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Sharing Archaeological Knowledge: The Interactive Reporting System

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ABSTRACT
This study describes the development of a digital reporting system designed to provide archaeologists with a dynamic and interactive 3D web platform that can be used for describing in great detail records and activities undertaken across a multi-year field investigation campaign. The system was used to compose the archaeological report of a multi-year investigation and employed during the pandemic crisis for supporting digital courses in archaeological practice; the paper also reports the preliminary results of the use of this platform within teaching activities. Unlike other web solutions, this system supports an assisted publication of archaeological contents that integrates a 3D visualization system in the reporting process, exploiting the communicative potentials of 3D models and the web. This study represents a contribution to research on sustainable forms of management and publication of archaeological contents and their reuse and sharing.

KEYWORDS
3D online publication; 3D narrative; archeological report; data reuse and sharing

Introduction

Context and aim

The archaeological report represents the final output of any excavation. It consists of a standardized textual document supplemented with images, tables, and references, where the results of surveys, excavation, and analysis are published (Börjesson 2017, 16). The archaeological report is considered the most authoritative means of knowledge in archaeology, and its adoption and diffusion provide the community of practitioners with shared guidelines on how to communicate archaeological data.

The results from archaeological field investigation are mainly published in the form of scientific articles and archaeological reports (Dallas 2015, 189), which are acknowledged as the final word in any investigation (Lucas 2012, 250). The text should follow a coherent narrative, and it should be structured in order to be accessible to non-archaeologists (Lucas 2012, 457–452). In their contribution about contract archaeology, Huvila and Börjesson discuss the role of the archaeological report in the process of knowledge production: their findings about archaeological information sources demonstrate that archaeological reports are often chosen over primary data (Huvila and Börjesson 2019, 110). Archaeological reports are, therefore, the key to accessing the information collected during the investigations.

Even though the shape of the report has not changed much since the modernization of archaeological practice, the digital revolution has nevertheless impacted it. The web offered new possibilities for managing archaeological data, increasing their visibility, and providing new opportunities for experimenting with new forms of publications (Evans and Daly 2006). The Swedish Pompeii Project (https://www.pompejiprojektet.se/insula.php) is a successful example of online reporting. Since 2001, the archaeological reports are published online and interlinked with different media through the project website (Leander Touati 2010; Landeschi et al. 2015, 350). This online resource is used by archaeologists and specialists as a platform for research and publication, and it is considered the main repository for the data collected on-site. The Last House of the Hill is another endeavor at the forefront of best practices, within the Berkeley Archaeologists at Çatalhöyük (BACH) project, for the management and online publication of archaeological content aimed at the harmonization and availability of the final report as a comprehensive digital resource (Ashley, Tringham, and Perlingieri 2011, 8) and at the presentation in an open access platform of the excavation data with their interpretation (Ashley, Tringham, and Perlingieri 2011, 3). The Giza Archive Project (http://giza.fas.harvard.edu/about/) is a pioneering attempt to publish online both traditional archival documentation and immersive 3D environments and to collect and link together as much data as possible about this complex site: it has become the reference repository to access archaeological data about Giza (Der Manuelian 2013, 730; 2017). Another relevant attempt at an online dynamic archaeological report has been proposed by Marlet and colleagues (2019). The web system is designed to make different levels of information and in-depth consultation available, and it is based on structured data exposed following a CIDOC-CRM semantic web standard (Marlet et al. 2019, 2).

More recently, important experiments were carried out combining results of archaeological field investigation and three-dimensional models. 3D models are commonly adopted by archaeologists in support of documentation (De Reu et al. 2013; Dellepiane et al. 2013; Forte 2014; Dell'Unto 2016; Dell'Unto et al. 2016, 2017; Opitz and Johnson 2016; Derudas, Sgarella, and Callieri 2018), and these represent a powerful medium for reviewing and

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presenting the excavation process. These systems allow for the visualization of contexts and materials no longer available in three dimensions, diachronically and spatially-aware, providing archaeologists with the possibility of experiencing new forms of interactive narration and promoting a more reflexive approach to the data (Forte 2014; Berggren et al. 2015; Opitz 2015; Dell'Unto 2016), as well as encouraging new archaeological interpretations (Opitz and Johnson 2016; Dell'Unto et al. 2017; Galeazzi and Richards-Rissetto 2018; Landeschi et al. 2019).

Although 3D visualization systems are nowadays commonly diffused in the field, they hardly ever deal with the narrative and communication aspects connected with data publishing, and, so far, very few pioneering experiments based on the use of 3D visualization technology have been conducted for engaging audiences at different levels and for facilitating data re-use (Richards-Rissetto and von Schwerin 2017; Sullivan and Snyder 2017; Opitz 2018). The use of the third dimension in archaeological practice has a profound impact on the way data are combined and processed. The possibility to access and review the archaeological records in a three-dimensional simulation environment provides incredible support when building an archaeological interpretation. The opportunity to employ 3D web-based components capable of establishing and publishing a dynamic link between narrative and archaeological data would provide researchers and scholars with the unique possibility of reading the data from multiple perspectives, enriching their interpretation and gaining a deeper understanding of the records retrieved by different researchers.

This paper fits into the discussion of sustainable online data management and publication of archaeological 3D contents and proposes a possible solution for the integration of 3D visualization systems in the archaeological reporting process. It also relates to research on digital curation concerning the accessibility and organization of unpublished data (Dallas 2015, 176). Throughout this paper, the preliminary results of the Interactive Reporting System (IRS) are presented and discussed (https://www.darklab.lu.se/digital-collections/dynamic-excavation/kampinge/). This system is a web-based tool which takes advantage of the potential of 3D web information for the generation of digital interactive reports of archaeological excavations. Existing solutions dealing with 3D content-management and dissemination propose alternative forms of digital publications (Sullivan 2017) and are aimed at both scholars and the general public (Opitz, Mogetta, and Terrenato 2016). Other proffered solutions deal more with excavation data analysis, management, and visualization through the use of web-based platforms (von Schwerin et al. 2016; Jensen 2018a).

Unlike these projects, our goal is to create a digital and interactive version of the archaeological report, strongly connecting the 3D documentation with the textual content of the report, creating a dynamic 3D spatial visualization of the site that is able to communicate the interpretation of the gathered data. We propose a novel system for authoring and accessing a narrative based on archaeological contexts and materials. Such an instrument was designed to encourage archaeologists in the use of the third dimension for data analysis, interpretation, and publication; in fact, as Campana (2014, 11) observes, 3D data should be employed across the entire archaeological process. This work aims to overcome the division between writers and readers (Huggett 2015, 92) by proposing a dynamic solution for promoting data publication and re-use.

This paper will present the design and implementation of a new form of digital reporting capable of supporting a narrative-based communication, the validation of the developed system by using the datasets of the archaeological field excavation campaigns at Kämpinge, Sweden (2014–2017), and the use of the Kämpinge interactive report in the classroom as a digital education platform.

Methods and Materials

The archaeological site of Kämpinge

The archaeological site of Kämpinge is located in the south-western end of the Swedish region of Skåne and is known for the large number of prehistoric artifacts uncovered in the southern part of an end moraine, where the seawater level was ca. 4 m above the present sea level (Figure 1). The site covers an area of 14,030 m^2 and belongs to a large, known group of Middle and Late Mesolithic coastal sites in the Öresund region dating from 8500–6000 CAL B.P. (Dell'Unto et al. 2017, 633–634). In 2014, the Department of Archaeology and Ancient History of Lund University started a new archaeological investigation of the site aimed at assessing the presence of intact stratigraphic layers in the area.

