by

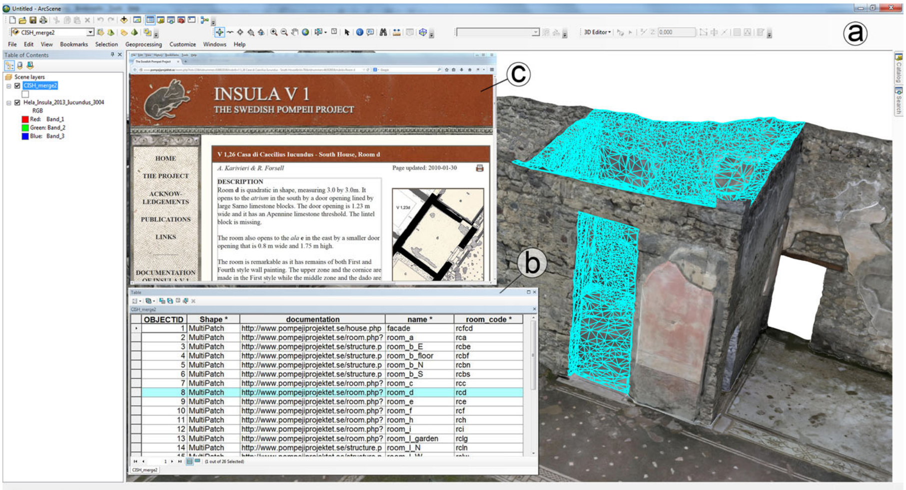

Fig. 8 This image provides an example of the query search linking 3D models and web-based documentation **a** 3D model highlighted by the selection tool, **b** the corresponding record highlighting the same feature in the attribute table and **c** the corresponding hyperlink (available in the attribute table) enabling access to the documentation on the Swedish Pompeii Project website

applying the same Δ value along *x*- and *y*-axes so as to get the exact position occupied by this entrance door on the opposite facade of the wall in the adjacent *triclinium* (room o). This operation allows us to put in their original context an architectural element no longer existing based on actual data derived from laser scanning acquisition and to take measurements of its width, height and perimeter along with the area occupied over the current wall surface (Fig. 14).

All of these operations represent a powerful instrument of analysis, which, if used systematically, will lead to the development of a robust methodology for use in the field, producing an optimal quantitative and qualitative study of the relations that characterize the different buildings of the *insula*. Particularly important is the system's flexibility to manage—in a 3D space—the new information together with all of the data previously realized, such as plans and elevation maps. This will allow researchers and scholars to achieve a complete status presentation and diachronic picture of all information recorded in the field.

Additionally, we started to explore the 3D GIS as an effective instrument for monitoring the architectural degradation of the structures. Specifically, we managed to digitize different levels of wall painting degradation in an arbitrarily chosen room (the *tablinum*). We thus obtained a multipatch layer where each feature is not a bi-dimensional drawing given by an orthogonal projection over the observed object, but rather the actual three-dimensional surface of the object itself where the physical appearance is better outlined, providing information about its length, width and depth. Additionally, each feature is connected to its own table of attributes, where all of these characteristics can be explored in a quantitative way. As a result, it is possible to produce a 3D map of the overall level of degradation with regard to the wall paintings surface, which can be summed up with a statistical assessment of the observed situation (Fig. 12). In other words, the 3D GIS opens the possibility to follow the state of the wall paintings and the under plasters on the walls of Pompeii over time and to register the erosion.

