The 13th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2012)
D. Arnold, J. Kaminski, F. Niccolucci, and A. Stork (Editors)

Interactive Semantic Enrichment of 3D Cultural Heritage Collections

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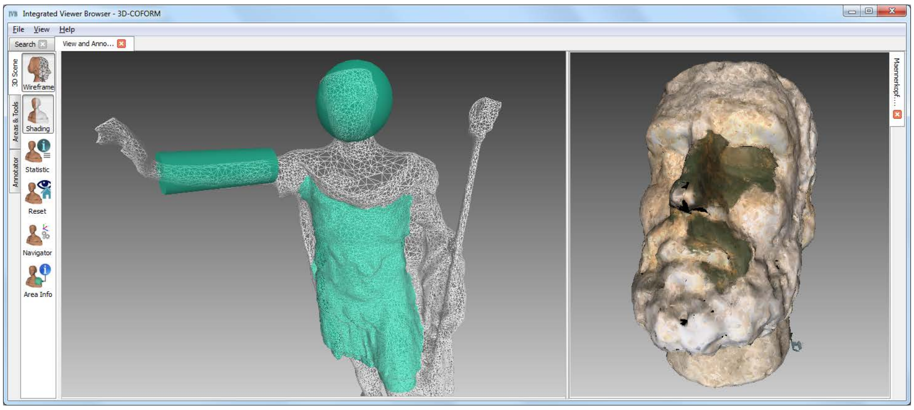

Figure 1: *Supported Areas by the interactive semantic enrichment tool. A sphere on the head, a cylinder on the arm, and the segmented chest of the statue of Antoninus Pius (left 3D window), as well as the bust of the Maennerkopf (right 3D window).*

Abstract

Virtual Surrogates of Cultural Heritage (CH) objects are seriously being considered in professional activities such as conservation and preservation, exhibition planning, packing, and scholarly research, among many other activities. Although this is a very positive development, a bare 3D digital representation is insufficient and poor for fulfilling the full range of professional activities. In this paper, we present the first interactive semantic enrichment tool for 3D CH collections that is fully based on the CIDOC-CRM schema and that fully supports its sophisticated annotation model. The tool eases the user interaction, allowing inexperienced users without previous knowledge on semantic models or 3D modeling to employ it and to conceive it for the professional workflow on 3D annotations. We illustrate the capabilities of our tool in the context of the Saalburg fort, during Roman times (2nd century AD), for the protection of the Limes on the Taunus hills in Germany.

Categories and Subject Descriptors (according to ACM CCS): H.3.7 [Information Systems]: Information Storage and Retrieval—Digital Libraries[Collection] H.5.2 [Information Systems]: Information Interfaces and Presentation—User Interfaces[User-centered design]

1. Introduction

Our perception of the world in 3D assists us in intuitively understanding and using existent information and knowledge, as well as the intrinsic relationships between the surrounding objects. Indeed, the digital world should in a similar way provide the same level of cohesion between the available information and the digital representations of the physical world. Some domains such as engineering, architecture, or

DOI: 10.2312/VAST/VAST12/033-040

medicine already exploit the benefits of a deep cohesion between the information and digital representations. The Cultural Heritage domain is also evolving in the same direction, for instance a 3D digital representation of a physical object enables the inspection of textures, the analysis of surface characteristics, the measurement of distances, and the examination of lighting behavior. Another benefit of such a 3D digital representation is that it can be accessed by many professionals in parallel and for multiple purposes, without affecting the workflows or jeopardizing the integrity of the physical object.

Nevertheless, isolated 3D digital representations do not provide the same level of information, as their peers from the real world, since these are not aware of the represented object, of its relationships, or of its history and provenance. Therefore, they need to be processed, analyzed and semantically enriched, in order to achieve a minimal professional level of cohesion. 3D annotation is the mechanism that enables the enrichment of a digital 3D shape with semantics. This process produces an annotation, which is the representation of the created relationship among the data. We aim to enrich 3D digital representations of CH objects with knowledge and information within a dynamic workflow, in an interactive manner, and without exposing the user to the complexity of the underneath standards. We present the first interactive semantic enrichment tool for 3D CH collections that is fully based on the CIDOC-CRM schema ([CDG*09]) and that fully supports its sophisticated annotation model ([DT11]).