Documentation and data management system

Since the beginning of the field investigation, 3D acquisition techniques have been used for the recording of archaeological evidence, and a three-dimensional Geographical Information System (3DGIS) was used for managing and reviewing the archaeological data gathered during the investigation. The combination of 3DGIS platforms and 3D models resulted in a broad and accurate overview of the different steps undertaken during the field investigation, providing the archaeologists with the possibility to review and reassemble information in a three-dimensional space. 3D polylines were used to highlight contexts and features visible on the 3D models. The context-sheet was set as the core element of the database, and it was implemented in the system in order to spatially connect the different entities in the geodatabase (Dell'Unto et al. 2017, 635–639).

3DGIS proved to be an excellent tool for running complex analysis across different datasets. However, the system was not designed for supporting data publishing or providing a way to help compile the excavation report. For this reason, we decided to develop a new software system based on the 3DHOP tool (3D Heritage Online Presenter), an open-source framework for the creation of interactive web-based presentations of high-resolution 3D models designed with the cultural heritage sector in mind (Potenziani et al. 2015; Potenziani, Callieri, and Scopigno 2018). The basic idea was to exploit the 3DHOP capabilities of displaying high-resolution 3D models, its configurability, and the possibility of creating pages containing different interconnected media to build an integrated, narrative-oriented system.

Other systems focus on 3D real-time recording and analysis (Dellepiane et al. 2013; Dell'Unto 2014; Jensen 2018b) and/or on publishing results of archaeological interpretations in a 3D interactive space (Galeazzi et al. 2016; Opitz, Mogetta, and Terrenato 2016). In contrast, this work

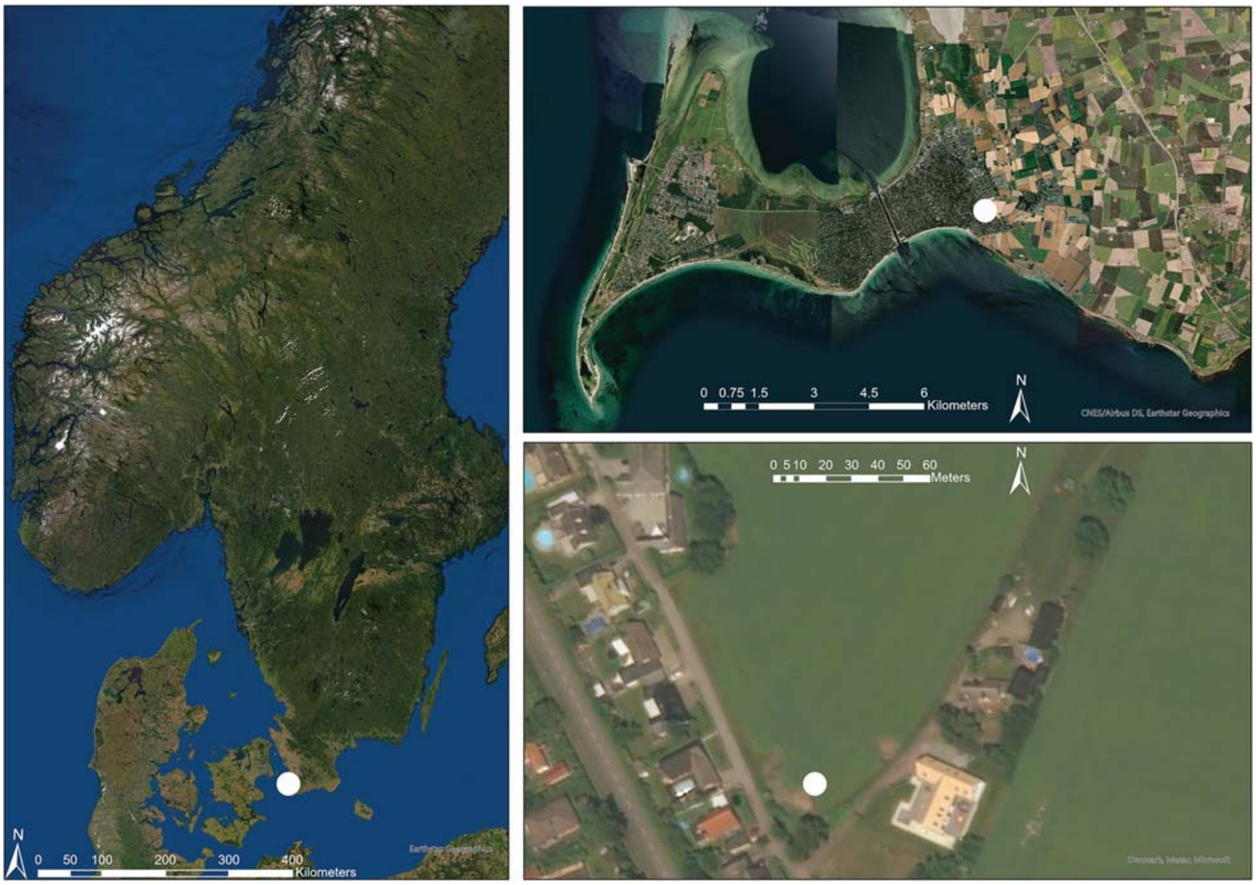

Figure 1. Localization of the site of Kämpinge. Source: Esri, GeoEye, Earthstar, Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and GIS User Community.

explores the limits and potentials of a tool designed for supporting the production of archaeological reports by means of a dynamic interaction between the archaeologists and the archaeological data in a 3D environment. The developed system provides an interface for creating, visualizing, and navigating interactive 3D-based narratives relating to different aspects of archaeological investigation. 3D data, context description and relationships, artifact localization, and standard documents are available in the system and can be used for constructing and reviewing different hypotheses, as well as for formulating different interpretations.

Designing the Interactive Reporting System

In Sweden, the archaeological report must be delivered to the national institution responsible for the administration of the archaeological records (Länsstyrelsen) at the end of each excavation campaign. Normally, the report starts with an introduction to the site, where the project and research questions are addressed, and goes on to present a detailed description of the activities undertaken by the investigation team during the fieldwork. In the text, contexts and artifacts are described according to the stratigraphic relationships identified during the investigation. The text narrative follows the excavation progress, motivating strategies, and decisions. Images are usually integrated within the text, while plans and tables are provided as appendices (Börjesson 2017). To incorporate all these elements into the Interactive Reporting System, the different components of the report have been treated as self-contained, independent bits of information that are interconnected to the system in a non-linear way. Thus, the archaeologists can review their interpretations dynamically by navigating a three-dimensional diachronic map of the investigation, where they can access and use all the available information and data concerning the excavation.

Considering the above-mentioned aspects, the Interactive Reporting System has been built on a modular structure and designed around the concepts of nodes and connections. The nodes are the basic components of the digital report, containing information about the archaeological investigation at different levels (site—year—trench). The nodes are then connected in a hierarchical way but also with cross-connections based on time and physical proximity. The system has been structured across three main types of nodes: the *site-node,* the *campaign-node* and the *excavation-node* (Figure 2).

The site-node (Figure 3) is the top-level page of the interactive reporting system for a given excavation site. It presents a broad description of the investigation project across the various excavation campaigns and is mainly composed of text and images; it holds specific sections containing information related to the site and links to site-specific documents and files. The site-node page gives access to the different field campaigns.

