Accessing interactively the spatio-temporal data-model of an archaeological site through its 3D virtual reconstruction

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Abstract

Information and communication technologies are increasingly used in all archaeological processes. However, archaeologists sometimes consider them as intrusive, too far from the traditional work methodology and even a hindrance. In this article we propose a framework to allow natural and therefore intuitive access to the archaeological record. The information retrieval process is carried out through a three-dimensional virtual reconstruction of the archaeological site. In this system, navigation and interaction with the three-dimensional elements of the environment triggers database queries. To achieve such functionality, a client-server architecture is designed in which the server maintains a spatio-temporal database with heterogeneous information, including the 3D models of the finds. To do this, a virtual replica of the site is created considering spatial restrictions and topological relationships among the finds.

Keywords: Spatio-temporal database, Virtual 3D archaeological site reconstruction, Topological relationship, 3D navigation and interaction

1. Introduction and state of the art

Many disciplines are contributing with new processes and methods for capturing, registering, analysing and disseminating data in Archaeology. Amid all of them, ICT (Information and Communication Technology) is one of the most relevant, since it can be useful for each of the mentioned phases [1]. Successfully incorporating ICT techniques in the archaeological workflow can be

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a real challenge, since archaeologists have to feel at ease with the new tools, and perceive them as really worth the effort of using them. This also implies that software development for Archaeology should be more user-centered, in order to provide the best user experience possible [2].

Considering that the real world is three-dimensional, one of these advances consists of using 3D virtual models in the archaeological workflow. Therefore, in the data acquisition phase, 2D images (photographs or drawings) can be replaced by three-dimensional models of the finds. Some advanced techniques such as photogrammetry or laser scanning are increasingly used for data capturing [3, 4]. Scanning of finds is a common desire of archaeologists, especially of pieces considered relevant. Although scanning equipment is increasingly portable and affordable, it is not always feasible to obtain 3D models of all the objects found. We find in the literature some approaches focusing on different techniques to facilitate the process [5, 6]. In any case, the process is slow, usually carried out in the laboratory with the right lighting conditions, and once the pieces have been cleaned. On the other hand, the amount of data generated by these technologies causes different issues that are not easy to solve [7]. Archaeologists are in charge of analysing and interpreting this information, and sometimes of managing the necessary software tools.

Documentation is a common goal of all archaeological processes, thus data acquisition on site is typically followed by an exhaustive review of the information and feeding of the archaeological record. For this reason, databases play a very important role in storing and organizing this information [8]. Data in records usually include varied information such as blueprints, photographs, scans, sketches or alphanumeric information. The way of accessing this information typically requires a certain level of expertise, especially in the analysis phase when it is necessary to run complex queries on this database. The integration of this workflow is the goal of many research groups [9, 10, 11].

Dissemination is an issue in which a significant amount of efforts have been concentrated. There is a great conviction that high detailed 3D virtual models are very useful tools to show ancient places and vestiges to the general public [12]. Virtual and augmented reality (VR/AR) have contributed to the displaying of pieces and archaeological sites, including the 3D reconstruction of the sites [13, 14, 15, 16]. However, the same efforts have not been made to improve the user experience of the software tools for archaeologists. As well as archaeological records should be transformed into more understandable formats for the general public, archaeologists should also be provided with more user-friendly software tools for managing such heterogeneous information.

In short, only a few efforts in the field of 3D graphics are aimed at facilitating the work of the archaeologists. The recreation of the archaeological site, as well as the excavation process in digital format while keeping the scale, shape and appearance of the objects is a clear goal in this context. Sometimes the archaeologists can feel overwhelmed by technology. Thus, ICT-based methodologies for the capture, documentation and analysis processes should be rethought, improving the user experience [17]. Software tools must be focused on the virtual recreation of the site conditions in terms of visualization, interaction, and even collaborative analysis, for example, through a web portal [18]. However, this issue can not be reduced to a mere implementation of a user-friendly interface. An archaeological record is complex and made of heterogeneous data [19]. On the other hand, archaeological methodologies were defined many decades ago, and fully migrating them into digital form is not a simple task.

There are several issues associated with handling 3D archaeological information. One challenge is sharing the 3D representation of an excavation through the Internet [20]. Apart from visualization, 3D models themselves provide poor information, and there is not always a supporting database [21]. 3D models are the result of a digitization process and have to be complemented with additional information stored in the digital record. This can make further data query and analysis difficult. Therefore, heterogeneous data such as text fields, photographs, drawings and complex 3D models have to be combined in the documentation process [22]. Developing a software tool capable of grouping all types of heterogeneous data under the same information system is not an easy task. Data has to be displayed with different visualization tools and thus being analysed separately by experts. This disaggregation of information associated with the archaeological record contributes to the lack of operability from the archaeological point of view.

Some of these problems can be solved using Geographic Information Systems (GIS), which provide geospatial storage capabilities [23, 24]. Advances in software and hardware in these platforms can contribute to the visualization [25], data storage and documentation [26]. Additionally, they also facilitate the spatial analysis of the individual remains, study the relationships among them, and with the ancient landscape. GIS can store the position of each find in the archaeological site and the layer or stratum where it was located. It is usual to add the UTM (Universal Transverse Mercator) coordinates for more accurate positioning [27, 28]. In order to deal with the issue associated with the statement: "excavation is destruction", it is highly relevant to keep as much information as possible about the position and spatial distribution of the finds to compensate for this loss [29]. However, GIS is not yet a standard tool for Archaeology, and they are still in the process of integrating 3D with full functionality.

One additional issue is that location, as an isolated piece of data, is not enough to establish relationships between one find and its environment. However, these relationships may help the experts discover new information that might go unnoticed during the excavation. Photogrammetric techniques help record the different stages of the excavation by obtaining detailed 3D models at specific moments of the process [5, 6]. However, there is typically a disaggregation between 3D models and the rest of the fields that complete the archaeological record. They are even accessible through different software tools. The process for registering one find considering not only its position, but also its spatial relationships with the rest of the surrounding elements can be performed with a spatial database that supports topological relationships [30]. In this way it is guaranteed that once one piece is extracted, it remains linked to its environment for posterity, just as it was in the past.

Topological operators have already been studied in archaeology [31]. The topological model named "Dimensionally Extended Nine-Intersection Model" (DE-9IM) is defined as a 3x3 matrix which determines the spatial relations between two 2D geometries [32]. This matrix can be extended to 3D as a more complex 5x5 matrix or 25-intersection model [33]. Although applying relational operators to each pair of elements to discover their relationships can be enriching, it does not replace the expressiveness that visualization can provide. Therefore, the record must be completed with figurative elements such as images or photographs. Again, the result is still a heterogeneous and decoupled dataset.