The design and development of the tool is conceived after an exhausting analysis and comparison of different initiatives and approaches, which have been proposed in the last years (Section 2). From this evaluation, the fundamental concepts and actions that need to be supported for the semantic enrichment process is specified and defined (Section 3). These concepts, as well as previous versions of the tool are assessed and refined during several informal testing workshops with end users (Section 4). The combination of all the collected know-how is then transformed into layout designs, interaction metaphors, and workflows, which allow the CH practitioners to best fulfill the enrichment process (Section 5). This enrichment process is tested with different 3D Cultural Heritage collections and the functionality of the tool is illustrated with a 3D collection of the Saalburg fort in Germany (Section 6). The user story, as well as the general capabilities of the tool are objectively discussed and the future work is sketched (Section 7).

2. Related Work

Different initiatives have been dealing with the challenges involved in the area of 3D annotations in the last 10 years, including projects such as AIM@SHAPE [prob], Focus K3D [proc], 3D-COFORM [proa], V-MusT [prod], Enhancing Engagement with 3D Heritage Data through Semantic Annotation [enh], and Semantic Annotations for 3D Artefacts [sem]. Current trends, like 3D Internet [ABK07] or the Linking Open Data [lin] movement, are also addressing these challenges. These initiatives have highlighted that the processes involved in annotating a digital 3D shape for semantic enrichment is complex and manifold. Although these and other projects have produced useful results, the technologies available to support 3D annotations do not offer a final solution. Thus, this remains an active area of research ([HF07], [SF09], [TSB10], [KFH10]), [CMSF11]), where different challenges need to be solved to fully support a semantic enrichment pipeline.

2.1. Geometric structure

A requirement prior to annotating a digital 3D shape is to understand its intrinsic structure. Thus, a geometric definition needs to accompany the annotation itself, in order to associate semantics with the relevant part(s) of the 3D shape. There are different techniques to understand the digital 3D shape ([ABM*06], [MSSPS07], [DFMPP10]) and to formulate such a geometric definition ([SF09]), including sketching, painting, outlining, fitting, segmenting and structuring. A comparison of segmentation techniques and of the different principles, which drive segmentation, are discussed by Attene et al. [AKM*06], Shamir [Sha08] and Chen et al. [CGF09]. Regardless of the current advances in the segmentation field, it is not always possible to generate a plausible and context-aware geometric definition for different classes of objects (e.g. articulated objects or mechanical objects) with an individual algorithm.

2.2. Semantic structure

The idea of representing semantically structured information and knowledge as well as creating links between the data has increasingly gained popularity, driven by the Semantic Web technologies [lin]. The alternative of annotating 3D shapes with free keywords provides more flexibility but less meaningfulness [ARSF07]. Within the current research on annotations, most examples of structured information include semantic models for describing the intrinsic structure of the 3D shape ([FPC08], [PDF09], [ARSF09]). Provenance information on the life cycle of the digital 3D shape, is also structured for the annotation process. For instance, Doerr and Theodoridou [DT11] proposed a model for describing the provenance of digital 3D shapes in the Cultural Heritage domain ([HSB*09], [RMA09], [PSSD*11]). Until now, most efforts in this area have been devoted to developing models for structuring information related to the 3D shape or the represented object. However, little attention has been paid on structuring domain knowledge and using this to facilitate the processing and analysis of 3D shapes within professional environments for the already established workflows.

2.3. Association of geometric and semantic structures

Generally, 3D annotating involves a mechanism to combine the geometric description of the 3D shape and the information related to the represented object. Different mechanisms have been proposed, which vary depending on: i) the application domain, ii) the degree of user intervention that they require, iii) the technology which supports them, and iv) the degree of structured information which they involve. Different domains have experimented with a variety of mechanisms to support annotations, some examples include engineering, architecture, medicine, and chemistry. In the Cultural Heritage domain, a variety of mechanisms are used depending on the type of artefact (e.g. sculpture, archaeological, museum artefact), which is being annotated ([HSB*09], [RMA09], [enh], [HG10], [Yu10], [PSSD*11]).