The site-node is linked to the campaign-nodes, where goals and descriptions of each excavation campaign are described (Figure 4). Again, the nodes may contain specific subsections for information and forms that are specific to that campaign and give access to lists of campaign-level documents. The results and interpretation of the excavation are sorted by excavation area and are presented via the excavation-nodes. These are accessible through an interactive map of the site and represent the detailed archaeological report of a specific area investigated in a defined season.

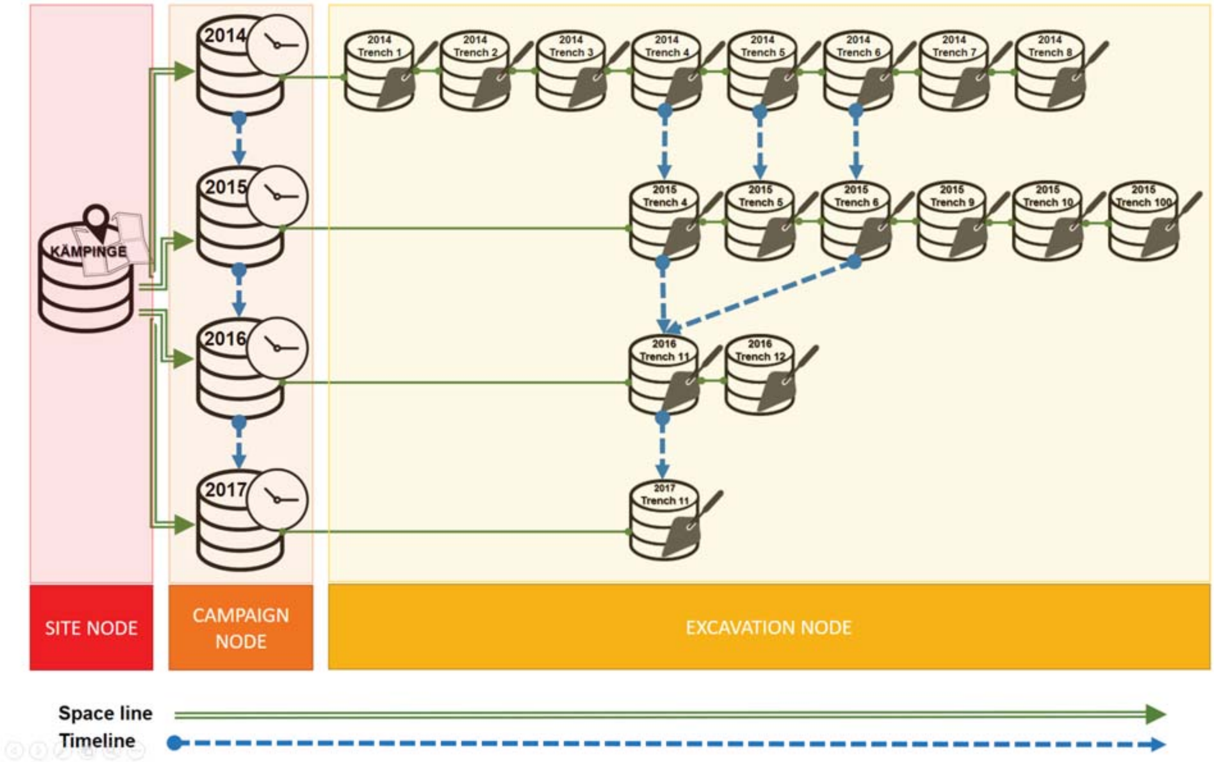

Figure 2. The spatial and chronological navigation of the excavation is made possible via the space-time organization of the nodes: the diagram illustrates the relationships between the different components of the Interactive Reporting System of the excavation: through the site-node, the user can access the various campaign-nodes (years), which in turn connect to the excavation-nodes (trenches). The dotted blue connections represent the excavation time line.

They allow one to review the field documentation produced for each context in great detail (Figure 5).

The excavation-node

The excavation-node is the core component of the modular structure of the Interactive Reporting System and provides an interactive, dynamic presentation of multimedia contents recorded in the field. The node contains all the elements that are relevant for describing any specific phase of the excavation: 3D models, contexts, and finds.

The main functionality of the excavation-node is to guide the users into the archaeologist's interpretation through a dynamic narration which represents the actual archaeological report. This is made possible by presenting the report as a series of narration elements called "blocks," where the stratigraphic relationships between elements of the excavation area are displayed in a three-dimensional environment and supplemented by textual and graphic documentation. The users may also freely explore the scene by navigating the 3D space, changing the visibility,

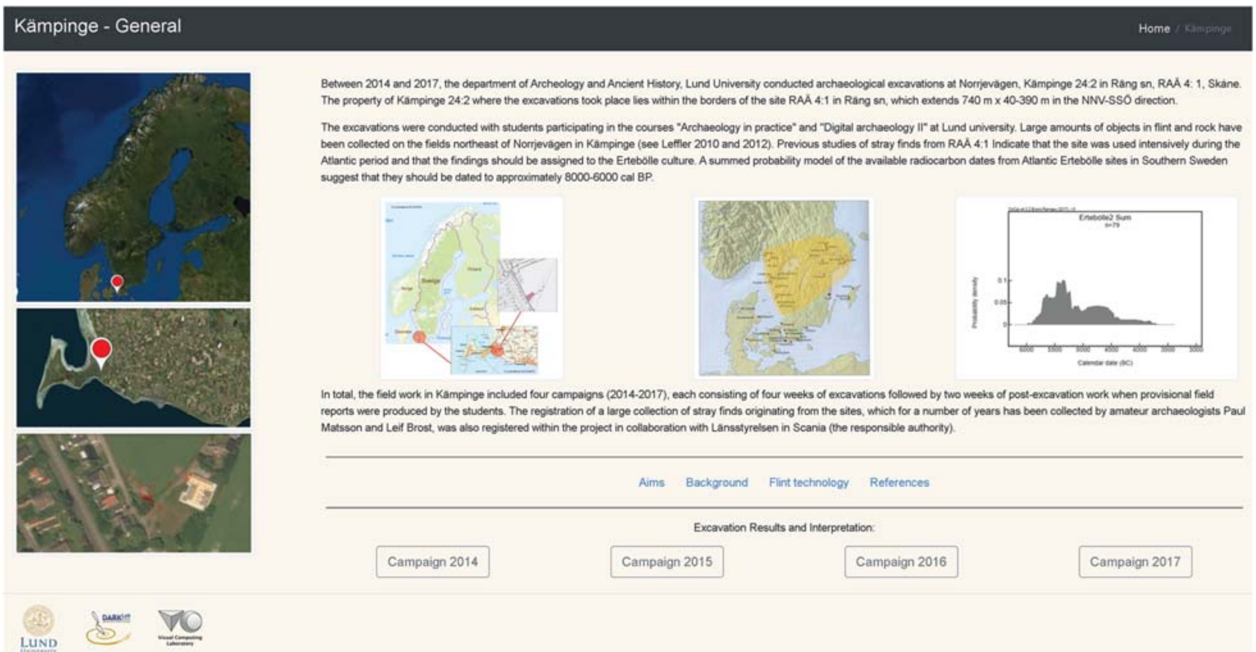

Figure 3. The site-node of the Interactive Reporting System of the excavation of Kämpinge. It presents a broad description of the investigation and gives access to several sections providing details about the investigation: Aims, Background, Flint Technology, and References. It also contains the links to each campaign-node.