Thus, software tools aimed at managing 3D archaeological records need the support of a specific data model able to integrate the diversified information of an archaeological site. An additional differentiating element in this type of 3D environment is the graphical interface to deal with the data. This type of tool generates a virtual scene in which both the remains and their spatial arrangement are recreated. With these tools, excavation does not necessarily imply destruction, but digital reconstruction. A digital copy of the site is obtained for posterity [34]. Therefore, software must go beyond a high resolution visualization of the finds distributed in the same spatial arrangement where they were discovered.

Navigation and interaction are two other important issues that have to be addressed. For these purposes, some approaches take advantage of the capabilities of video game engines [13, 35, 36]. Regarding navigation, the virtual reconstruction of an archaeological site allows us to remove irrelevant elements like the soil surrounding the vestiges, and thus enables us to analyze aspects such as the spatial arrangement of the finds. Interaction with the 3D virtual site can become the natural way for accessing the archaeological record. Interaction is already accepted as the most intuitive way to access information [35, 37]. The concept of computer-human interaction is being incorporated as the natural way to access 3D models, sometimes using haptic devices [38]. Clicking on a model can trigger a set of different operations, including spatial and non-spatial queries and analysis. This might require a previous stage to separate the virtual vestiges from the surrounding soil and objects applying segmentation techniques [39]. One step further in these processes is enabling access to the 3D environment through an Internet connection, which facilitates experts all over the world to virtually visit the site.

Finally, the registration process normally carried out throughout different campaigns, can also be analysed considering its temporal information, not only in relation to history, but detailing the work sequence carried out on site. The spatio-temporal component has traditionally been another important factor when querying and analyzing archaeological information [3, 31, 40]. The problem sometimes is the way this information is provided to the researchers in terms of usability.

In this paper we present a framework in which an archaeological site is virtually recreated with the main objective of facilitating access to the information system. The integrated data model can be managed exclusively through an interactive Graphical User Interface (GUI). The heterogeneous information is maintained in a database with spatio-temporal and topological capabilities hosted on a server. On the client-side, an application running on a video-game engine provides the user with a 3D graphical interface to visualize and interact with the reconstruction of the archaeological site. The information in the database is accessed through this interface, by interacting in real-time with the elements in the 3D scene. The temporal component of the data is also available for the user using two timelines, one related with the excavation process and the other one related to the historical dating of the finds. The resulting software prototype is aimed at providing a good user experience to the archaeologist, facilitating access to the archaeological records. The client-server architecture allows the expert to access the archaeological site from any place at any time since, contrary to a real site, the 3D model remains for posterity.

The paper is structured as follows. Section 2 synthesizes the main contributions of this work. Section 3 describes the data and the nomenclature used in this framework. Section 4 provides an overview of the system architecture. The spatio-temporal database is described in Section 5 and finally, Section 6 shows how advanced queries to the database can be performed by interacting with the virtual replica of the archaeological site. Conclusions and future work are presented in Section 7.

2. Main contribution

In this paper, we propose a new methodology focused on the user experience of archaeologists for managing the information of an archaeological excavation. A paradigm shift is proposed to make the mode of accessing such information closer to the archaeological work, and not the other way around. To achieve such an objective, an information system is implemented in which the archaeological site is virtually reconstructed as a digital replica of the site. The way of accessing the archaeological record is directly interacting with the 3D Graphical User Interface of the system. The most natural way of accessing a piece is directly through the object itself, by allowing its visualization and manipulation. Taking advantage of the fact that the finds have been digitized and stored in a database, these mechanisms can also become virtual. Therefore, accessing the information means to observe strata and findings like the soil around them disappears. In addition, accessing the data stored in the spatial database is performed by simply navigating and clicking on the virtual site. These objects maintain the original spatial arrangement in terms of scale, position and orientation. Additional topological and temporal relationships between finds are also configured in the database. The result is an integrated system with database query and analysis capabilities that help the archaeological work change the concept of "excavation is destruction" to "excavation is virtual reconstruction".

We have designed a spatio-temporal and topological database implemented in PostgreSQL using the PostGIS extension. Each element can be stored with different kinds of attributes, including its 3D model. Topological relations can be added to these models to link the elements by their spatial relationship as they were found during the excavation. Moreover, new relationships can be suggested automatically, based on topological operators. Advantages of maintaining topology in the database are mainly focused on further analysis. If, for example, two ceramic pieces have been found together, it is very likely that they are parts of the same original recipient, or at least be part of the same set. Any click on a model can provide the set of objects related to it, their appearance and relative position. Even relative distance between each other can be directly obtained. Obviously, these actions generate queries to the topological database. As a response, the system provides the required information, that is shown through the 3D GUI.

As part of this analysis is the possibility of keeping the extraction process alive, reliving the state and initial placement of the finds in relation to the rest of the pieces and the environment. In addition to the spatial analysis, the temporal nature of the extraction process can be represented in our data model, allowing the temporal sequencing of the process. In short, a query like: *"list all the objects extracted from the layer <<layer_name>> after the date <<yy-mm-dd>> made of material <<material_type>>"* can be easily formed through the interaction with the 3D virtual site.

In summary, this paper presents a framework and a system prototype with the following capabilities:

- The 3D recreation of the archaeological site maintaining scale and spatial arrangement.
- A user-friendly interface to provide access to the information through a virtual 3D replica of the archaeological site.
- Integration of all the processes in the same platform: capture, data recording, visualization, analysis and dissemination.
- A topological and spatio-temporal database able to manage heterogeneous information, including 3D models.
- Accessible through the Internet for collective and remote analysis.

