# The role, opportunities and challenges of 3D and geo-ICT in archaeology

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**Abstract** Archaeology joins in the trend of three-dimensional (3D) data and geo-spatial information technology (geo-ICT). Currently, the spatial archaeological data acquired is 3D and mostly used to create realistic visualizations. Geographical information systems (GIS) are used for decades in archaeology. However, the integration of geo-ICT with 3D data still poses some problems. Therefore, this paper clarifies the current role of 3D, and the opportunities and challenges for 3D and geo-ICT in the domain of archaeology. The paper is concluded with a proposal to integrate both trends and tackle the outlined challenges. To provide a clear illustration of the current practices and the advantages and difficulties of 3D and geo-ICT in the specific case of archaeology, a limited case study is presented of two structures in the Altay Mountains.

**Keywords:** Archaeology, Data Standards, Data Exchange, 3D, GIS, GEO-ICT

## 1 Introduction

Three-dimensional (3D) information is having a rapid expansion in different areas. Employing these 3D data in existing practices offers new opportunities such as a more realistic overview of data and enhanced analyses. At the same time, however, this poses some challenges, like an increasing amount of data which has to be handled. Another trend is the increasing use of geospatial information and its integration with ICT. The latter is referred to as geo-ICT and includes among others geographical information systems (GIS). In this regard, one can also think of a growing amount of location-based applications for smartphones, resulting in the advantage that people become more familiar with spatial data.

In the archaeological domain, these two trends are also followed. Archaeological research projects are more and more using 3D techniques to reconstruct sites, and GIS have been part of archaeological research for decades (De Roo et al. 2013a; De Reu et al. 2013; Forte 2014).

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As archaeological excavations are destructive, many researchers aim for a complete 3D digital documentation of archaeological excavations (Katsianis et al. 2008; De Reu et al. 2013). Sharing this documentation will enable the transfer of knowledge between different parties occupied with archaeological data (e.g. policy makers, field archaeologists, tourists, etc.) (Shaw et al. 2009; McKeague et al. 2012). For the purpose of analysis and interpretation of 3D information, the application of a 3D GIS should be incorporated in this 3D documentation workflow. However, the creation of such a complete 3D digital workflow and the exchange of these data and documentation is challenging, e.g. due to the data structure and storage costs.

This paper intends to assess the current role of the third dimension in archaeology and to outline opportunities as well as challenges which need to be accepted when fully implementing 3D and geo-ICT in the archaeological process. Subsequently, a possible approach to the integration of 3D data and geo-ICT in archaeology is introduced. To illustrate clearly the role, opportunities and challenges of 3D and geo-ICT and to give a better insight in the proposed approach, a case study is included, which is shortly described in section 2.

## 2 The Yustyd Valley, Altay Mountains: Case study

### *2.1 Geographic location*

Located on the border between South-Siberia and Central Asia, the Altay Mountains form part of the Eurasian Steppe, an area stretched over 5000 km. The climate of the Altay is more extreme than the typical continental climate in the Steppe. The Russian part of the Altay Mountains is situated in the Altay Republic, subject of the Russian Federation. The case study site lies in the Yustyd valley, in the east of the Kosh Agash district (Fig. 1).


**Fig. 1.** Overview of the research areas in the Altai Republic

## *2.2 Archaeological setting*

The Altai Mountain region and especially the Yustyd valley has an archaeological profusion (Plets et al. 2012). The lower and more flat part of the valley (2000-2200 m above sea level) is covered with a large concentration of archaeological structures (Gheyle 2009). Several campaigns have been organized to fully investigate the region.

For this paper only two of the more than 5100 found structures are considered, namely two so-called dwellings (Plets et al. 2012). These are geometric structures consisting of a single or double line of stones in rectangular or circular formation and a rectangular pavement in the center (Gheyle 2009; Plets et al. 2012). Based on Optically Stimulated Luminescence (OSL) technique, the two structures can be dated back to a period around 2000-1600 BC. Although the function remains unsure, they may be seen as virtual burials to remember a death and give this person a house for the next world (Jacobson-Tepfer 2008). The two considered dwellings, KA-771-016 and KA-771-006, are of the most simple typology (Fig. 2).