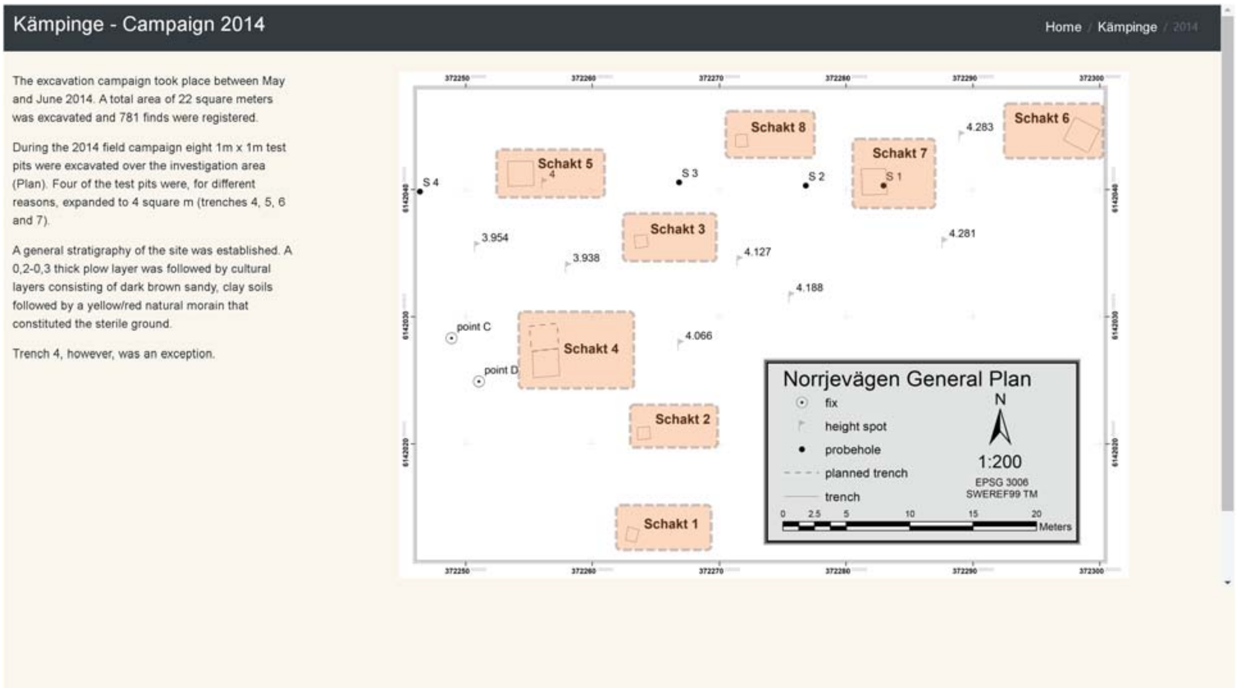

Figure 4. Through the campaign-node, it is possible to get information about a specific excavation campaign. A brief description illustrates the main facts about the investigation, and the interactive map representing the excavation areas allows access to each excavation-node.

transparency, and rendering options of the 3D models, and using measurement (tape measure and coordinates picking) or visualization tools (light control and cut-through sections). In this way, the users may either access the documentation following the narration and interpretation of the dataset by the archaeologist responsible for the excavation, explore the whole dataset, or use a mix of the two, as each step of the narration is still an interactive 3D viewer with all the navigation and visualization controls.

The excavation-node page is divided into sections. At the top of the page, the header identifies the node; the 3D canvas, where the three-dimensional content is displayed, is the larger section. The bottom-right panel hosts the measurement and rendering controls of the scene. The left panel contains two tabs: each tab has the controls for exploring the node by following one of the two paradigms described above, either following the report narration with the Report tab or exploring autonomously the elements with the Scene tab (Figure 6).

The Report tab shows the report as a series of framed blocks. A traditional report is generally made up of text paragraphs (describing the different stages of the excavation, peculiar characteristics of the contexts, and findings) and some images depicting what is described in the text. The idea of this block-based structure is to replicate the text-plus-image structure by overcoming the limits of printed media. Here, each block contains a text paragraph with an associated "state" of the 3D viewer that the final user can activate to visually experience the content of the paragraph in the interactive 3D scene. A 3D viewer state creates a specific viewpoint but also defines which 3D elements are displayed and how they are rendered. Additionally, a block may contain links to documents or to external pages and a set of images shown as expandable thumbnails (Figure 7). Each block also shows the elements that are embedded in and connected to this part of the report (3D models, contexts, and findings) as buttons connected to information cards containing the element's metadata (Figure 8). The final user can either read one block paragraph after another, observing the details in the 3D view, with the option of interacting with the scene and taking measurements or autonomously explore all the 3D models and media available. This navigation style still mimics the way a traditional report is used but provides more comprehensive and interactive access to the information.

The Scene tab contains a list of models, contexts, and findings that make up the report, together with basic descriptions. Through checkboxes, the user can show or hide each element and set its rendering mode. The connections among the various components are hierarchically visualized through a graph. The contexts are connected to the models in which they are represented, and the localizations of the finds are related to the context to which they belong; in this way, interconnections are established among the dynamic elements of the report (Figure 9).

The viewer page is what the final user can access from the web front-end of the system. In order to create the node (the scene and the report), the archaeologist responsible for the documentation and interpretation uses a modified version of the viewer page. Here, an additional tab is available to create the scene elements by uploading 3D models and setting their properties. The report tab is also different, as it contains the controls to create and modify the report blocks.

The workflow for authoring starts with the creation of a scene in the Report tab, using the three color-coded sections, *New Layer*, *New Context*, and *New Finding* to upload the various elements of the report (Figure 10). Once the scene has been created, the author starts creating the blocks of the report one at a time. The text for each block is written using an integrated rich-text editor. The 3D viewer state associated with the text is obtained by setting the desired combination of model-, context- and artifact-visibility and rendering options using the Scene tab. Here, the author can also set a view interactively in the