3. Data description

In this section, we describe the concepts and terminology used in the paper associated with an archaeological excavation. We have used data from

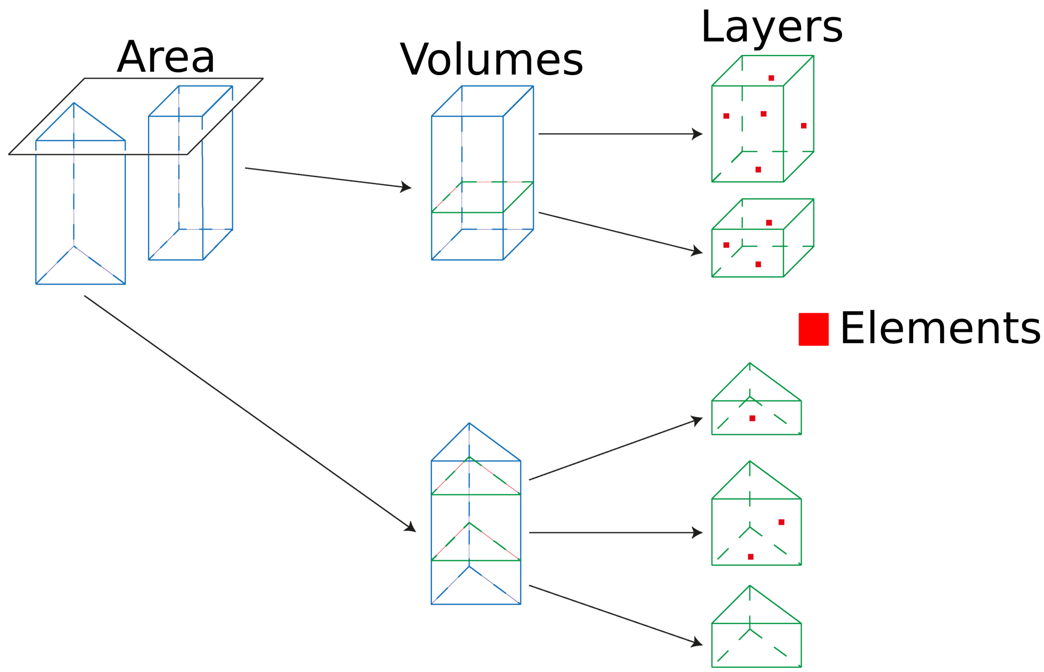


Figure 1: Schematic view of the concepts of *Area*, *Volume*, *Layer* and *Element*

the excavations in the Iberian-Roman city of Castulo, one of the capital centres in southern Spain during the Antiquity. Castulo was the most important population centre in the Iberian Oretania and it later turned into a Roman city. The archaeological site contains other settlements from the Prehistory to the Late Middle Ages, which complete the historical value of this archaeological area. This complex stratigraphic and temporal sequence, which remains in our time with exceptional integrity and preservation conditions, constitutes a significant segment of the whole history of Andalusia.

Archaeologists working on Castulo use the following concepts to organize the information from the site (Figure 1 represents the relationships among several of these concepts).

An *Archaeological Site* is a location where archaeologists decide that there are interesting remains to be explored and discovered through excavation. The usual way of working on an archaeological site is through excavation *Campaigns* that have a given start and end date. Each campaign can have different duration. In order to organize the space in an archaeological site, the archaeologists define *Areas*. Each area is a closed superficial perimeter that

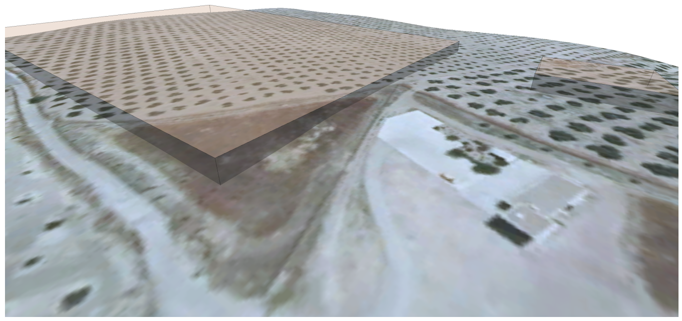


Figure 2: Aerial view of an archaeological site, with two highlighted areas. Although areas are not 3D, they are drawn here as parallelepipeds, so that they can be seen over the 3D terrain model

encloses excavation activities (Figure 2). Inside an area, a variable number of *Volumes* (Figure 3.a) can be defined. A volume not only comprises a closed superficial perimeter, but also the ground below. As the ground from the volume is removed, the archaeologists define *Layers* (Figure 3.b), determined by relevant changes in the ground (different composition, color, materials found, dating of the discoveries, etcetera).

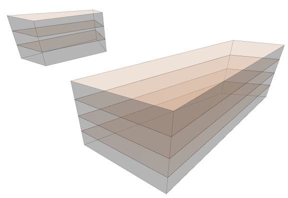
Finally, the materials found during the excavation of each layer can be of different natures: pottery, bones, buildings, statues, etc. In our database structure, we have used the more general term *Element* to group all these findings, and then allow a unified treatment of the information (Figure 4).

4. System overview

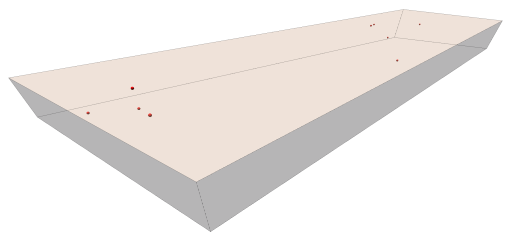
Figure 5 shows the system architecture of the client-server prototype. The archaeological records containing all the information are stored in a spatial database hosted on the server side. On the client-side, a user application implemented in Unity, allows full access to this information throw the 3D virtual recreation of the site.

4.1. Server side

As Figure 5 shows, the server maintains a database in PostGIS, an extension for PostgreSQL that supports geometric and geographic data types and their operations. The database is fed with the information obtained in the acquisition phase, which can be performed with traditional or new



(a)



(b)

Figure 3: a) Two volumes defined inside an area. Each volume is composed of a series of layers (b), in which the elements are located (red dots)