**Fig. 2.** Two dwellings found in the Yustyd valley: KA-771-006 (left) and KA-771-016 (right) (Department of Archaeology, Ghent University, Altay Mountains Survey Project)

These two dwellings were excavated in July 2011 to make a study of the chronology, typology and function possible (Plets et al. 2012). An accurate recording and documentation of the dwellings and the other structures in this area is highly important, since multiple factors threaten this archaeological remains. Seasonal river activity, vegetation and bioturbation are some of the natural threats, while increasing tourism, thefts, growing industry and car tracks are the most harmful effects caused by humans (Gheyle 2009). The two dwellings of this case study as well have been partly damaged by car tracks.

## 3 Current role of 3D in archaeology

The third dimension is naturally linked to archaeological data. On the one hand, archaeological objects have, like all real-world objects, a three-dimensional and mostly complex irregular shape. On the other hand, the excavated objects are found in the 3D space, which mostly implies the issue of depth. Both aspects of three-dimensionality play a substantial role in the analysis and interpretation process and therefore in the archaeological documentation. The shape of an object may for example give information on the functionality, whereas the depth or 3D spatial relation between finds reveal important temporal indications. The two dwellings consisting irregular shaped stones are found in the 3D space. Since the stones are found on a similar level and make up a regular shape, they are assumed to form one structure. In some cases, the shape of a stone may indicate a special function, e.g. an entrance, however, due to the simple type, this is not the case for our dwellings.

During the archaeological fieldwork, the location of finds and marks is recorded. This spatial data is nowadays acquired by means of land survey technologies, like total station and GPS. Born digital data is obtained which comprises not only the two horizontal dimensions but also the third, vertical dimension. Consequently, nearly all spatial archaeological data are 3D. The use of these digital sensors have also changed archaeological data recording in a quantitative way, since more data is gathered within a shorter period of time (De Reu et al. 2013; Stal et al. 2014). Formerly, GNSS measurements were used to record the internal corners of the dwellings (Plets et al. 2012). This resulted in 2D line drawings where the detailed configuration of the stones was not spatially acquired. Since the location of the individual stones is requisite for the study of the typology of the dwellings, more accurate registration was needed (Plets et al. 2012). Total station measurements were performed and during the excavation, site plans and sections are drawn on graph paper and scanned afterwards (Fig. 3).

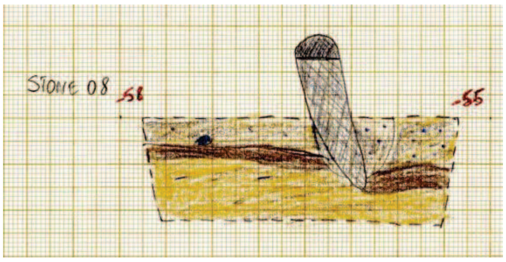


**Fig. 3.** Example of a scanned section drawing of stone 08 of KA-771-016 (Department of Archaeology, Ghent University, Altay Mountains Survey Project)

Although the spatial data is to a large extent available in 3D, two-dimensional representations still constitute the major deliverable. Either the vertical or one of the two horizontal dimensions is in this case ignored. When the combination of both horizontal and vertical dimensions is of importance a series of 2D maps are created (see Fig. 4), e.g. site plans for varying depths or a series of section drawings (Harris and Lock 1995). In the case of the dwelling, no major depth differences exist and thus, no series of horizontal maps is created. On the other hand, drawings or site plans are created during the different excavation phases, so showing different depths (Belien 2012). Several sections were drawn during the excavation, which result in a set of vertical maps, however, not in a linear relationship.