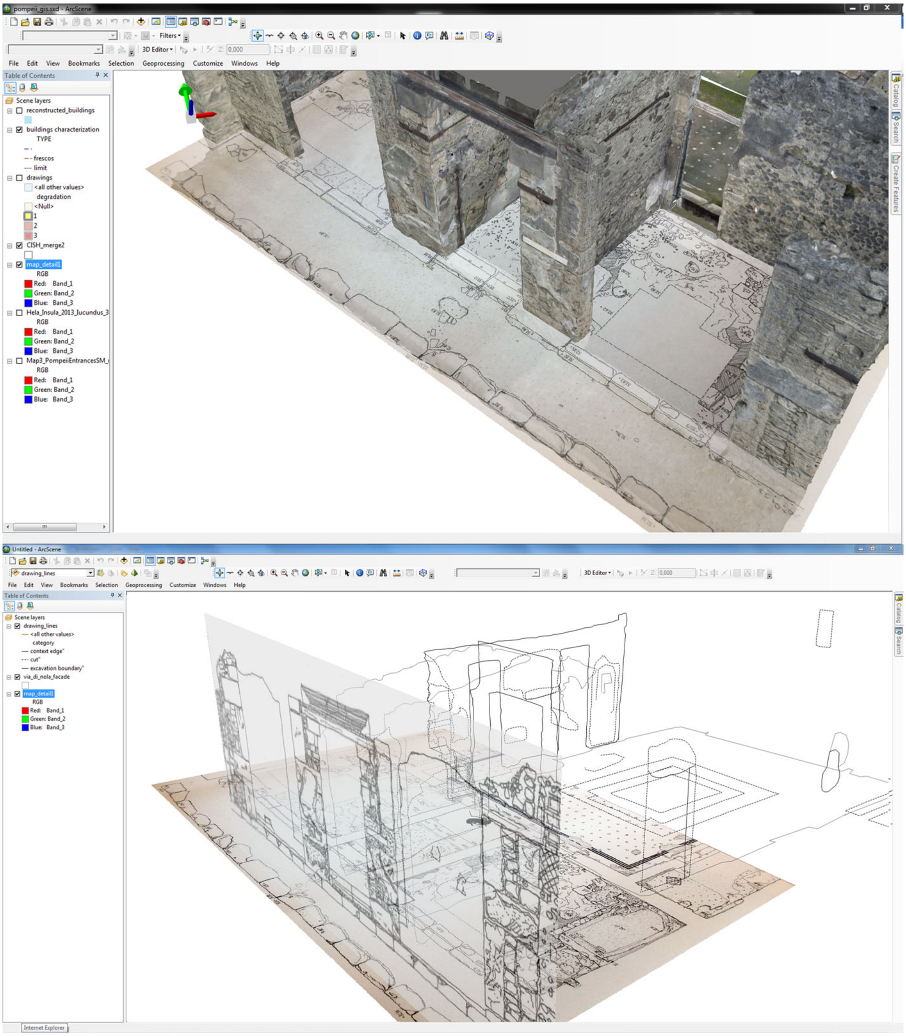

Fig. 9 This image shows an example of implementation of different typologies of data. The screenshot display includes the implementation of a manual drawing realized during the excavation campaign in 2005 (after Ezequiel Pinto-Guillaume). The 3D models of the house provided the control points to geo-reference the digitized drawings

The Pompeian case shows that the analytical potential of GIS is significantly improved by using the third dimension as an additional explorative field. Its web-linkage functions further enhance the archaeological narrative of the study context, increasing what Gillings and Goodrick (1996) claimed to be one of the ultimate scopes of GIS: meeting the unique demands of archaeology problematic.

Issues to be Addressed

According to Goodchild (1995), GIS systems have been used by archaeologists mainly as a mapping tool. Up until now, only some additional potentialities have been