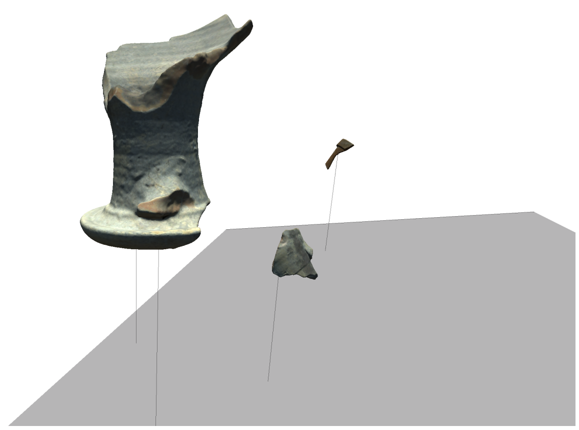


Figure 4: View of the elements inside a given layer

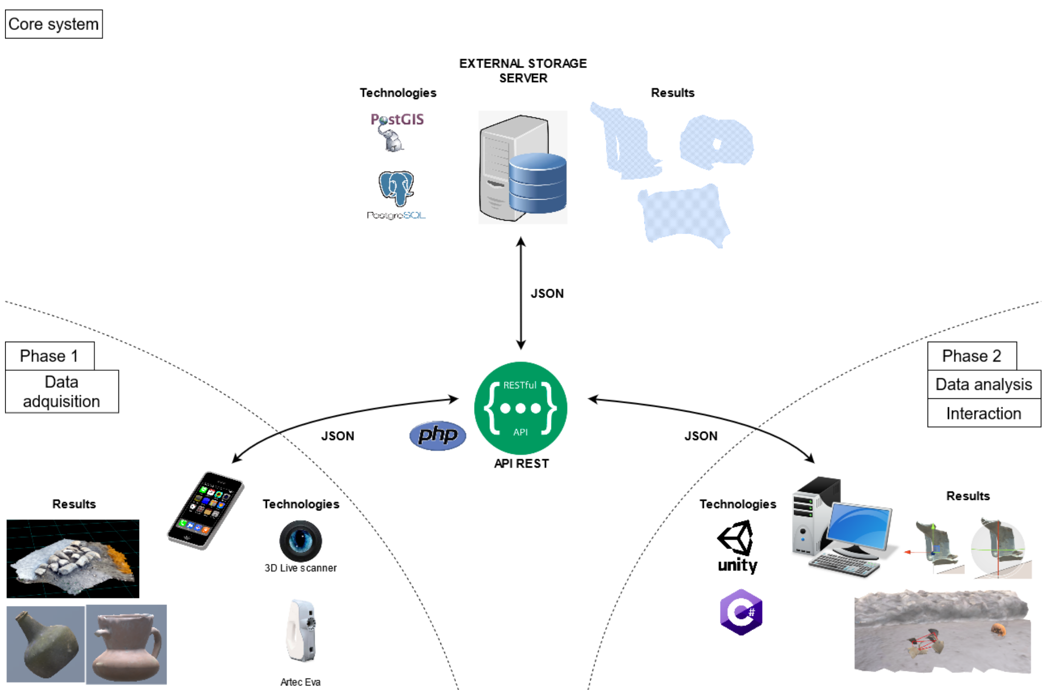


Figure 5: General scheme of the system and technologies used

methodologies. The more complete the acquisition process, the more analytical capacity the future system will have. In this paper we are not focusing on this facet of the system but on the interactive access to the data.

The connection between the database and the user application is performed by means of a REST (Representational State Transfer) API, as depicted in the same figure. This Application Program Interface is a stateless client-server protocol based on HTTP requests that contain all the required information when data is transferred between origin and destination. This protocol allows a fluid communication between client and server to perform operations of data querying, insertion, deletion or update without the need for external libraries. The server hosts the REST API and receives requests using the JSON (JavaScript Object Notation) data exchange format; then, the server interprets, processes and sends back data to the client in the same format. The advantage of the REST protocol is the separation between the user interface and the data storage system. This improves the portability of the interface as well as increases the scalability of the project, allowing their different components to evolve independently.

4.2. The client application

Once the database has been fed, including the 3D models of the finds, the analysis phase can start on the client side. For that purpose, any device connected to the Internet and with certain graphic capabilities can be used. As stated above, this application is implemented in Unity, a cross-platform real-time video game engine with 3D visualization and interaction capabilities. This virtual scenario is presented to the user as the natural way of accessing the information stored in the archaeological database. This means an easy browse based on the virtual replica of findings instead of writing complex queries using languages like SQL.

Figure 6 shows the user interface of the application. It normally visualizes any of the entities described in Figure 1. In this example, the elements of a specific layer are observed, together with their topological relationships. In the scene, the user can freely navigate and interact with the objects using the mouse or any Virtual Reality device by taking advantage of the Unity game engine capabilities. The figure highlights the application main screen and its controls. Selecting specific layers or volumes can be performed by directly writing them on the text box attribute filtering (6.(1)), or by navigating in the hierarchy of screens (Figures 2 and 3). Some additional controls such

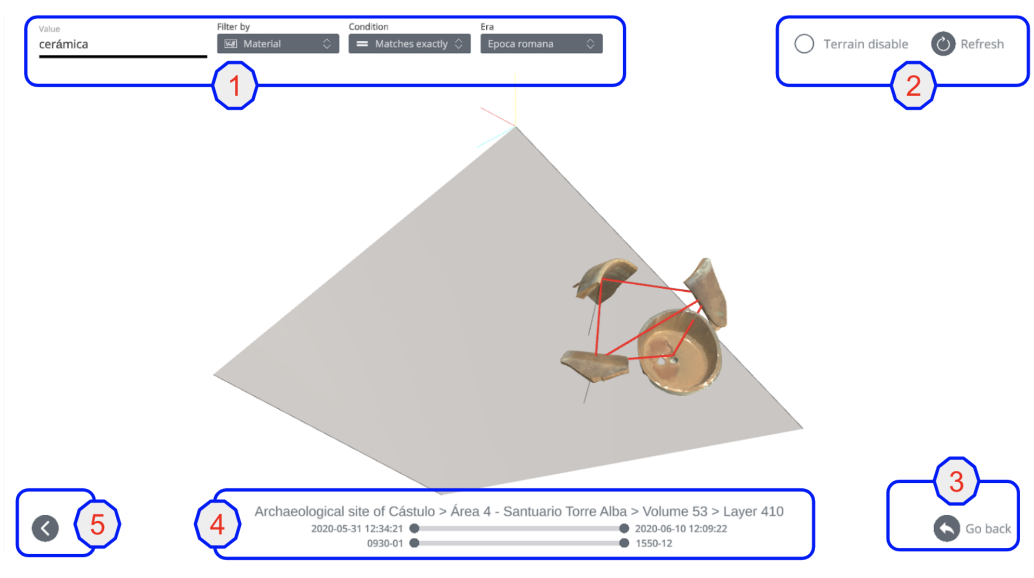


Figure 6: Main screen of the application. (1): attribute filtering options. (2): switch for enabling/disabling the visualization of the digital elevation model of the terrain and refresh view control. (3): control to browse back in the data model. (4): breadcrumb trail and time slider. (5): shows/hides a table with the data in the current view.