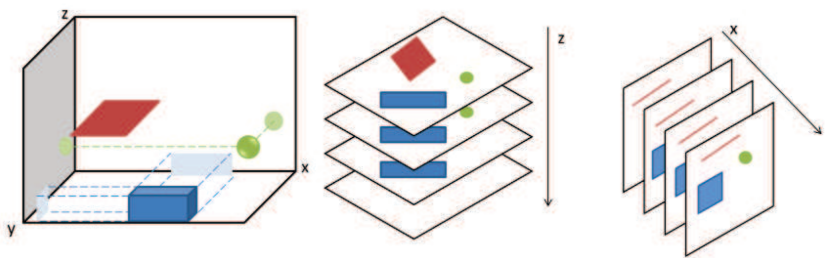


**Fig. 4.** 3D data as a series of 2D horizontal and 2D vertical maps

Nevertheless, by the use of 3D acquisition technologies as total station, GPS, laser scanning and digital photogrammetry an increase of 3D output products can be observed (Forte 2014; Stal et al. 2014). Digital elevation models, orthophotos and digital 3D models can be useful to support interpretations and geometric analysis, although the focus in the creation of these outcomes lays mainly on the visual representation (Forte 2014). In the summer of 2011, the two dwellings were photographed and using photo modelling and photogrammetry, orthophotos and 3D models were produced (Belien 2012; Plets et al. 2012). Based on the orthophotos digital site plans were reconstructed (Fig. 5).

The same 2D abstraction of the reality occurs when integrating the data in currently available GIS. Although in some cases the vertical dimension is stored as an attribute, an elaborate 3D analysis is impossible (Harris and Lock 1995; De Roo et al. 2013a). In conclusion, the final product of current excavations is generally a written report which includes some 2D plans of the site and list of the finds.

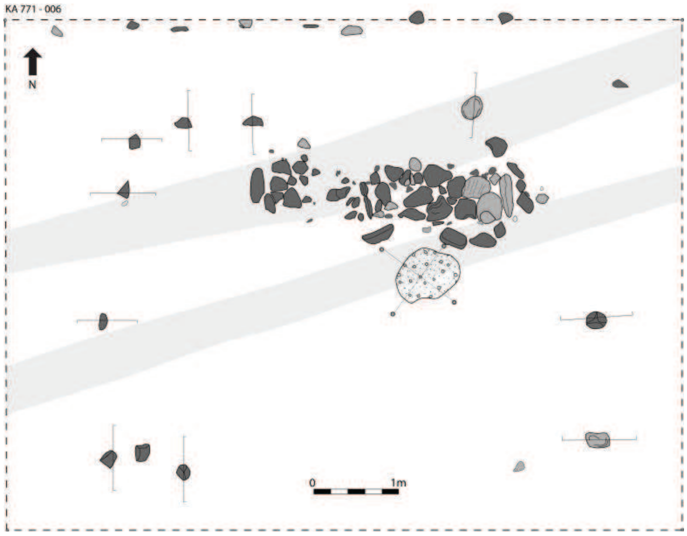


**Fig. 5.** Digital plan of dwelling KA-771-006, with location indication of the vertical sections. (Department of Archaeology, Ghent University, Altay Mountains Survey Project)

## 4 Opportunities of 3D and geo-ICT in archaeology

Considering the archaeological workflow in a very generalized way, it consists of a planning stage, the actual fieldwork, the analysis and interpretation and finally the reporting and communication. Due to the destructive nature of excavations, the precise documentation of the fieldwork is of indispensable importance. The resulting report in combination with the original acquired and processed data will be used as input for the planning of excavations in the future or form the basis for a detailed academic investigation. This way, a cyclic process exists. During the complete project cycle, the use of 3D information and geo-ICT can be profitable.