The semantic enrichment of 3D shapes has been an active and fruitful field of research in previous years, generating new insights and experiencies, which built the basis for our tool. Notwithstanding, the proposed approaches are not integrated within a single solution nor streamlined for the needs of the end users. Therefore, aspects about layout designs, interaction metaphors, and workflows in real professional environments have not deeply been explored. We cope with these challenges and develop an interactive semantic enrichment tool for 3D CH collections. The tool eases the user interaction, allowing inexperienced users without previous knowledge on semantic models or 3D modeling to employ it and to conceive it for the professional workflow on 3D annotations. The following four sections describe the needed concepts, the associated challenges, the design layout and interactions metaphors, as well as a user story, which illustrates the tool capabilities.

3. Concepts on 3D annotating

In order to develop the interactive semantic enrichment tool, we have collected and defined concepts that need to be supported in the 3D annotation process. The following concepts are considered the building blocks of our 3D shape semantic enrichment approach:

3.1. Areas

It is a media independent definition of a region on a text, a 2D, or a 3D document (a picture and a 3D shape respectively). Areas can be one-dimensional as in the case of text (start and end position in the text), 2-dimensional in case of a region of a picture, or 3-dimensional (parts of the surface of a virtual 3D model or a partition of the 3D space). This abtract definition of Areas is used in the annotation model, enabling a media-independent process.

3.2. Annotation Types

In our context, an annotation is the result of the association between the geometric structure of the media object and the semantic structure about the represented object. In other words, it is a link (in the semantic network) between Area(s), which can be of the type Comments or Relations:

3.2.1. Comments

Comments are textual information that can be linked to an unlimited number of Areas defined on one or more media objects (text, image, 3D shape). Beside the link to the Areas, comments carry the following information:

- a label that can be used for searching it;
- a classification to assign comments to a specific category, e.g. all comments that describe and document *damages*;
- a free text field that contains the actual comment.

3.2.2. Relations

Relations are directed links between Areas defined on media objects. In relations, we distinguish between source and destination Areas. Relations can link many source Areas to many destination Areas. The Areas themselves can again be defined on any number of media objects. Beside the link to the Areas, relations carry the following information:

- a label that can be used for searching it;
- a relation type that classifies the kind of existing relation between the media objects, e.g. a text document that *refers to* a certain part of the CH object.

It is important to note that there is no free text for relations, because relations are meant to associate media objects between each other. These concepts follow the CIDOC-CRM annotation model, which was introduced by Pena Serna et al. [PSSD*11]. The flexibility and potential complexity, as well as the sheer amount of linked information render its exploration and display a quite challenging task. Informal user tests (see Section 4) revealed that users prefer to see and be able to read each individual information over graph visualizations that may occlude parts of the information.

4. User requirements toward semantic enrichment

We have conducted several informal user tests with earlier versions of our tool, in order to gather feedback on its usability and design. The potential users stem from a range of professions and backgrounds ranging from practicioners, who are used to work with 3D software systems, e.g. modeling tools such as Maya or 3ds Max; to professionals, who work with 3D acquisition devices and the accompanying geometry processing software; to users, who are not familiar with 3D systems at all. The semantic enrichment process is mainly supported by the viewing and annotating functionalities of the tool, thus the collected feedback is focused on these two aspects:

- ability to show more than one model at a time (the comparison of two models side by side);

- usable interaction metaphors to select Areas to be used in comments and relations;
- presentation of Areas with all the corresponding metadata and provenance data;
- exploration of all the comments and relations associated to an Area;
- functionality to follow a relation from one Area to another (navigation on the semantic network);
- consistent manipulators to intuitively navigate through the scene and the associated information.

Beside these viewing and annotating requirements, general user interface (UI) design requirements need to be considered, in order to ease and streamline the professional workflow. These requirements are represented by the following questions:

- How to place and order screen content to best support typical workflows of CH professionals?
- Which interaction mechanism to most conveniently and intuitively support such workflows?
- How to extend interaction metaphors, in order to combine 2D and 3D widgets without interfering with navigation and still keeping mode switching minimal?
- How to best integrate interaction metaphors for 2D and 3D widgets within the workflows?
- How to display and structure information kept in a semantic network, into a sequential form, which is easy to access, view, sort, filter, and comprehend?