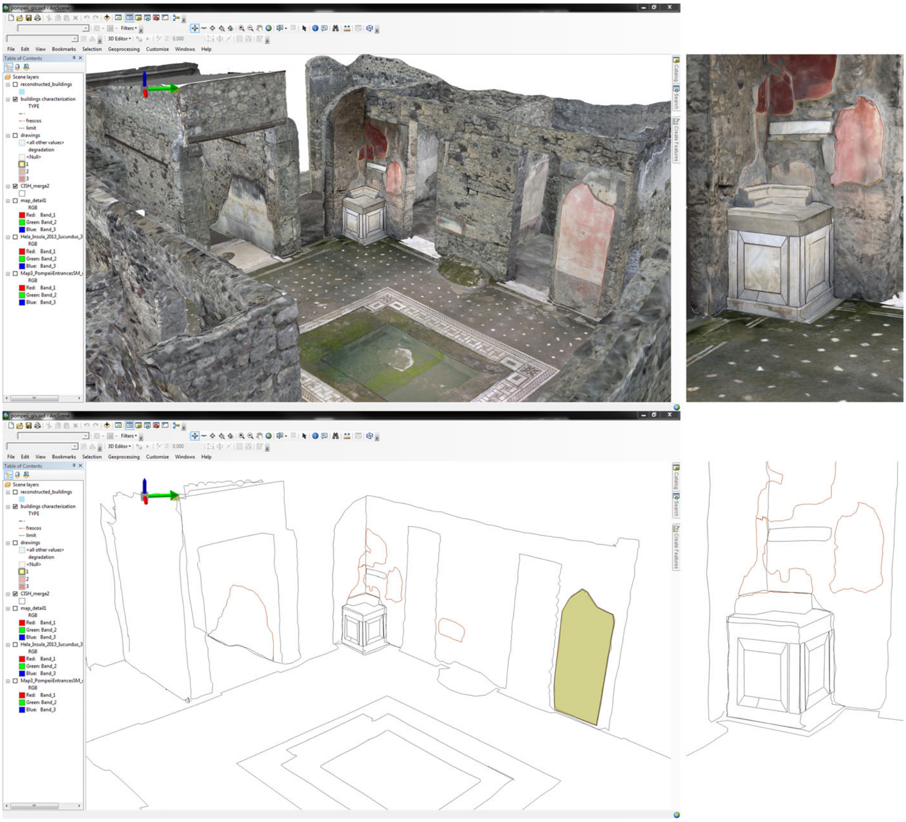

Fig. 10 This image shows a screenshot representing the atrium of the house of *Caecilius Iucundus*. The model was acquired with a laser scanner and used as geometrical reference into the 3D GIS to map and analyse in three dimensions the features detected by the archaeologists. (*Top* 3D model with the digital drawing superimposed as a separate layer; *Bottom*) 3D polygons and polylines used to characterize the interpretation

explored, mainly to perform viewshed analysis or predictive modelling. Conversely, 3D has often been introduced in the frame of the archaeological projects with the exclusive purpose of improving the qualitative experience of a user in terms of visualization (Landeschi and Carrozzino 2011, 2013). As Frischer still noted in 2008, a sort of separation seems to characterize the domains of GIS and 3D in archaeology, with GIS users focusing on the application of tools for analysis and 3D specialists concerned with issues related to navigation in the virtual space. The aim of this project was to push towards an integrated approach where the potentialities of GIS could be used in conjunction with 3D technology in order to set a well-grounded basis for good and reliable analysis. The availability of high quality models along with a virtual interpretation (Dell'Unto *et al.* 2013a) providing documented and clearly defined awareness of the degree of uncertainty in the reconstruction process gives us the possibility of using 3D as a further explorative layer. As remarkably noted by Conolly and Lake (2006:8–10), the integration between GIS and 3D can provide archaeologists with a localized experience of past material conditions. It is in this direction that we have tried to move the Pompeii Project.