The planning stage includes among others the consultation of heritage inventories to assess the archaeological potentials of the project area. Such archaeological and cultural heritage inventories are usually maintained by (local) authorities as a tool for decision making in different fields. An inventory which gives a general overview of all archaeological and cultural heritage sites, comprises essential geospatial information and therefore, needs to be conceived as a geodatabase. If this database comprises the substantial metadata to understand the broad context of the site without giving detailed information on the precise findings, its use range can be strikingly increased and it can “support collaborative and even interdisciplinary research” (Labrador, 2012, p 241). Furthermore, a broader public can be reached by using web-based services, e.g. web maps. Since the case study is part of a research excavation, the planning stage mainly concentrates on the results of previous excavations by the institution itself and on the inventory maintained by the department of Archaeology of Ghent University. This database is called the Altai Archaeological Inventory (Altari) and maintained in Microsoft Access. A GIS project in ESRI ArcGIS is created, which links point layers for the sites and polygon layers for the individual structures to the Altari database. The database is therefore not a pure geodatabase. Web-based services would be advantageous for the project as well, since it is a collaboration between Ghent University and Gorno-Altaisk State University. Such a web-based services can facilitate the sharing and maintenance of an up-to-date geodatabase. Furthermore, a web-based service can be used in the promotion of the tourism in the region.

A geodatabase could provide advantages for excavation databases too. When the geodatabase is developed according to an archaeological data exchange standard, a common understanding and structure of the data set originates, which, for its part, would increase the data interoperability. This way, data can be “gathered once and used often” (McKeague et al., 2012, p. 49). Since spatial archaeological data are nearly always available in 3D, it is obvious to handle this third dimension in the geodatabase as well. The Altari database consists of data of both the site and the individual structures. Data on structures are similar on different sites because of a common table/form structure. However, the spatial data is not incorporated in the database.

The combined employment of 3D data and geo-ICT, mainly GIS, would offer favorable opportunities for the analysis. Although GIS are widely used in archaeology, the archaeological data complexity, i.e. 3D, temporal information and imperfection, makes an intensive application a difficult task. A GIS which is able to handle the three dimensions simultaneously and even incorporates the fourth, temporal, dimension would facilitate analysis and interpretation. One could think of performing geometric calculation, creating section cuttings, using colors to highlight or mask some elements, zooming and rotating to investigate the site form different viewpoints, executing 3D spatial analysis such as nearest neighbors, etc. Based on the GIS project in combination with the Altari database, 2D analyses are possible. Analyses and action which could be beneficial for the Altay Mountains Survey Project are 3D spatial analyses, for instance to investigate the orientation of the structures in combination with their depth. Since the dwellings are endangered by natural as well as human factors, their integration in a 3D GIS or in a web-map would enable revisiting and reinvestigated them.

## 5 Challenges of 3D and GEO-ICT in archaeology

The exchange of archaeological data forms a major point of interest. The management of archaeological data is spread among various parties: academic researchers, national or local authorities, archaeological companies, heritage agencies, etc. (Wagtendonk et al. 2009; Labrador 2012; Huvila 2014). A similar list can be obtained for the parties who seek or use archaeological data. This results in the need for a common agreed-on data standard (Anichini et al. 2012; De Roo et al. 2013a). Data standards influence the consistency within databases, but assure as well a better data interoperability and exchange. A 3D GIS based on an accepted data model would further facilitate the data integration, spatio(-temporal) analyses and the understanding of the data. Developing such a standard demands considerable efforts. Due to the minor economic benefits (Green 2011), these struggles will not be taken by commercial software developers as a result of which the initiative needs to come from the scientific community. The data of the Altay Mountains Survey Project is used by different parties as well. On the one hand, Ghent University and Gorno-Altaisk State University acquire and maintain the data and mutually exchange them. On the other hand, local and national authorities, and other researchers may want to use the data for policy making or research as well. Considerable efforts have been made to integrate all the data form the Altay Mountains Survey Project by the creation of the Altari database and the GIS linkage (Gheyle 2009). Nevertheless, this database includes some elements which could hamper data consistency and querying functionalities, e.g. question marks are used to indicate unknown data. To facilitate data exchange, the input values for certain categories are written in both English and Russian. They are, however, stored in the same field, which may cause problems in query or other functionalities.