What is usually and trivially solved - when using a simple annotation model that just links one tag to one Area, as done by many systems (e.g. [ARSF09] and [PG11]) - turned out to be a challenging design task that took several iterations of improvements and optimizations, and which culminated in the current state of our interactive semantic enrichment tool.

5. Interaction design and metaphors

Although the backend functionality of our interactive semantic enrichment tool has been implemented along with the development of the graphical user interface (GUI), the main focus of this section resides in the interaction and design metaphors. This is motivated by the feedback collected during the informal testing workshops, given that the tool was functional but the users were hardly able to profit from the development, as we were expecting. Moreover and in terms of multimedia objects, the description addresses the interaction with 3D shapes, since this has associated requirements, which are more interesting and challenging to solve. Figure 2 shows an overview of the layout of our tool, which consists of:

- *Actions Sets*: it is the set of supported actions, which are grouped according to the workflow: a) 3D scene related actions, b) Area creation related actions, and c) Annotation creation related actions. We combined the provided functionality into three clusters and we show them as vertical tabs. The actions in each tab are presented in iconic form. This approach is basically motivated by ribbon interfaces. In order to optimize our use of screen space, we designed and implemented a vertical ribbon style, adapting the Qt framework [QT12].
- *Working Window*: in this window, the user can visualize a 3D shape, a picture, or plain text, and create Areas that have a spatial extend. For more details see the corresponding section below.
- *Browsing Window*: this window can show other (or even the same) media object. All the media objects that are loaded, are presented as tabs - again we opted for a vertical configuration because given our general layout, we can easily optimize the space with screen width rather than with screen height.
- *Metadata Viewing*: this section collects information (metadata) attached to the media object (3D shape, picture or plain text). For more details see corresponding subsection below.
- *Annotation Interface*: this area is used to enter Annotation information, i.e. comments and relations, and create corresponding semantic structures in a semantic repository ([DTT*10]).

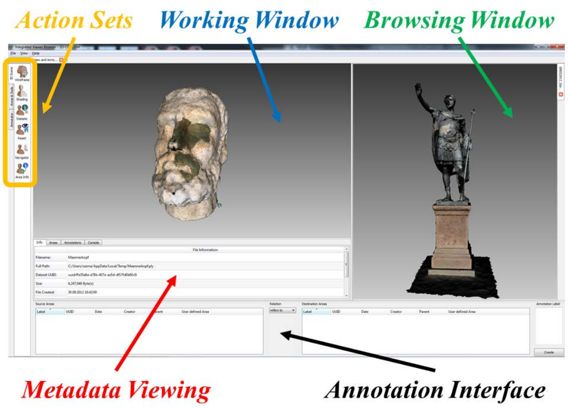

Figure 2: *General Graphical User Interface of our interactive semantic enrichment tool, divided into 5 different sections.*

5.1. Working window

This is the primary 3D window, where the user interaction with 3D shapes is performed. It provides the following key functionality:

- view and navigate 3D shapes;
- create Areas on top of the 3D shapes;
- segment 3D shapes in parts of its surface;
- hover over Areas to highlight information about the selected Area;

- select Areas to display information about the associated annotations.

It is fundamental to note that given the extensive CIDOC-CRM annotation model that allows us to link many media objects to one or more Areas, and that generates metadata along with the relationships, it is not possible to simply show a text, a picture, etc. on top of the 3D shape in the 3D scene. For doing this, we use the other sections of our GUI and display the linked 3D shapes and pictures in the browsing window and in the annotation interface (see Figure 2).

5.1.1. 3D visualization and navigation

The fundamental viewing capabilities of our tool are based on the scene graph system OpenSG [OSG12]. To be able to display highly sophisticated material models, e.g. BTF, OpenSG has been extended by the 3D-COFORM consortium into the Visualization Support Library (VSL). The VSL is an integral part of the 3D viewers of our tool. Navigating the scene is configurable at run time. Since prospective users are coming with different backgrounds and experiences with other tools, we designed a component into our tool that allows the user to individually customize the mappings between mouse events and movements to actions in the viewer. In this way, the behavior of other systems (e.g. MeshLab, Maya, 3ds Max) can easily be mimicked in our tool.