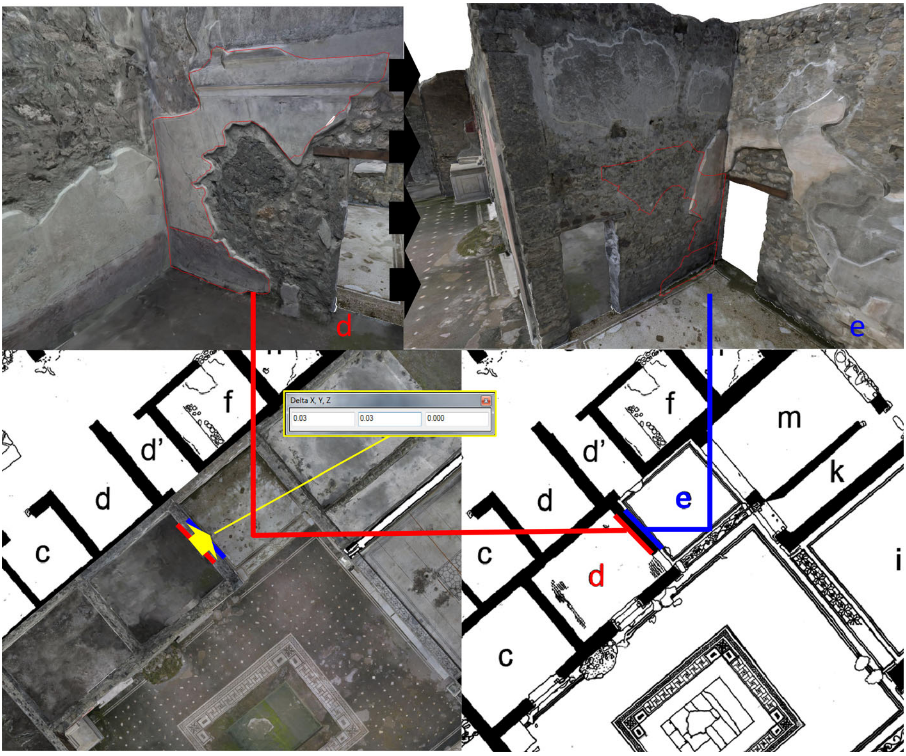

Fig. 11 The possibility of analysing the geometrical relations between the opposite faces of a same wall made possible by means of the 3D editing tools. As shown in the above image, the digitized painted plaster patch preserved on the N wall of room d can easily be shifted along the *x*- and *y*-axes and appear as a "phantom image" on the opposite face of the wall (room e, S wall), in a position of exact correspondence

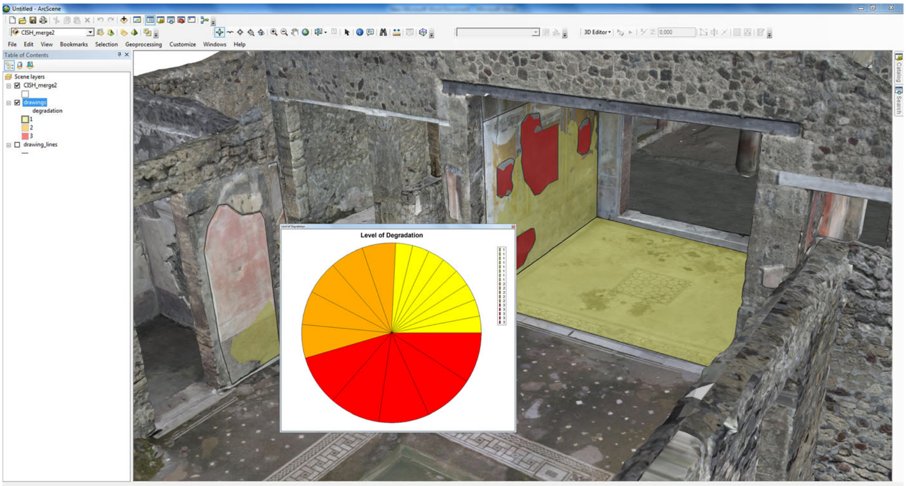

Fig. 12 This image shows the 3D model of the *tablinum* and part of the *atrium*. A vector layer drawn on the internal structures of the *tablinum* shows a quantitative assessment of the overall architectural degradation affecting both walls and floor