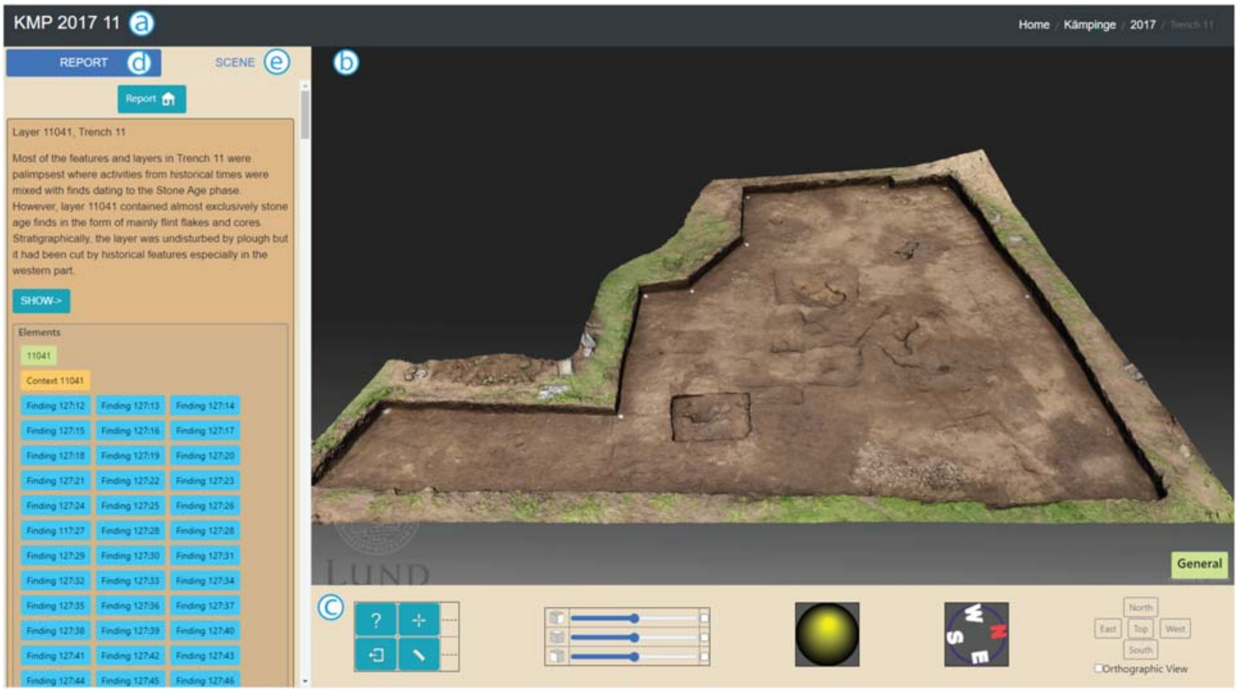

Figure 5. The excavation-node of trench 11, divided into different sections: A) the header, which identifies the node (the excavation campaign, and the trench); B) the 3D canvas, which displays the three-dimensional contents; C) the bottom-right panel, which hosts the measurement and rendering controls of the scene; and, the left panel containing two tabs: D) the Report tab and E) the Scene tab.

3D canvas; then, a specific button allows saving the state of the chosen combination. Additional media may be added to the block through other specific buttons. Blocks may be modified at any moment and re-ordered or deleted if necessary. It is important to note how this authoring tool is completely WYSIWYG (What You See Is What You Get): the report is built incrementally in a modified viewer interface, and the content creator has access to all the tools available to the final user to see and interact with the report and scene.

Implementation of the system

The excavation-node is made up of three basic elements: a data structure describing the scene and the body of the report excavation-node (stored as a JSON file), a set of media files (3D, images, and PDFs), and webpages for the authoring and visualizing of the aforementioned data structure. We know that HTML web technologies are volatile: it is not possible to know how long this technical solution (3DHOP and WebGL) will be supported by browsers. For this reason, we

Figure 6. The report-block of the excavation-node from trench 6, excavation campaign 2014, appears in the report tab. A) The archaeological features are described and their stratigraphic relations are shown in a 3D environment by clicking B) the "show" button. C) In the element's box, the 3D models, contexts, and the findings' localizations, which compose the narration of the block, are displayed; here users may also access the attached media, such as D) pictures and pdf files.

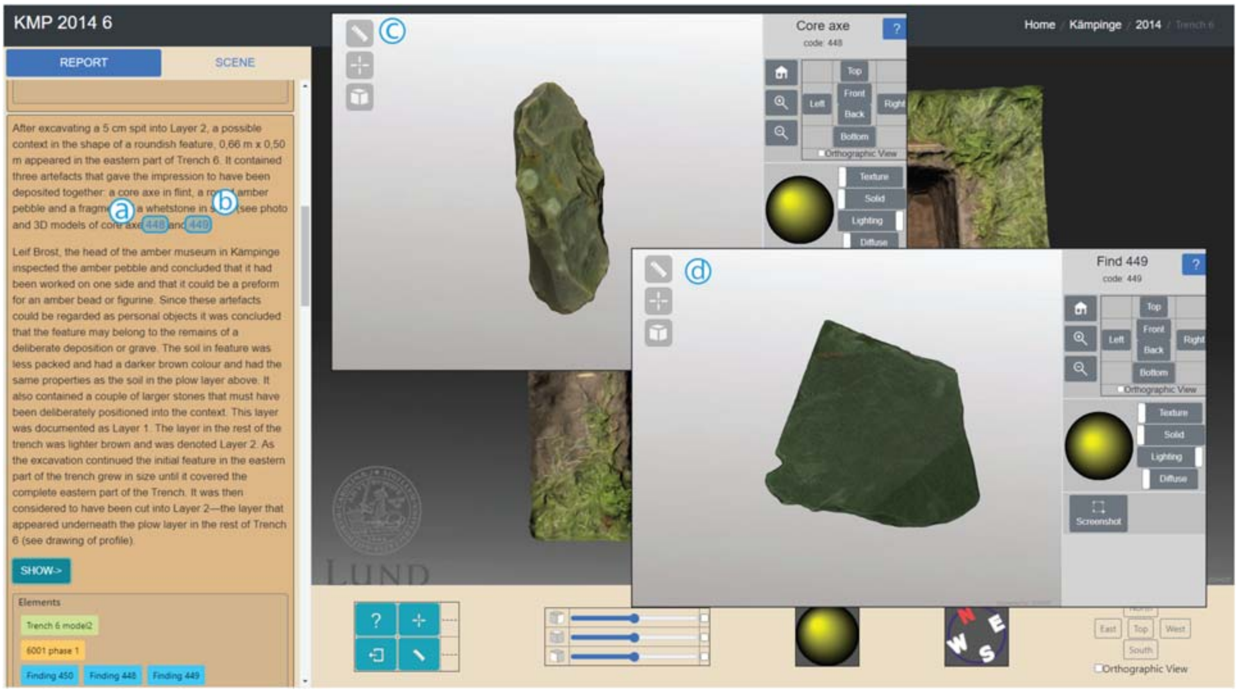

Figure 7. The report-block of the excavation-node from trench 6, excavation campaign 2014, including A–B) the links to the external pages with C–D) the detailed 3D models of relevant artifacts.

enforced a complete decoupling between the three elements of the node. Media files are stored in formats suitable for long-term archiving: they are converted into a streaming-friendly format for this specific viewer, but the original data may be viewed and used in any other 3D software tool. The data structure describing the excavation-node represents the scene and the block-based report as a set of fields that are agnostic with respect to the viewer: lists of 3D models, position and orientation data, locations, texts, links, and visualization parameters. These elements are translated into 3DHOP-specific entities and webpage content by the editor/viewer HTML pages, but implementing a different front-end for the same data (report + media) will always be possible, for example, by using libraries such as Three.js or tools like Unity3D.

Another interesting aspect of the independence between the viewer and the data + media is the possibility of transforming the data + media into another format: instead of a dynamic, interactive view, it is possible to flatten all the information (as blocks of text and static renderings), as is normally done in a classic, paper-based report, generating a static PDF; this option is currently under development.

Viewer and editor

The excavation-node page is a single HTML page—the interface and styling use Bootstrap, a popular front-end library, and 3DHOP is used to display the 3D contents; some other minor JavaScript libraries are used to manage input and output functionalities. The basic editor and view pages are blank, and the content is dynamically loaded from a JSON file describing the node. The JSON file is a structured description of the scene and the report, while all the media files (3D models, images, and documents) are stored in an appropriate folder hierarchy. When using the editor, the author builds the scene and then the report, filling the JSON structure that can be exported for further editing or publishing. When exploring the node, the appropriate JSON is loaded and parsed. The page is then filled with the interface elements and controls, and the 3D scene is loaded. Each element used by the node (listed in the "scene" part of the JSON structure) is created in 3DHOP as a 3D element. 3DHOP takes care of the interactive navigation and of the measurement (tape measure and coordinates picking) and visualization tools (light control and cut-through sections). 3DHOP also implements the screenshot functionality.