Second, a system suited to multiple purposes and audiences is required (McKeague et al. 2012; Huvila 2014). Due to the different objectives of the archaeological information providers and seekers, for all these groups their respective requirements need to be outlined. Together with the characterization of the use context, this forms an essential part of the human-centered design cycle, which is investigated by De Roo et al. (2013b) by means of a questionnaire. It is obvious that researchers make higher demands on the functionalities of a 3D geo-ICT system, then organizations do for touristic purposes. Furthermore, the planning of a pipeline will require accurate information on the location of the sites as well as on their respective importance and conservation state.

A third challenge concerns the collection and storage of 3D data. Even though acquiring 3D data during the fieldwork leads to a larger amount of data, topographic technologies record 3D data anyway. On the other hand, larger data volumes will result in higher storage requirements and thus higher costs. Therefore, the usefulness and challenges of incorporating 3D data and techniques need to be balanced against each other for each of the groups. To study the typology of the dwellings, accurate 3D documentation by means of photographs to produces 3D models fulfills the requirements (Plets et al. 2012). This detailed documentation has led to 2,85 GB and 1.85 GB of photos and scanned drawings for KA-771-006 and KA-771-016 respectively. Including the orthophotos of the different excavation stages resulted in 2,99 GB and 2.05 GB resp. A 3D reconstruction of the platform of dwelling KA-771-016 stored in a pdf-file required 8,71 MB of storage. Considering the area of the structures, approximately 21,5 m² and 17,4 m² respectively, and their simple typology, these numbers are quite high.

A fourth challenge is the necessary education and training on the use of new techniques and analyses. This risk can yet be reduced by keeping the system easy to use and comprehensible. By doing so, another issue is partly tackled, namely the risk to lapse into complexity. As shown in Table 1, this is identified by the users as major potential drawback of a 3D system (De Roo et al. 2013b).

**Table 1.** Drawbacks conceived of a 3D or 4D system (De Roo et al. 2013b)

| Drawbacks | % |
|---|---|
| Complexity | 46.2% |
| Hardware requirements | 23.1% |
| Data management | 11.5% |
| Failure chance | 3.8% |
| Teaching requirements | 3.8% |
| Costs | 3.8% |
| Time consuming | 3.8% |
| Data requirements | 3.8% |

## 6 Possible Approach to integrate 3D and geo-ICT

As described above, several challenges have to be accepted in order to reap the full benefits of 3D and geo-ICT in archaeology. The integration of 3D and geo-ICT during the complete archaeological project cycle would ideally result in a completely digital 3D workflow. Currently, 3D are mainly found in the first - acquisition - stage of the archaeological process and to a small extent also during the last – communication - phase, whereas Geo-ICT and especially GIS are employed in the middle - analysis and interpretation - stage. Extending the use of 3D to the middle stage and geo-ICT to the acquisition and communication phase will give rise to a complete digital 3D workflow. This division also exists in the Yustyd survey. The data are acquired in 3D using GNSS, total station and photo modelling, but then analyzed and interpreted using 2D GIS or site plans. 3D models were created from the two dwellings and the platforms. Although the database is used in the field as well, a linkage with GIS would even facilitate the acquisition stage.

Multiple parties dealing with archaeological data could be assisted by such a complete digital 3D workflow. For example, archaeological databases combined with a web-based GIS could blur the boundary between experts and leeks, and even involve a wider public (Labrador 2012). However, 3D is not always necessary or feasible for all parties dealing with archaeological data. As Huvila (2014) suggested an investigation of a supply-chain and customership of archaeological data and products is needed.

Since data exchange between various parties will be stimulated by a digital workflow, data interoperability is the major challenge. As explained in section 5, a data standard is desirable (De Roo et al. 2013a). Attention has to be given to existing international standards or data models from other research fields. One can think of CityGML, GeoSciML, etc. Implementing any links to those models will increase the usefulness for a broad range of parties interested in archaeological data.