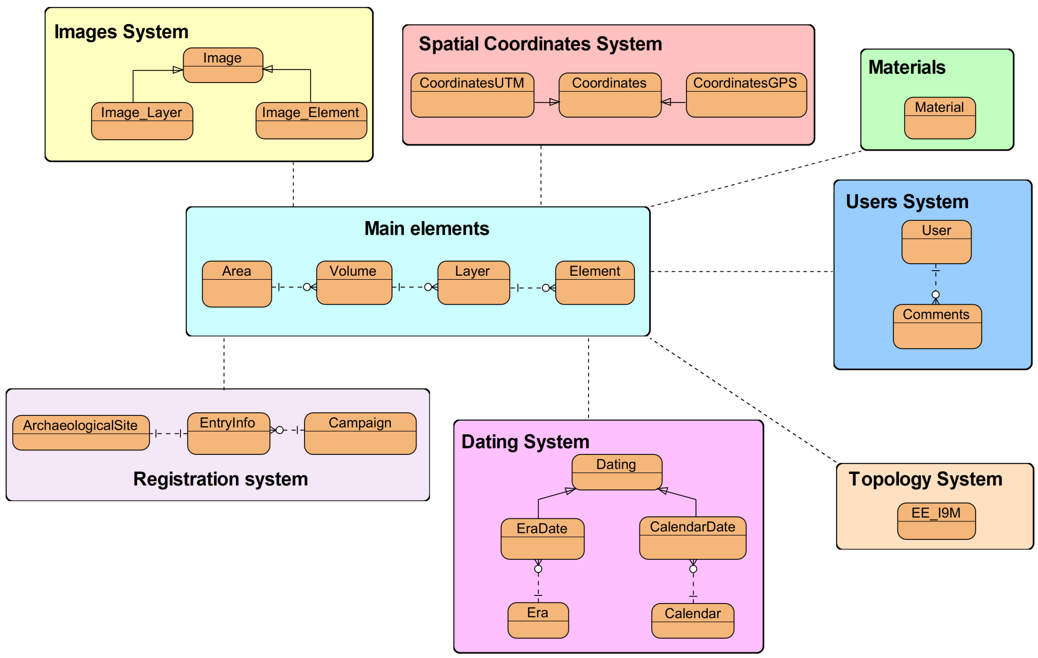


Figure 7: Overview of the whole structure of the database. Figures 8 to 16 focus on each block

as the one of Figure 6.(4) facilitates temporary queries. Section 6 describes some use cases comparing this interactive method and the SQL queries.

5. Database

Our interface proposal is supported by a database that includes not only the typical record information related to each find (id, name, material, type of object, etcetera) that can be seen in similar proposals, but also the information related to locations, topology and dating. Figure 7 shows a general view of the database structure that we have defined. We are going to summarize the main characteristics of our design in the following subsections.

5.1. Main entities

Figure 8 shows the table structure chosen to store the basic information about the excavation structure and the findings. The table structure and relationships match the description from Section 3.

For each find (*Element*), apart from its 3D model, we store a transformation matrix (to place that 3D model in the virtual reconstruction of the

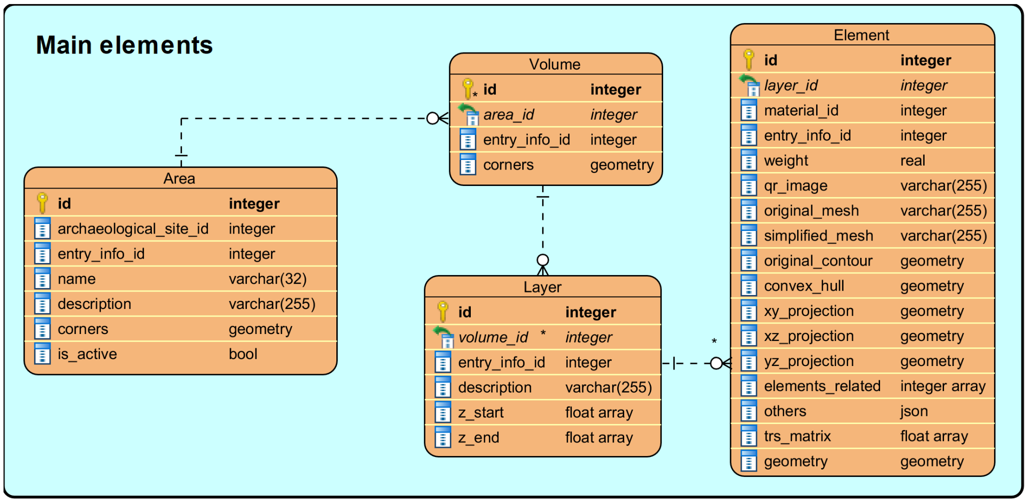


Figure 8: Entities defined to store the basic information about the archaeological site

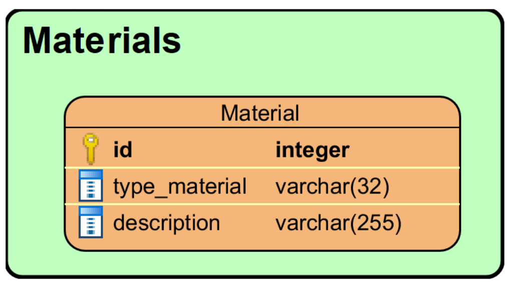


Figure 9: Materials representation

site) and the projections of that 3D model into the Euclidean planes XY, XZ and YZ. These projections are necessary in order to compute the DE-9IM matrices between each pair of finds that are close enough. These projections are computed only once when the 3D models are inserted in the database. Apart from that, a JSON attribute is included in this entity, so that any additional information not considered in the design can be added. This information can be easily handled with the PostgreSQL JSON functions and operators, therefore enriching the expressiveness of the model.

5.2. Materials

The information related to the material each finding is made of is quite simple, as we are not focused on this topic. We simply have one entity with

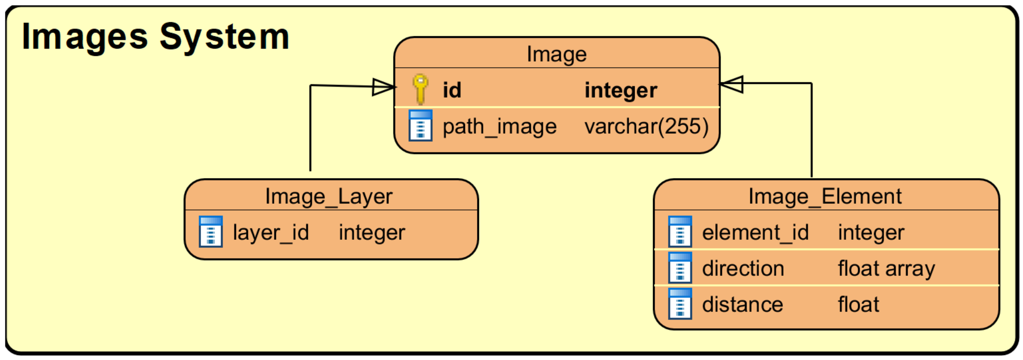


Figure 10: Image storage system

the name of the material and a description (Figure 9).