The Scene tab is easily created, as it just contains a hierarchical list of the 3D entities of the scene, each one with interface controls to set their visibility/transparency/color, linked to the 3DHOP viewer via JavaScript. The Report tab is slightly more complex: a panel is created in correspondence with each block. The panel contains the paragraph text and a button linked to a function which is able to set the viewer status. This is done by employing the appropriate 3DHOP functions to set a specific point of view over the scene and to set the visualization properties of each element. Additional documents are added to the panel as links, while images are embedded as enlargeable thumbnails.

Data preparation

The only data that requires pre-processing are the 3D models and context polylines, as the rest can be readily integrated into the designed system. The steps consist of a coordinates' shift and a file type conversion. Absolute geo-referencing of the 3D models (feasible within GIS) is not supported within 3DHOP because of the limited numerical accuracy of browsers and graphics cards. To overcome this issue, 3D models were shifted to a local Spatial Reference System. This change only affects the 3D data used in the rendering: measurements and coordinates are reverted to the absolute space when computed and displayed in the excavation-node page. After this coordinates shift, 3D models were converted into a multiresolution compressed format (Ponchio and Dellepiane 2015, 199–207, http://vcg.isti.cnr.it/nexus) used for streaming the data to the web viewer: this makes it possible

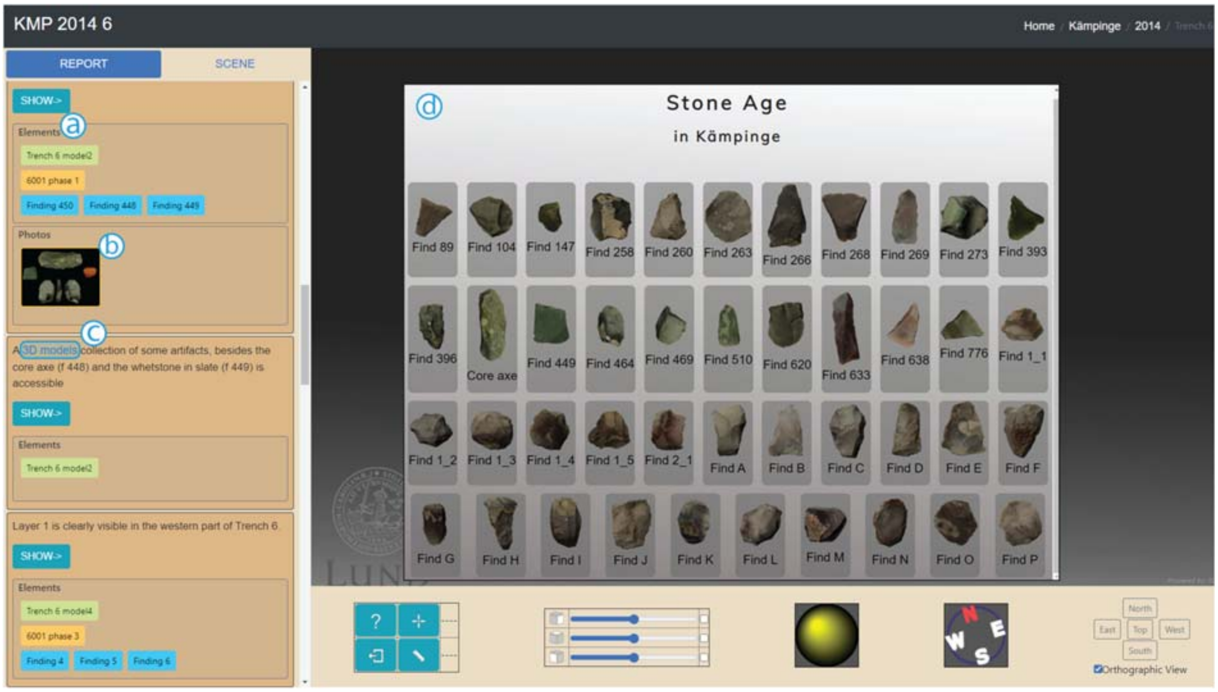

Figure 8. In the text description of one report-block of the excavation-node from trench 6, excavation campaign 2014, are displayed the elements (models, context, and findings' locations) that make up the block, visualized through colored buttons that connect to information cards with A) their metadata, and the photos expandable through B) thumbnails. C) The link allows access to the 3D collection of D) the relevant findings retrieved during fieldwork.

to use full-resolution models over the web. This conversion is an automatic, one-time operation.

In this version, the stratigraphic contexts are displayed as triangulated surfaces, while originally, they were stored in GIS as contour 3D polylines. The conversion from polylines to surfaces was semi-manual and will require a better strategy in the future: we are considering a direct shapefile import or a tool to draw the context outlines directly within the editor page.

System architecture

The system is still under development and currently works using a hybrid approach, where the content is created on a local machine and then uploaded. The structure of the website is mostly static pages (site-node and campaign-nodes) created from templates and then uploaded to the web server. The excavation-nodes are created using the editor page as described above, and the result is a JSON file, plus the media files that are then uploaded to the web server. Both

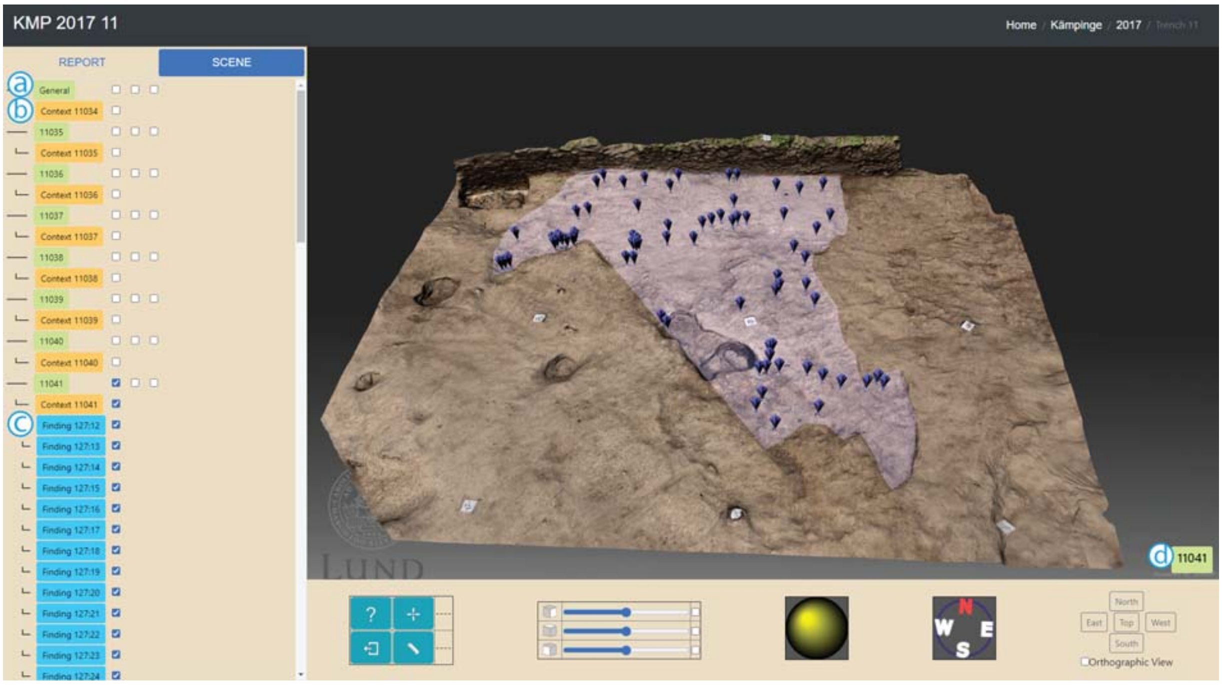

Figure 9. A screenshot from the Scene tab of the excavation-node of trench 11 (campaign 2017): the checkboxes allow setting the rendering mode of the elements: A) visibility, the transparency, and solid color for the 3D models, B) the visibility of the contexts, and C) the artifacts' localizations, which can be made visible or invisible. The graph shows the hierarchic connection between the various components. D) In the bottom right of the canvas, a label displays which element the mouse is hovering over.