We now turn to the potential approach for the integration of 3D and geo-ICT in a completely digital 3D archaeological workflow. The examination of an integrated object-oriented and data-driven approach for the basic structure of the database model is suggested (Fig. 6), since both approaches can directly be translated in an archaeology-specific relationship: object-space-time (Arroyo-Bishop and Lantada Zarzosa 1995) and place-people-event-stuff (Cripps 2012) respectively. The combination of objects, space and time is charactering for archaeological research, so it is obvious to handle those three elements simultaneously (Arroyo-Bishop and Lantada Zarzosa 1995). Besides, "archaeologists attempt to record and document the results of past events through a series of events or activities in the present" (Cripps et al. 2004, p.4). Such an approach, links places, people and objects by events and results in a place-people-event-stuff relationship as defined by (Cripps 2012).

First, we propose to use the event-oriented relationship as basis for the more general archaeological inventory (Fig. 6). Since this inventory will be used in the planning phase of an archaeological excavation or in policy decisions, for instance regarding land administration or spatial planning, no detailed analysis are requisite and the spatial information can be limited to 2D. This does not alter the possibility to incorporate, 3D reconstruction models for tourism purposes, conservation decisions, etc. As stated in section 4, we consider this inventory as a geodatabase, which includes essential metadata of the excavation or project. Detailed information on the excavation findings will be separated from the inventory, but kept traceable. The latter can be realized by, for example, including the contact details of the archaeological project manager or a link to the electronic deposit location.

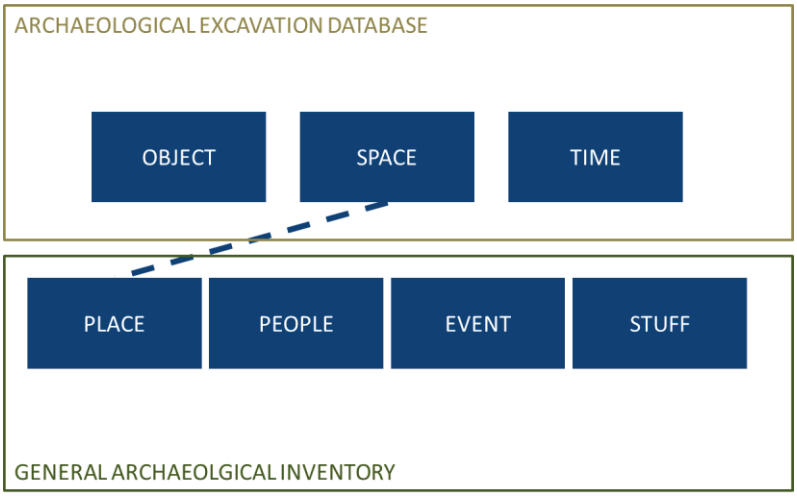


**Fig. 6.** Proposed structure for an integrated archaeological database by combining object-based and event-based approach.

Second, the excavation database should be used during the field work as well as the analysis and interpretation. Detailed information on the objects, their location and temporal and other attributes should be recorded in it. As 3D spatial data is generally recorded, this database should be geospatial and incorporate 3D data where feasible. We propose to develop the database according to the 'object-space-time' relationship, where the connection with the general inventory can be made through the 'space-place' linkage (see Fig. 6). An integrated database can thus be developed.

With regard to the case study, the integrated database may look as follows (Fig. 7). For the general inventory the 'place' part will contain information on the administrative place, such as the country 'Russia', the province 'Kosh Agash', eventually cadastral parcels, etc. and the coordinates of the site. Preferably, this are the coordinates of the site boundaries, but at least it should be a point location '49°47'51"N, 89°09'10"E' for the Yustyd site. All persons and organizations involved in the archaeological project will be recorded in the general database, and linked to the events they have taken part in. These events can be both field (e.g. excavation, sampling, etc.) and desktop events (e.g. administration or report writing). Ghent University and Gorno-Altaisk State University will be identified as participating organizations, and the individual field archaeologists will be included in the data base and linked to what kind of activity they have participated in, e.g. excavation, OSL sampling, report writing, etc. The events are then linked to the stuff, which gives a general indication of what one can expected of the site. For the case study site, the same site type category as in the Altari database can be used, namely ritual/other. Additional information can be given: 'A line of square structures with platforms,…'. The detailed information of what is actually found on the site is stored in the 'object' part of the excavation database. All details such as the material 'stone', the type of structure 'dwelling', the findings 'stones, …', etc. can be stored. For all of them the shape is stored including the three dimensions or at least a 3D point is indicated. This will form the basis for linking the two databases. Another option is to link the two databases by the site ID 'KA-771'. The latter will be useful if the site location is only known as a point. Since the temporal information is as important as the spatial information, this forms a separate axis in the database. Different temporal categories such as the excavation time 'July 2011' and the cultural period, in this case still unknown, can be stored (De Roo et al. 2014).