5.1.2. Creation of Areas on top of a 3D shape

The user can specify a spherical or cylindrical subspace (see Figure 1) of the volume as an Area to which annotations can be associated in a subsequent step. Additionally, a label and a color can be assigned to the created Area.

5.1.3. Segmentation of the 3D shape

In many cases, it is required to more precisely specify a contour of an Area than just creating a sphere or a cylinder. Therefore, the 3D viewer provides an interactive segmentation functionality (see Figure 1). Segmenting the surface of a 3D shape can sometimes be tedious, thus we designed our segmentation functionality with the following goals in mind:

- decoupling navigation from segmentation to easily rotate the object while specifying the border(s) / contour(s) of a segment;
- outlining contours on the surface of the object;
- enabling the possibility to specify many contours for a segment, e.g. to segment the body of a statue from its arms and legs;
- auto-closing contours to relief the user from exactly ending the contour where it started - auto-closure follows the surface based on the shortest path to the starting point;
- specifying the segments by a 'surface-filling' approach, defining one or more seed points to create segments on different sides of the contours.

In this way, we address the sophisticated requirements toward segmentation in the CH domain that ask for the possibility to segment complex shapes into parts, to segment according to its texture, to segment out damages of the surface, etc. - all which is impossible with today's state of the art automatic segmentation algorithms.

5.2. Metadata viewing

In this section of the UI (see Figure 3), four tabs are grouped together, presenting information to the user about:

- metadata of the media object (under the Info tab);
- Areas that are defined on the 3D shape shown in the working window;
- annotations that are linked to the Areas of the 3D shape;
- auxiliary system information (under the Console tab).

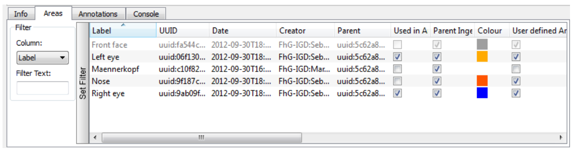

Figure 3: *Interface for the Metadata Viewing section.*

Each table (in a tab) can be user-configured with respect to the order of columns, visibility of columns, etc. The content of the table can be sorted by any column title, e.g. by creation date. Upon request, the user can activate a filter (by dragging the corresponding widget from left to right) to only show entries in the table that match a certain condition, e.g. the name of the creator. For the Area creation, the corresponding tab also serves for entering the label of the Area and for activating a color editor to specify its color in the scene. Additionally, the tab shows the status of the Area, i.e. has it already been used in an annotation, is it ingested into our repository, and the like. Hovering over the list of Areas highlights the corresponding area in the 3D scene. The Annotations tab lists all annotations defined on the 3D shape in the working window, it shows their type (Comment or Relation), and it shows which Areas are linked by which annotation. The free text content is being displayed on *the Annotation Interface* section of the UI (see next section).

5.3. Annotation Interface

The annotation interface enables the creation of annotations (Comments and Relations) in the repository, as well as the presentation of the detailed information contained in either type of annotations, which are on-the-fly retrieved from the repository. Areas are the only elements, which can be dragged and dropped to this interface.

5.3.1. Select and display of annotation information

In order to display the annotation information attached to an Area, the Area can be selected (see Figure 4) to trigger a retrieval of its attached information from the repository. A preview of this information is presented in the 3D scene and the full information is displayed within the viewing mode of the *Annotation Interface* section. This retrieval always gives us up-to-date information from the repository, which is important in collaborative scenarios. However, it might introduce some delay on slow internet connections, while searching and retrieving the information from the repository.