5.3. Images

Instead of storing the images inside the database as binary information, we decided to store them in an external storage, and keep in the database just the URL to find them (Figure 10). Images are directly linked to either an element (a finding) or a layer. The client application offers the possibility of showing the images related to a find near its 3D model; for this purpose, the orientation (*direction*) and distance from the 3D model where the image is to be placed are also stored.

5.4. Users

User accounts do not require any special treatment. The typical information for allowing user identification is complemented by a set of permissions to operate on the information stored in the database. As the users are allowed to add comments to the finds (*elements*), this information is also stored in the database (Figure 11).

5.5. Coordinates

The two most relevant features of our proposal are related to the spatial and the temporal information. In order to provide a successful and friendly interface to the users, we opted not to restrict the spatial representation to a single coordinate system, but to offer the possibility of storing each coordinate using either the UTM or the WGS84 reference system (Figure 12). Conversions are performed as necessary during the calculations required

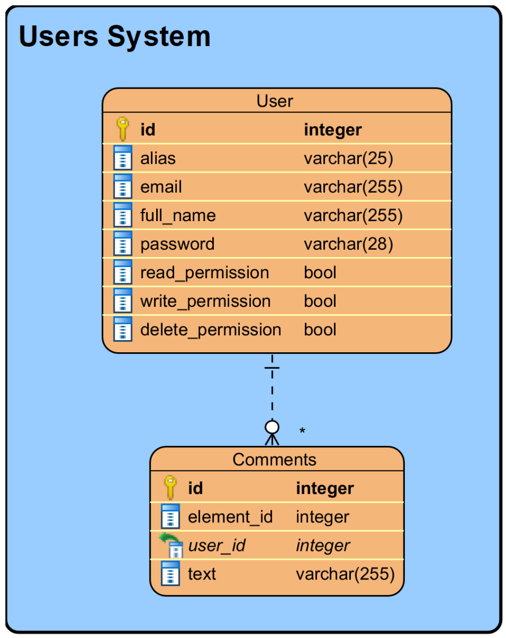


Figure 11: Tables to store the user information and their comments

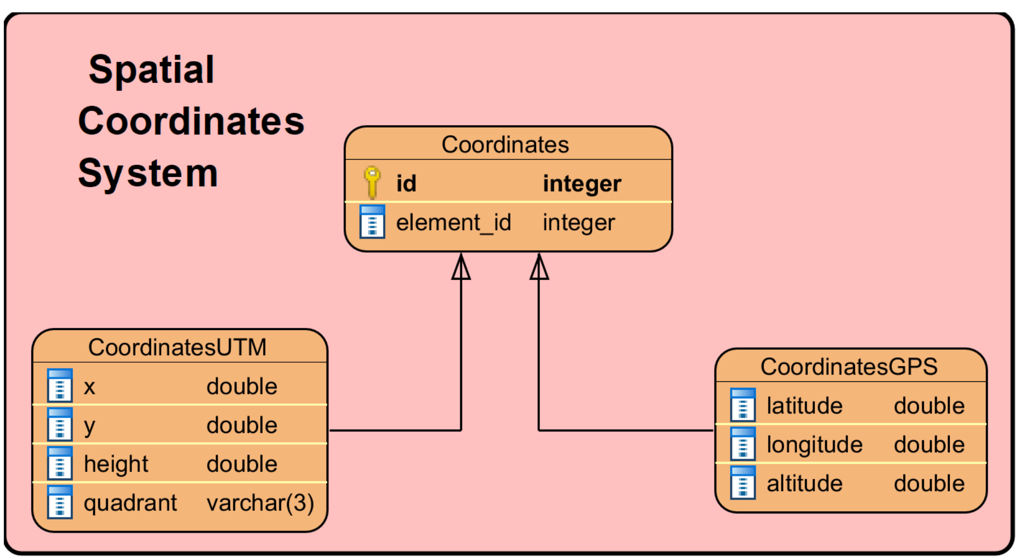


Figure 12: Data representation for spatial coordinates

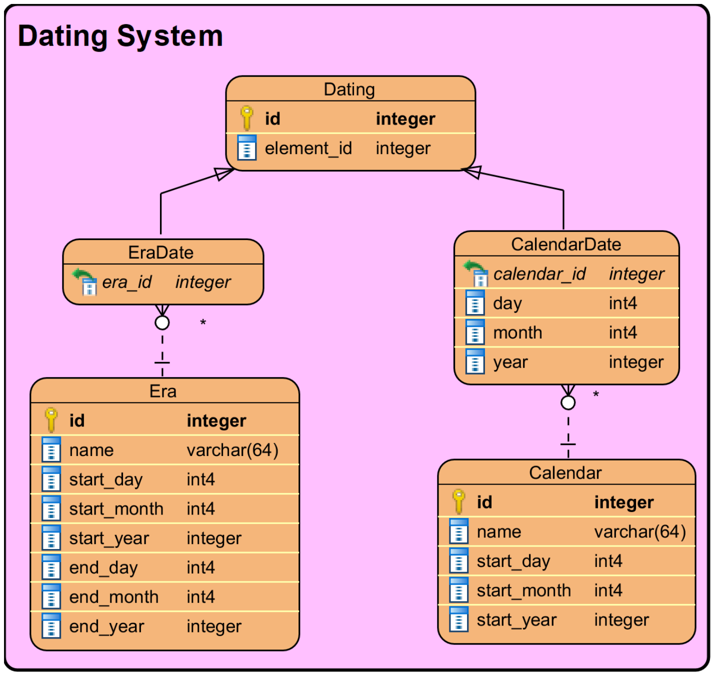


Figure 13: Entities for storing historical data information

for data visualization or any other spatial query, since UTM is our preferred reference system, but internally, the original information is kept as it was inserted by the users.

5.6. Dating system

We keep track of two different dating information: the historical (Figure 13) and the excavation dating, which usually is the date of insertion in the database (Figure 14). We do so in order to allow the possibility of using the GUI of our application to review the findings in sequence either according to the date they were discovered, or according to the dating the archaeologists assign to them.