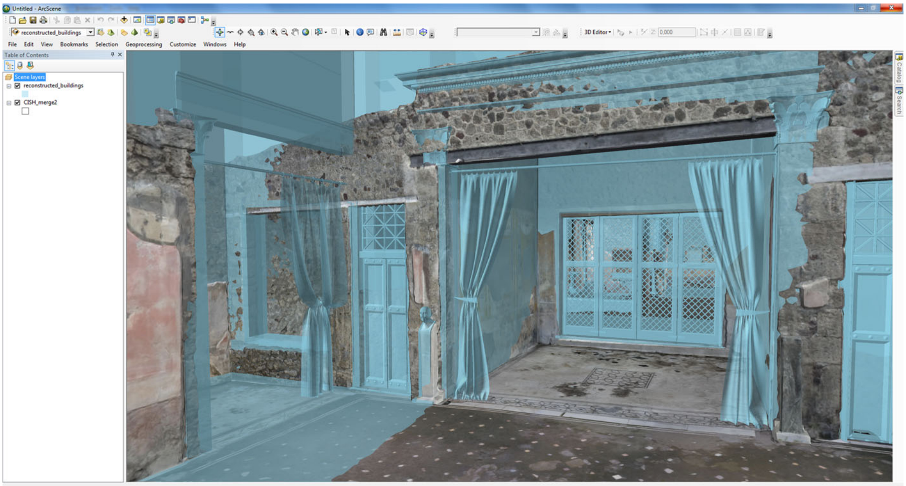

Fig. 13 This image shows the 3D model of the virtual interpretation geo-referenced inside the 3D GIS and superimposes the 3D surfaced model of the house of *Caecilius Iucundus*

Able to set up a digital environment from which we may retrieve data connected to the documenting campaigns, query the database and digitize new informative layers over the acquired models, we turn the 3D experience not only into a mimetic representation of reality but also into an effective means for depicting the dynamic complexity of a past social landscape (Gillings and Goodrick 1996). This way of working opens up new insights under a phenomenological perspective by making the space not just a neutral backdrop of action (Tilley 1994:7–11) which original inhabitants would hardly recognize (Conolly and Lake 2006:8) but the means by which events and activities actually took place. To accomplish this, it is important to overcome the concept of a "static GIS", where the nature of the modelling process has been for a long time characterized by a detached, immanent representation of the (ancient) space as a set of purely environmental variables with scarce consideration for the symbolic and cultural aspects inherent to it.

Having a virtual replica of the archaeological site inside the GIS, as it appears today, gives us the possibility of making a more reliable reconstruction of the ancient space of, in our case, the Roman house. In turn, this reconstruction constitutes a necessary condition for the development of a scientific methodology that allows archaeologists to explore the cognitive dimension of the ancient space, a dimension that needs to be based on a careful analysis and examination of the archaeological record. In this process, it is crucial to take into consideration the "contemporary mind" perspective, which Merlo 2004 carefully examined, stressing the importance for archaeologists of considering any possible bias in the process of understanding the ancient perception of space derived from their own interpretative paradigms, which are strongly affected by the way in which digital technology is used. In this sense, some critical concerns need to be considered. Despite the high degree of accuracy of the model reconstruction, we have to be very clear in stating the overall rate of uncertainty, which means that we have to clearly state our assessment concerning the level of confidence on which each single element inside the virtual space is based. Accordingly, the *Caecilius Iucundus* residence, made at a former stage of the project in the GIS, was reconstructed with this specific purpose in mind (Dell'Unto *et al.* 2013a) (Fig. 13).