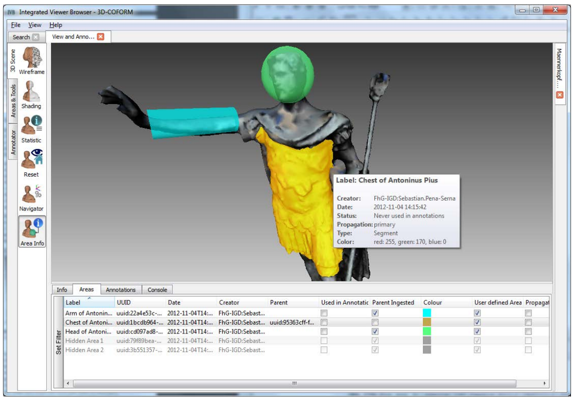

Figure 4: *Selection of an Area to retrieve associated information (e.g. annotations and metadata).*

5.3.2. Creation of annotations

Creating an annotation is a straight-forward activity. The user has to choose, whether she wants to create a Comment or a Relation - the corresponding UI will be brought up (Figure 5 shows the UI for creating a Relation). Now she can start to *drag and drop* Areas from the *Metadata Viewing* (2D-to-2D dragging), or from the *Working Window* or *Browsing Window* directly (3D-to-2D dragging) into the *Source Area* and *Destination Area* fields of the Annotation Interface. Here, she defines the label and type of relation, and she also triggers the ingestion process to store the information (in RDF / XML syntax [PSSD*11]) into the repository.

5.3.3. Viewing of annotations

In the viewing mode (see Figure 6), the user can drag and drop any Area into the left part of this UI, in order to see on the right hand side all the Comments and Relations associated to the Area. Comments and Relations are sorted into different tabs to provide a clear distinction and a better overview.

6. User story

In this section, we present a typical user story and its realization by means of our interactive semantic enrichment tool. The user story takes place at Saalburg, Taunus in Germany, a castle along the former Roman border - the Limes. Four media objects are involved in this user story:

1. the scan of the Maennerkopf bust - represented as a digital 3D shape - which is on display at the Saalburg;
2. metadata about the bust which is incorporated as legacy data into our system;
3. a scan of the statue of Antoninus Pius - a Roman emperor displayed at main entrance of the Saalburg fort;
4. a digital picture of the Saalburg - the place where the bust and the statue are present.

The user starts with annotating the face of the scan of the bust with a comment that captures the characteristics of the face by using information from the legacy data about the Maennerkopf. Figure 7 illustrates the process of creating the comment annotation. In order to realize this, the user starts with defining a spherical area on top of Maennerkopf's face. The Area appears in the metadata viewing section of our UI, where the user inputs a label for the area ('Face detail'). Then, she selects to create a Comment and the Annotation Creation region is displayed in the UI. The user drags and drops the Area that shall be annotated, chooses a Comment type ('mark') and selects a part of the text from the legacy metadata and copies it into the Comment region of the UI. Finally, she creates a label for the Annotation and triggers its creation (ingestion) in our repository.

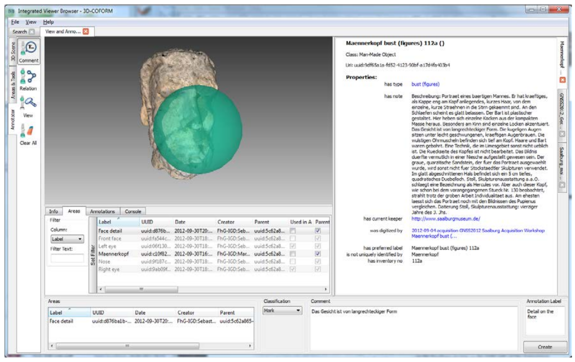

Figure 7: *Comment annotation between the Maennerkopf bust and its legacy data.*

Furthermore, the user continues with establishing a Relation Annotation between the bust and the place, where it is found / shown, represented by a picture of the Saalburg fort. Figure 8 depicts the creation of a relation between the 3D shape of the Maennerkopf and an image of the main entrance of the Saalburg fort. In this case, the user starts from a configuration of our tool that shows the 'Saalburg' at the left hand side and the bust on the right head side. The user chooses to create a Relation. Next, she drags the Area on the bust (right side) to the Source Area region into the Annotation Interface (3D-to-2D dragging). Then, she selects the Relation type (was present at) and drags the area defined on