Regarding excavation dating, every new insertion of areas, volumes, layers and elements also includes a new tuple in the *EntryInfo* table, in order to keep track of the excavation chronology. These dates are also linked to a *Campaign*, as described in Section 3. This allows us to browse through the evolution of the excavation, in order to provide further evidence for the analysis of the discoveries.

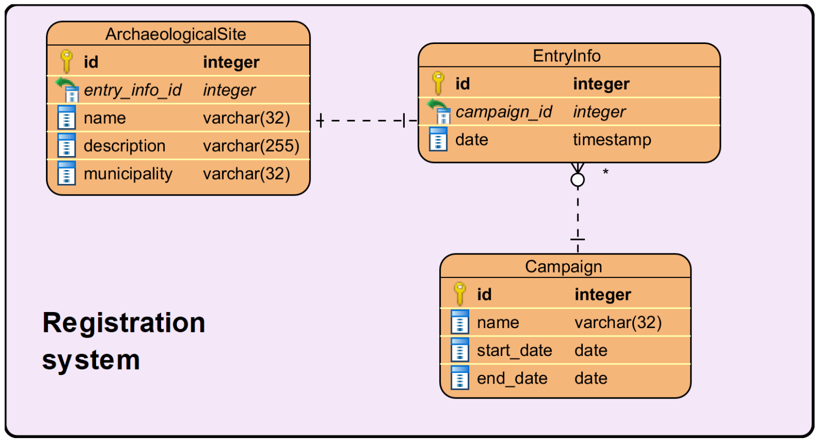


Figure 14: Entities for storing excavation dating information

Partly inspired by the work by Belussi and Migliorini [31], the historical dating system considers two different possibilities to assign a date to a discovery. For those cases in which the date is clear (for example: a tombstone with the date of the death), a *CalendarDate* can be assigned. However, most of the time the exact dating of each finding is not clear. Therefore, we also allow assigning an *EraDate* to the finding. Each *Era* can have a starting and an ending date, more or less accurate (day, month and year, only year, or month and year).

5.7. Topology

In this context, topological relationships describe how finds are connected in the site under the premise "if two objects are close together in the site, they could have been related in antiquity". This premise may not be true, but it provides the archaeologist with a catalog of possible related pieces with additional information such as the type of the possible topological relation (disjoint, meet, overlap, contained, etc.), as well as the distance between the pieces (in the case of disjoint).

The standard to describe spatial relations in 2D is the Dimensionally Extended 9-Intersection Model (DE-9IM) [32, 41], which determines how two objects are spatially connected, no matter their rotation, translation and scaling transformations. The DE-9IM model is really useful for 2D geometrical models, but it can not be applied to 3D models straightforwardly. Due to the fact that the 3D version, called DE-25IM [33], is not available in Post-

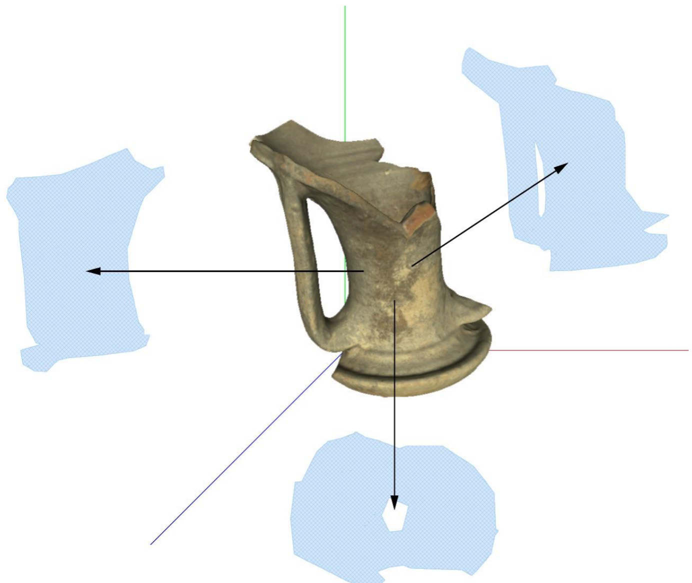


Figure 15: Projection of an amphora fragment into the three orthogonal planes

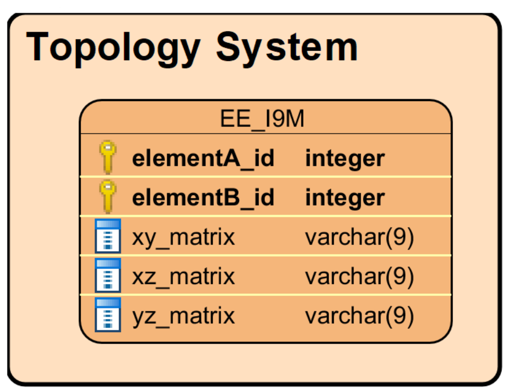


Figure 16: Entity used to store topological information

GIS, we propose another solution based on DE-9IM. In this approach, we compute the 2D projections of the original 3D geometries on each of the three orthogonal planes: XY, YZ and XZ (Figure 15). Then, for each pair of pieces that are close enough, according to a distance threshold that can be chosen by the user, the DE-9IM matrices computed from their projections are obtained and stored in the database (Figure 16).

In order to find close elements, the PostGIS function *ST_Buffer* is used to create influence buffers using the distance threshold for each 2D projection; then, these 2D influence buffers are checked for intersection with the function *ST_Intersects*. For each pair of elements whose buffers intersect, the DE-9IM matrix of their projections is computed and stored using the function *ST_Relate*.

The fact that there is an intersection between the projections in 2D does not necessarily mean that the objects intersect in 3D. However, this allows the expert to do a massive filtering of pieces that for spatial reasons are not likely to have a relationship.

6. Data analysis

One of the biggest challenges in the application of ICT to archaeological recording is providing archaeologists with a user-friendly method to browse through the recorded data. The amount of records obtained in a typical excavation campaign is usually very high, and successive campaigns on the same site continue increasing this number. In the end, trying to locate a given record can become an arduous task, even through running SQL standard queries.

In order to prove the usefulness or our system proposal, in this section we are going to show two example queries on our database, comparing them with the steps in our client 3D application for obtaining the same result. The biggest advantage is that no SQL knowledge is required for creating really complex queries.