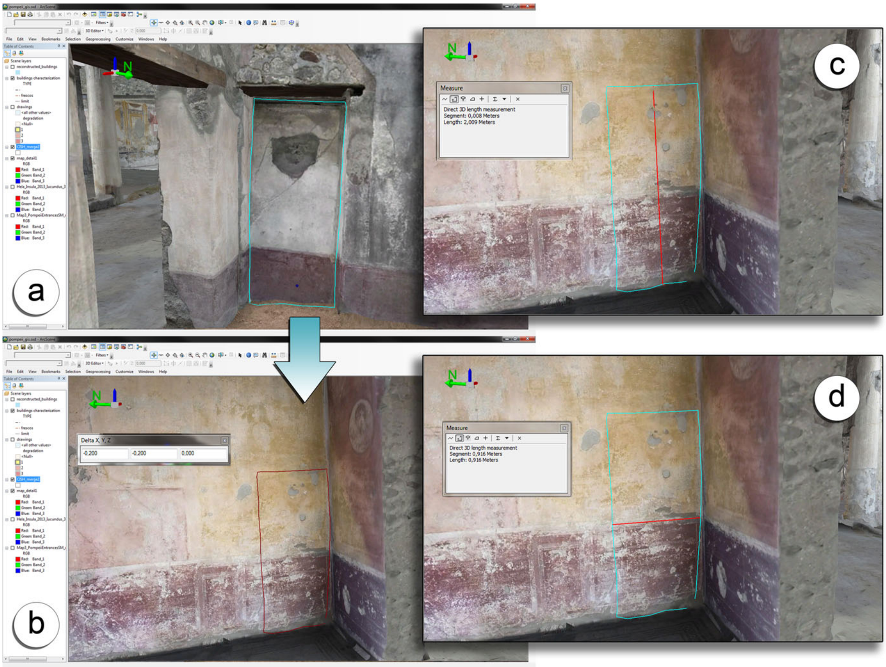

Fig. 14 Editing tools have been used to test hypotheses about the possible location of a door entrance on the opposite face of the *cubiculum* wall (room p, W wall), starting from the analysis of the current position of the alcove in the south-western corner of the room (**a**). The boundaries of this alcove have been digitized and then moved perpendicularly on the opposite face of the wall (**b**). It was thus possible to analyse geometrically the impact that an entrance would have been on that side of the *triclinium*, by measuring its height and width (**c**, **d**)

Future Developments

The research performed to date has sought to demonstrate how the integration of 3D and GIS can foster the set-up of a digital environment where the quality of data storage and analysis can be significantly improved. Notably, the interpretative framework developed in the course of the reconstruction of the house of *Caecilius Iucundus* lays the foundations for innovative research paths in the field of computer-based simulation within an ancient space. In a phenomenological perspective, some of the claims raised by cognitivist archaeologists, who insist on adopting a more "sensual" and interpretative approach (Brück 2005:51–64, Shanks and Tilley 1992:103–115), can be partially satisfied by the abovementioned technological developments. Considering the social significance intrinsically embedded in the ancient space, particularly the space of the Roman buildings (Allison 1997; Foss 1997; Grahame 1997; George 1999), the use of advanced visual analysis tools can provide us with interesting results in terms of cognitive simulation. Recently, some interesting contributions have been provided by the integrated use of GIS and 3D software for the analysis of the so-called visualscape (Paliou 2013:1–4, Paliou and Knight 2013). This is essentially the "spatial representation of any visual property associated with a spatial configuration that has an inherent visual structure" called for by Llobera (2003). It may be assessed only by means of careful examination of the archaeological context and all collected documentation. With regard to Pompeian houses, the symbolic dimension of the domestic space constitutes an interesting case study to test 3D GIS as an analytic tool to put in a quantitative-measurable context the cognitive framework connected to specific objects (Lake and Woodman 2003:694). In this sense, one of the next goals of our research will be focused on the study of those elements (i.e. wall inscriptions, graffiti) inside the architectural space constituted by the Roman house. These are remains with unquestionable symbolic value, which still maybe associated with their original spatial location and which may be examined in new cognitive depth thanks to the use of 3D GIS analytic tools.

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