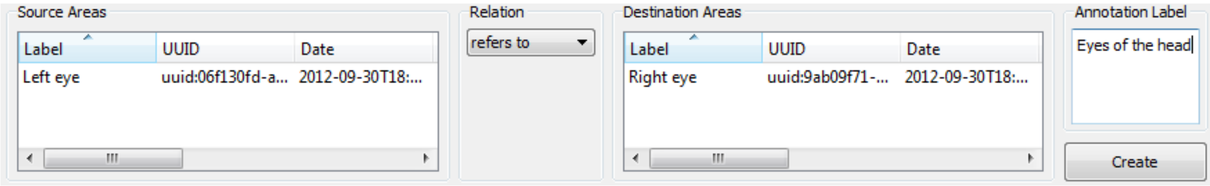

Figure 5: *Interface for creating the Relation Annotation.*

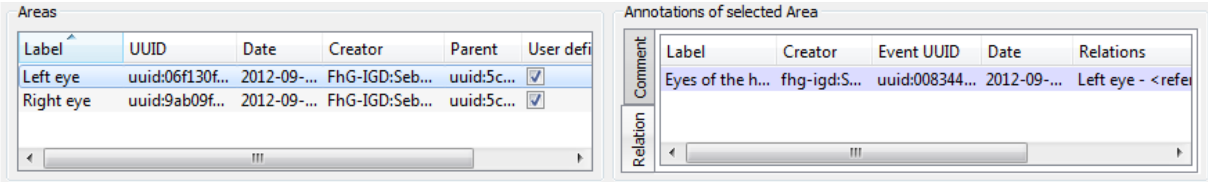

Figure 6: *Interface for viewing the annotations associated to the Areas.*

the Saalburg picture to the right side of the Annotation Interface (2D-to-2D dragging). Finally, the Relation gets an Annotation label ("Found at Saalburg") and it is ingested into our repository.

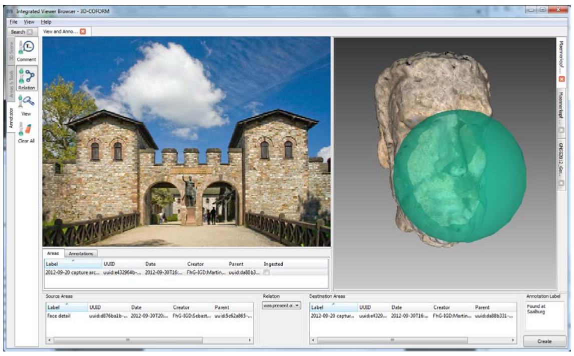

Figure 8: *Relation annotation between the Maennerkopf bust and the Saalburg fort, represented by an image of its main entrance.*

Finally, the user explores an Annotation defined on the 3D representation of Antoninus Pius. The 3D shape of Antoninus Pius is the only media object loaded into our tool at the beginning. The Annotation viewing mode displays all defined annotations associated to it. The Source and Destination Area information is used to follow the relationship and to open the media object, where Antoninus Pius is places at, just by leveraging the link (path in the semantic repository). The picture of the Saalburg is retrieved from our repository and displayed as the result of this user action. The accompanying video shows the workflow of this user story. The interaction principles implemented in our tool to minimize user interaction (number of mouse clicks, distance of mouse movements), become obvious from the video. In addition, the video shows the four media objects involved in this user story, the thumbnail previewing, and the drag and drop techniques to change the media object into the working window.

7. Conclusions

In this paper, we present the first interactive semantic enrichment tool for 3D CH collections that is fully compliant to the CIDOC-CRM schema and that fully supports its sophisticated annotation model. Working on one shared repository allows CH professionals to collaboratively work and research on CH artefacts, share and see each others comments, relationships and hypotheses, and create new insights together. The tool has been designed, implemented and optimized according to collected requirements from CH professionals during several cycles of informal user tests. The tool provides the following innovative interaction concepts / principles of which some have not been realized in other applications before: i) thumbnails that are created on-the-fly for previewing 3D models *hidden* in tabs currently not shown, ii) thumbnail dragging to switch models in active view, and iii) drag and drop functionality between 3D and 2D windows. A future challenge resides on supporting information through Linked Open Data.

8. Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 231809 for the integrating project 3D-COFORM. We especially thank the project partners FORTH-ICS, TU Graz, CNR-ISTI and the Victoria and Albert Museum for the fruitful collaboration, as well as the Saalburg Museum for allowing us to access their CH objects.

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