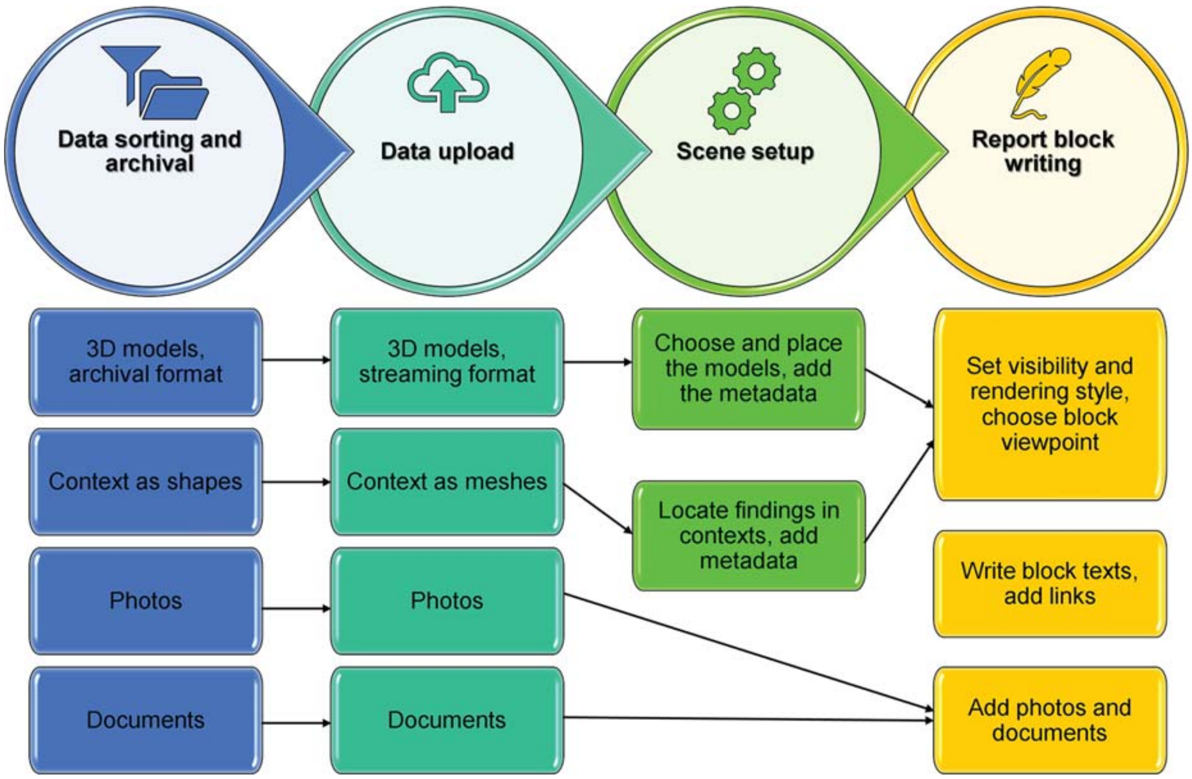

Figure 10. The representative scheme of the authoring workflow of the Interactive Reporting System; data is sorted and archived before uploading it in the system. Once the scene setup is complete, you can write the report blocks.

the 3DHOP visualization component and the interactive pages do not require server-side computation: it is only necessary to have some disk space on a web server.

As it is now, the reporting system can be used to create other reports by starting from these templates and authoring pages; the process does require some manual work, but is doable with a basic knowledge of HTML and informatics. While not automated, this process does offer some advantages: as it directly produces HTML files, the individual parts of the report site may be customized and expanded to cope with the specific needs of a project/site. On the other hand, all these authoring tasks could be made easier and more complete by having a fully server-based online system, supporting data uploading, and online, assisted authoring. This would make the creation of a report site much more accessible and more integrated with existing online systems (like the 3DGIS already mentioned or other databases and repositories used in the same institution). This solution is still in early development.

Validating the report system

To validate the system as a working tool, the Kämpinge excavation team used the Excavation Interactive Reporting System for compiling the final report. All the 3D models produced over four excavation campaigns were added into the system, as well as all the archaeological records produced during and after the excavation campaigns. A total of 48 high-resolution texture 3D models and 58 triangulated surface contexts were used in the system to virtually represent the excavation sequence. Despite the large amount of information, storage space is not a major concern—as the multiresolution format is also compressed, the final size of the 3D models ranges between 5 and 30 MB; the meshes for the contexts are negligible in size. For the composition of the report blocks of the eleven excavation-nodes, a total of 102 images and 40 PDF documents were used, including plans, context sheets, lists of samples and finds for the various contexts, sketches, and tables. These data files were embedded in the appropriate node, to support the interpretive narration.

The first part of the report was assembled using texts, images, and documents describing the investigation project and is practically identical to that of the standard report on paper. The site-node (Kämpinge-General) presents a broad description of the survey project with sections dedicated to specific aspects such as Aims, Background, Flint Technology, and References. A description of each excavation campaign was used within the four campaign-nodes (Kämpinge—2014/15/16/17 Campaigns), which give access to the excavation-nodes referring to each specific campaign. The data setting and archiving performed for each of the eleven excavation-nodes of the Kämpinge project involved uploading the 3D models and related contexts within the system. For each element, the information was gathered from the 3DGIS (identification numbers and short description) and added to the platform. The visible artifacts were placed on top of the 3D models and connected to their reference contexts; their identifications and descriptions were also added.

The body of the report in each excavation-node was composed as a sequence of text blocks. In each block, the relevant 3D models, contexts, and artifacts were selected and displayed, choosing a view state that appropriately presented the narration text. In some cases, the text also incorporates links to other webpages, like in trench 6 (campaigns 2014 and 2015), where 3D models already available online are reused (Dell'Unto et al. 2017, 641). Some report blocks were then completed with documents and pictures, enriching their content.

Testing the system in a classroom

The first experiment in the use of the system was performed with the students of the advanced field-course in Archaeology at Stockholm University. Due to the Covid-19 pandemic, all in-campus activities at Stockholm University were suspended, including archaeological excavations, which are a significant part of the course.

Each spring, the Department of Archaeology and Classical Studies at Stockholm University gives a course in field archaeology (15 credits, using the European Credit Transfer and Accumulation System—ECTS). During this course, the students participate in a four-week field excavation where they are introduced to archaeological field practice and documentation techniques. During spring 2020, the Covid-19 pandemic forced the teaching staff to conduct the spring field course at a distance. This situation provided an opportunity for testing the efficiency of the Excavation Interactive Reporting System for supporting teaching and data reuse in archaeology. For the course, four excavation-nodes (belonging to three excavation areas excavated throughout the four seasons: trenches 6, 11, and 12) were chosen. Because these four contexts were the most relevant from an archaeological point of view, they were considered the most appropriate to test the functionalities and usability of the reporting system.