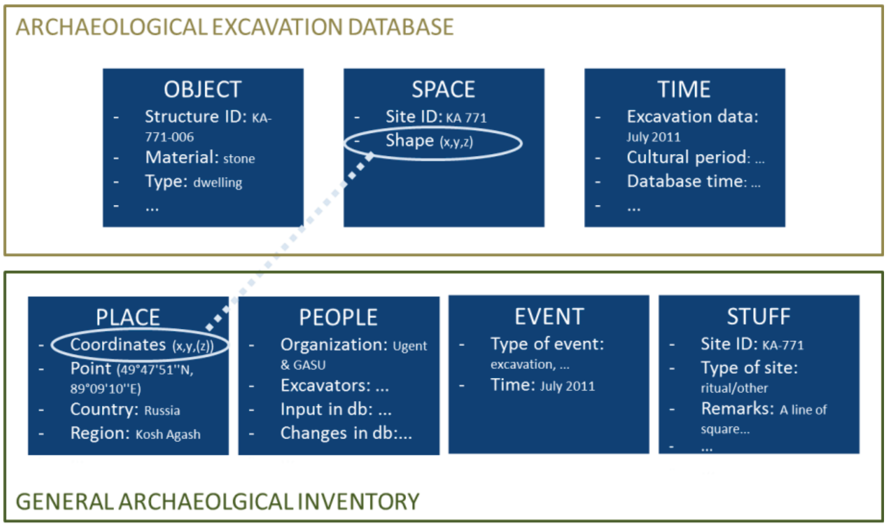


**Fig. 7.** Example interpretation of the integrated archaeological database

The integrated database, for its turn, can give rise to the development of information systems and analysis tools. According to the various actors who provide or use archaeological data, different objectives exists. This implies to define different levels of usage in line with these actors and their requirements (Anichini et al. 2012). For example, a tourist seeking for more information is not assumed to be able to make changes to the excavation database entries, while it is obvious a field archaeologist working in that project can do this. An archaeological information infrastructure will be created that way, and will allow archiving, accessing, integrating and mining disparate data sets (Kintigh 2006).

Finally, it should be noted that the proposed approach is not unassailable. Future work need to show the positive and negative implications arising from the implementation and testing in a real archaeological project cycle. Furthermore, elements such as implementation costs, storage space and costs, policy and control structures need to be thoroughly assessed as well. However, this research has shown that opportunities are granted by incorporating 3D and geo-ICT in the entire archaeological project cycle. An integrated archaeological database including a general inventory and a detailed excavation database, will facilitate interdisciplinary research and interoperable data for use within archaeological research and in other fields, such as land administration and other policy decisions.

## References


Anichini F, Fabiani F, Gattiglia G, Gualandi ML (2012) A database for archaeological data recording and analysis. MapPapers 1 en II 21–38.

Arroyo-Bishop D, Lantada Zarzosa M (1995) To be or not to be: will an object-space-time GIS/AIS become a scientific reality or end up an archaeological entity? In: Lock G, Stancic Z (eds) Archaeol. Geogr. Inf. Syst. Taylor & Francis, London, pp 43–53

Belien E (2012) Methodologisch onderzoek naar de optimalisatie van documentatie van archaeologische opgraivngen door middel van fotogrammetrie en fotomodellering (Altaï-Rusland). Ghent University

Cripps (2012) Places, People, Events and Stuff: Building blocks for archaeological information systems. Proc. Comput. Appl. Archaeol. Conf. 2012.