6.1. Example 1

Consider the following query: *show all the pottery pieces from the Roman Age that were found between June 6th, 2020 and June 7th, 2020 in layer 410, together with the pieces that are likely to be related to them.* Implementing this query in SQL results in a code as complex as the following:

```
select e.id, e.elements_related related,
       trim(m.type_material) material, trim(era.name) era,
       ei.date date
from public."Element" e
inner join public."Material" m on e.material_id = m.id
inner join public."EraDate" ed on e.id = ed.element_id
inner join public."Era" era on era.id = ed.era_id
inner join public."EntryInfo" ei on e.entry_info_id = ei.id
where e.layer_id = 410 and m.type_material = 'Ceramics' and
      era.name = 'Roman age' and
      ( ei.date >= '2020-06-06 00:00:00' and
        ei.date <= '2020-06-07 23:59:59')
order by e.id;
```

With our client-side 3D application, the steps to achieve the same result are the following:

1. From the initial view, browse to layer 410 (click on the area, then on the volume and then on the layer).
2. Use the attribute filter to choose "material", choose operator "equal to" and write "ceramics".
3. Use the "historical era" filter to choose "Roman Age".
4. Use the "excavation dating" filter to restrict the range to the dates June 6th, 2020 - June 7th, 2020.

The result of following these steps is shown on Figure 17. Red lines link the pieces that are considered as related, according to the information in the database.

6.2. Example 2

Consider the following query: *show all the pieces from layer 410 dated in 1310, with identification number less than 3125 and that were found on June 1st 2020.* Trying to obtain this information from the database using SQL results in a piece of code similar to this:

```
select e.id, make_date(cd.year, lower(cd.month),
       lower(cd.day)) as min_date,
       make_date(cd.year, upper(cd.month)-1, upper(cd.day)-1) max_date,
       ei.date
```

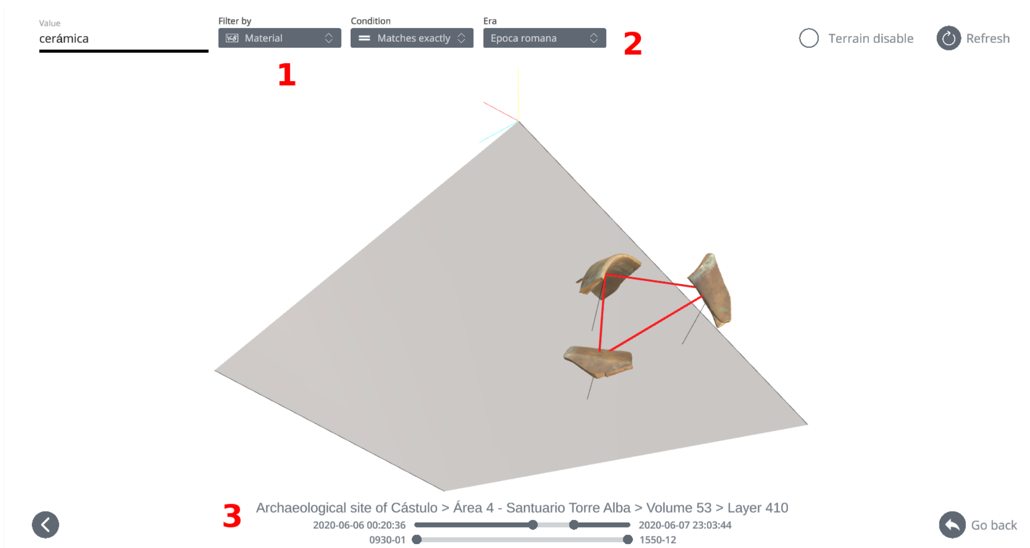


Figure 17: Result of one query using our client-side 3D application. Numbers in red identify 1- Attribute filter (in this example, it is set to "material = ceramics"). 2- Historical era filter (in this example, it is set to "Roman Age"). 3- Breadcrumbs to help the researcher know what they are browsing, excavation date filter (in this example, it is set to the interval [2020/06/06, 2020/06/07]) and historical dating filter.

```
from public."Element" e, public."CalendarDate" cd,
     public."EntryInfo" ei
where e.id = cd.element_id and e.entry_info_id = ei.id and
      e.layer_id = 410 and e.id < 3125 and cd.year = 1310 and
      ( ei.date >= '01-06-2020 00:00:00' and
        ei.date <= '01-06-2020 23:59:59' )
order by e.id;
```

However, obtaining this information interactively with our client-side application is as simple as following these steps:

1. From the initial view, browse to layer 410 (click on the area, then on the volume and then on the layer).
2. Use the attribute filter to choose "id", choose operator "less than", and write 3125.
3. Use the "historical dating" filter to set the interval to the year 1310.
4. Use the "excavation date" filter to set the interval [2020/06/01, 2020/06/01].

The result is shown on Figure 18.

Figure 18: Result of one query using our client-side 3D application. Numbers in red identify 1- Attribute filter (in this example, it is set to "id < 3125"). 2- Breadcrumbs to help the researcher know what they are browsing, excavation date filter (in this example, it is set to the interval [2020/06/01, 2020/06/01]) and historical dating filter (in this example, it is set to year 1310).

7. Conclusions and future work

This paper introduces a prototype of an information system with spatial, topological and temporal features for archaeological recording. The main objective of this work is providing intuitive access to the archaeological information through a graphical 3D user interface. This allows querying the database by means of navigating in the virtual scenario and interacting with the models of the finds. The process is therefore similar to being present on the site, since the user works with a replica of the place, both in the modeling of the pieces and in their spatial arrangement.

The paper describes both the spatio-temporal database structure and the system architecture. It also describes how complex SQL queries that are normally necessary to extract spatio-temporal information can be replaced by intuitive interactions to access the information through the 3D representation of the archaeological site. The system proposes spatial and topological relationships that a human expert has to confirm or discard. This means of accessing the database provides a powerful tool to support researchers that have to deal with the massive amount of data that can be produced in a typical archaeological excavation.

Future work is focused on the application of these techniques in a real archaeological site. The best sites to be applied is in new excavations, in which recording and analysis methodologies can be put into operation from the beginning. Although we do not currently have access to any site that meets this requirement, we do expect to implement it in one that is already in progress. Archaeologists from the University of Jaén are working in the Santo Domingo Convent (Jaén), currently not in religious use and managed by the city council. In previous campaigns, very diverse vestiges have been found, including the remains of a plasterwork arcade of Almohad period that would be dated in the XII-XIII century. Findings from the Christian era were also discovered in upper strata. The excavation process has not concluded, and we are ready to start working using the proposed methodology from this moment on. Regarding previous campaigns, the excavation team carried out a traditional recording process, including several scans of the strata. With these data, the photographs of the site and the access to the remains, we do not guarantee perfect replication, but it may mean an improvement in the way of accessing the information already acquired.

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