The system was not originally designed to be used for teaching field archaeology, and so the platform was customized in order to highlight and display archaeological situations usually encountered in the field. By granting access to the platform through the internet, the students had the possibility of using the online 3D platform to review the datasets collected during the investigation campaigns, to access the dynamic reports compiled by the excavation team, and to solve the digital assignments provided by the teachers during the course.

The system was reviewed by the students through an anonymous evaluation conducted in the form of a questionnaire after the course. The questionnaire was answered by 9 out of 15 participating students and showed that although there was some uncertainty about the use of the digital platform as a total substitute for field activities, the students were generally very positive about using the system for addressing archaeological practice. This platform gave the students the opportunity to reflect on and work, through their computers, with several tasks that are related to field archaeological questions, such as vertical and horizontal stratigraphy, rearranging processes and accompanying problems, the relationship between those finds coming from plough layers and those recovered in locked layers, and the handling and documentation of bone depositions and graves.

In addition, the system was used to create illustrations of features, structures, and finds that were used in presentations and reports and as a basis for different types of analyses. Within the framework of the digital field course, the students could use the IRS to solve several such tasks during the course and finally produce a new kind of field report for the site.

Results and Discussion

The design and testing of the Interactive Reporting System utilized the large amount of data collected and produced across the four excavation campaigns carried out at Kämpinge. For the construction and visualization of the dynamic report, a modular structure was defined to design the system, comprising the various elements (2D, 3D, documents, and so on) made accessible in different ways. The traditional report form, based on the presentation of the single contexts composing the archaeological stratification, was preserved and improved upon in the digital version.

Its use shows that the advantages of the Interactive Reporting System are related to the possibility of including deep interaction with all the 3D contents in the documentation output, as well as the standard format documentation. The framework was designed to be circular, so that the data interpretation remained transparent and thus allowed for further reuse and reinterpretation of the archaeological stratigraphy. The aim was to develop a useful and usable tool which was sustainable and flexible, tailored to the needs of daily archaeological fieldwork. Its modular structure was designed to cope with different kinds of archaeological inquiry, thus meeting most of the needs of archaeological investigations: it could be employed both in single area excavations and in long-term projects, where several excavation areas are dug at the same time.

The IRS combined the potentials of the web visualization tools with the data management system adopted during the field investigation. Within the Interactive Reporting System of Kämpinge, a simulation of interpretative scenarios was thus performed. Views and spatial relationships among contexts documented during the fieldwork were shown. It was possible to virtually reveal the distribution of the artifacts in relation to their contexts, allowing us to present the evidence for intact Stone Age layers and finds, and providing archaeologists with the chance to deliver, together with the report, the reasoning behind the interpretation process. This also provided the chance to document this interpretation process and to perform a reflexive approach. By writing the interactive report of the trenches at Kämpinge, it was possible to foster self-reflection and discussion while exploring and combining, again and again, the virtual assemblages embedded in the system.

In the case of trench 11, dug during the 2017 excavation campaign, the Interactive Reporting System application can be considered a support for the report writing. Thanks to the report composition mechanism, structured on individual blocks, it was possible to visualize the desired 3D model, combining its view with the connected contexts and the localization of the retrieved artifacts. By choosing the best perspective and zoom level to illustrate the specific part of the report, the reader has been provided with the ideal point of view for understanding the archaeologists' field activities, reasoning, and interpretation. The complete storytelling was then supplemented with the various attached files, photos, documents, and further 3D models.

Writing the interactive report, once the data setting had been completed, proved to be a manageable task with just a short training. The authoring method, with its steps, helps the author in better organizing the narration. Furthermore, the experimentation carried out with the students from the University of Stockholm proved that the Interactive Reporting System is also an easy-to-use and user-friendly tool, as it does not require training in informatics. The report composition scheme, articulated into report blocks, fosters structured reasoning for data interpretation that can be valuable even in pedagogical and educational programs. This follows Opitz and Limp (2015), who have demonstrated that digital models used for teaching and education foster active participatory engagement and afford creative means of communication. 3D models are indeed valuable elements in knowledge production, both in education and dissemination, as they are the result of active participation in field activities (Dell'Unto 2018, 56). 3DGIS enhances and illuminates the complex relationships between stratigraphical elements; however, the advantage provided by the IRS is that it also delivers a narrative in a way that would never be possible with traditional 2D drawings and static textual reports (Dell'Unto et al. 2017, 640).

The next goal of this project is to expand real-time integration to off-site collaborations around the world, to bring together interdisciplinary specialists who often cannot be in the field together, despite the relevance of their contribution (Galeazzi and Richards-Rissetto 2018, s2). Although the targeted users of the Interactive Reporting System are archaeologists, both inside and outside academia, an important future development will be fostering collaboration with specialists from different disciplines working with archaeology.

Conclusions and Further Work

The design and development of the Interactive Reporting System represent an innovative proposal for the publication of archaeological excavation data and the establishment of a form of dynamic narration that is built around multimedia. After the system validation within the Kämpinge excavation project, we could define the IRS as a support for archaeological report writing, as it functioned well within a complex research project characterized by many campaigns and excavation areas. By using it, the archaeologists were able to describe, through a reflexive approach, the reasoning behind their interpretation process. Thanks to the use of the system within the field course in Archaeology at Stockholm University due to the Covid-19 pandemic, the IRS proved to be a valuable pedagogical tool and a means to supporting archaeological teaching and data reuse. By using the system, the students had the opportunity to review the available datasets, to access the dynamic reports, and to solve the digital assignments.

This freely accessible online platform links narration and archaeological data and, thanks to its modular structure, allows access to the data from multiple perspectives. Through its interface, it is possible to visualize, create, and explore interactive 3D-based reports and to compose and review more than one interpretation. The IRS can be considered a suitable tool for sharing archaeological data and its interpretation process through a transparent pattern that is open to scholarly critique and further data reuse. This tool can be considered a sustainable method for publishing archaeological content. It also addresses the need for the promotion of 3D models as scholarly resources and for integrated links to Digital Heritage 3D assets that has been made explicit in a recent contribution on the sustainability of 3D Digital Heritage by Champion and Rahaman (2019).

The system is still a prototype and has a few limitations. It lacks a structured server back-end that could provide an integrated archival tool and support advanced queries for the stored data and metadata. At the moment, the IRS is just a presentation front-end, interconnected with the 3DGIS archive at data level, but not fully interoperable for metadata and query-based access. This integration would represent a valuable contribution to the current debate on the responsible archiving of archaeological data (Huvila 2016; Börjesson and Huvila 2019; Champion and Rahaman 2020) in terms of accessibility, transparency, and completeness of archived and presented data. The use of the system requires some improvement: the authoring process is easy enough for an archaeologist to create report nodes with a little training, but, still, the help of a computer scientist is required to connect the results of the authoring and publish the finished report. These and other improvements will be explored in a next round of design and development, exploiting existing research projects involving academia, development-led archaeology, and education. The aim of this ongoing research is to make it possible to publish all the research projects carried out at the Department using the Interactive Reporting System through a dedicated server set up at Lund University's Department of Archaeology and Ancient History and Digital Archaeology Lab—DARKLab (https://www.darklab.lu.se/digital-collections). The dynamic reports could then be used in research and education, thus ensuring long-term infrastructure, preservation, and data reuse, which is currently missing in much academic research (Champion and Rahaman 2019, 7).

Notwithstanding its limitations, this study lays the groundwork for future research within archaeological theory and methods connected to documentation, archiving, management, and publication. This new form of archaeological report can positively impact the community of practitioners and the daily field practice, as it allows accessing, sharing, reusing, and reinterpreting archaeological contents and interpretations.

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