Cripps P, Greenhalgh A, Fellows D, et al. (2004) Ontological Modelling of the work of the Centre for Archaeology.

Forte M (2014) 3D Archaeology: New perspectives and challenges-The example of Catalhöyük. J East Mediterr Archaeol Herit Stud 2:1–29.

Gheyle W (2009) Highlands and Steppes: An Analysis of the Changing Archaeological Landscape of the Altay Mountains from the Eneolithic to the Ethnographic Period. Ghent University

Green CT (2011) Winding Dali's clock :the construction of a fuzzy temporal-GIS for archaeology. 159.

Harris TM, Lock GR (1995) Multi-Dimensional GIS : Exploratory Approaches to Spatial and Temproal Relationships within Archaeological Stratigraphy. In: Kamermans H, Fennema K (eds) Interfacing Past. Comput. Appl. Quant. Methos Archaeol. CAA95. Vol. II (Analecta Paehistorica Leiden. 28). Institute of Prehisotry, University of Leiden, Leiden, pp 307–316

Huvila I (2014) Process and appropriation in the digitalisation of archaeological archives and archiving practices. Paris, France, pp 1–6

Jacobson-Tepfer E (2008) Culture and Landscape of the High Altai. Preserv. Frozen Tombs Altai Mt.

Katsianis M, Tsipidis S, Kotsakis K, Koussoulakou A (2008) A 3D digital workflow for archaeological intra-site research using GIS. J Archaeol Sci 35:655–667. Kintigh K (2006) The Promise and Challenge of Archaeological Data Integration. Am Antiq 71:567–578.

Labrador AM (2012) Ontologies of the Future and Interfaces for All: Archaeological Databases for the Twenty-First Century. Archaeologies 8:236–249. doi: 10.1007/s11759-012-9203-2

McKeague P, Corns A, Shaw R (2012) Developing a Spatial Data Infrastructure for Archaeological and Built Heritage. Int J Spat Data Infrastruct Res 7:38–65.

Plets G, Gheyle W, Verhoeven G, et al. (2012) Three-dimensional recording of archaeological remains in the Altai Mountains. Antiquity 86:884–897.

De Reu J, Plets G, Verhoeven G, et al. (2013) Towards a three-dimensional cost-effective registration of the archaeological heritage. J Archaeol Sci 40:1108–1121. De Roo B, Bourgeois J, De Maeyer P (2013a) On the way to a 4D archaeological GIS: state of the art, future directions and need for standardization. In: Addison AC, De Luca L, Guidi G, Pescarin S (eds) Proc. 2013 Digit. Herit. Int. Congr. Institute of Electrical and Electronics Engineers (IEEE), pp 617–620

De Roo B, Bourgeois J, De Maeyer P (2013b) A survey on the use of GIS and data standards in archaeology. Int J Herit Digit Era 2:491–507.

De Roo B, Van de Weghe N, Bourgeois J, De Maeyer P (2014) The temporal dimension in a 4D archaeological data model: applicability of the geoinformation standard. Innov 3D Geo-Information Sci Lect Notes Geoinf Cartogr. doi: 10.1007/978-3-319-00515-7

Shaw R, Corns A, McAuley J (2009) Archiving Archaeological Spatial Data: Standards and Metadata. Comput. Appl. to Archaeol. 2009

Stal C, Van Liefferinge K, De Reu J, et al. (2014) Integrating geomatics in archaeological research at the site of Thorikos (Greece). J Archaeol Sci 45:112–125.

Wagtendonk AJ, Verhagen P, Soetens S, et al. (2009) Past in Place: The Role of Geo-ICT in Present-day Archaeology. In: Scholten HJ, Velde R, Manen N (eds) Geospatial Technol. Role Locat. Sci. Springer Netherlands, Dordrecht, pp 59–86

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