# Visual Metaphors for Semantic Cultural Heritage

Rossana Damiano
and Vincenzo Lombardo
Dipartimento di Informatica and CIRMA
Università di Torino, Italy
Email: rossana@di.unito.it, vincenzo@di.unito.it

Antonio Lieto
Dipartimento di Informatica
Università di Torino, Italy
Email: lieto@di.unito.it

*Abstract*—During the last decade, cultural heritage has moved toward the encoding of information in semantic format. Ontologies make the description of artworks clearer, unambiguous and often self-explanatory, with advantages in terms of interoperability. In cultural heritage, the current shift toward semantic encoding opens the way to the creation of interfaces that allow the users to orientate themselves easily in media repositories through a visual representation of their properties and relationships. In order to illustrate this approach, we describe a case study in ontologies and visualization for cultural heritage, Labyrinth. In Labyrinth, the user is immersed in a 3D labyrinth where turning points and paths represent a set of cultural artifacts and the semantic relations holding among them.

*Keywords—3D visualization, cultural heritage, ontologies*

## I. INTRODUCTION

In the last decade, the access to cultural heritage and the distribution of media objects have moved toward a digital convergence [1]. This convergence has favored the development of digital platforms for cultural heritage, such as online museums and cultural websites, aimed at encouraging the access of the general public to cultural heritage (consider, for example, the Europeana web portal[1]). In the paradigm of digital convergence, where new and old media interact, content producers and consumers cooperate to share existing contents and generate new contents, working alongside the traditional paths of cultural markets and education.

The convergent culture has not been effective yet in creating user instruments for generic organization and access to media repositories in the field of cultural heritage. Searching media objects, in fact, is still largely based on keywords and/or tags, through which users can filter contents to find what they need. The search returns a list of objects (books, pictures, videos, etc.), but it does not contain an explicit representation of the meaning relations they entertain with the input keywords. In addition, differently from specialized audiences, the general public is not committed to specific search goals, that can be expressed through a query: rather, they are in most cases interested in exploring the archive, as pointed out by [2]. So, paradigms that support exploratory search are required to meet the needs of this audience.

As reviewed by [3] and [4], computational ontologies are especially suitable to encode conceptual models for the access to digital archives, since they contain an explicit description of concepts and can be directly employed to structure the interaction between the archive and the users. Thanks to the advent of semantic technologies, the encoding of the meta information associated with cultural heritage is now moving to a semantic format, open to a higher integration among media, as exemplified by the Europeana Data Model [5]. The use of ontologies makes the description of artworks clearer, unambiguous and often self-explanatory, with advantages in terms of interoperability among systems. However, they do not remove the need for an "abstraction layer" [6], i.e., an explicit conceptualization of the content interposed between repositories and users, whose function is to support access from a range of complementary, different perspectives. In cultural heritage, as pointed out by [6], relevant perspectives may be history, archaeology, aesthetics, narratology, etc.

In this paper, we propose the use of visual metaphors, embedded in virtual environments, as a tool to convey the conceptualization of cultural heritage items and the relations holding between them, described in an ontology. Using visual metaphors to convey the information stored in an ontology allows communicating the conceptual model it encodes in an immediate and engaging way, as shown by an established line of research in information visualization [7]. As a case study, we describe the application of the framework to the design, development and editing of the Labyrinth system. The Labyrinth system is a 3D application that relies on an ontology of "cultural archetypes" to create and visualize a "labyrinth" of semantic relations between the artworks contained in a repository.

The plan of the paper is the following: after surveying the related work (Section II), we describe the framework for representing semantically described heritage objects in a visual environment (Section III) and illustrate it through the case study (Section IV). Section V describes the navigation in Labyrinth and the evaluation conducted on the system. Conclusion ends the paper.

## II. RELATED WORK

In cultural heritage, the use of visualization, and 3D visualization in particular, is normally intended as a support for study and dissemination activities. 3D projects in cultural heritage can be roughly divided in two types: virtual equivalents of physically existing locations, like museums and historical buildings, and reconstructions of physical environments that have disappeared, like archaeological locations or temporary art works. Google Art Project[2] and Arounder[3] are examples

---

[1]http://www.europeana.eu

[2]www.google.com/culturalinstitute/project/art-project
[3]www.arounder.com

of the first type, where 3D is often obtained through PMVR techniques and it integrates high definition images of artworks in the 3D environments. Rome Reborn [8], the 3D reconstruction of Rome as it appeared in the IV century, is an example of the second type. In this project, the use of 3D is integrated with avatars of Roman characters who interact with the users. [9] present a framework for 3D real time applications in web browsers, employed to develop virtual reconstructions of Rome (Virtual Rome project) and other Italian locations [10]. Reconstructed artworks also concern contemporary art: the VEP project [11], for example, is a reconstruction of the Poème Electronique Virtuel created by Varèse and Le Corbusier in 1958 at the Brussels World Fair in 1958 and subsequently removed.

While some of the projects mentioned above are targeted at dissemination, some recent projects leverage 3D to support research and study activities. For example, the work described in [12] consists of the reconstruction of a Roman villa, as a tool for supporting archaeological research. [13] describe a stereoscopic research and training environment for archaeologists called ArtifactVis2. This application enables the management and visualization of diverse types of cultural datasets within a collaborative virtual 3D system and is aimed at the supporting cooperation and information sharing among archaeologists. A third type of use of 3D, that we don't take into account in this work, is concerned with the reconstruction of small and medium scale objects, separately from their environment, as reviewed in [14].

Semantic technologies are employed in 3D applications to describe the environment and its element and perform automatic reasoning on this representation. The work by [15] is one of the first attempts to provide a semantic representation of 3D environments that integrates a model, a methodology and a software framework. In this work, an ontology of concepts, geared to 3D modeling, describes the scene and the objects it contains, such as windows and doors, and other graphics elements such as materials or background. The 3D ontology, then, is mapped onto a domain ontology describing the properties of the objects through semantic relations such as "represents", "has behavior" or "has function", with benefits for scene manipulation and retrieval. Content reuse and management of virtual scenes are also the goals of OntSceneBuilder [16], where the scene creation process is driven by domain ontologies, which encode the knowledge about the represented domain. Finally, [17] focus on semantic models of spatial environments (and on directional relationships in particular) that can be exploited by artificial agents to exhibit human-like behaviours or to assist users in the virtual environments.

There are some notable exceptions to the use of semantic representation for describing the 3D environment. [18] describes the integration of semantic information into 3D models in a web site about public sculptures and monuments in the United Kingdom. The ISEE project [19] addresses the access to information in the navigation of 3D environments. Starting from the assumption that several sources of digital and 3D information are available today on the web, this project developed a notion of spatial relevance of information called "view zone".

With respect to the use of 3D representation in cultural heritage, the work we present in this paper differentiates from the approaches surveyed above since in our approach the 3D representation is not employed to reconstruct real environments or create virtual ones, but as a tool to convey semantic relations through a visual environment. In the works surveyed above, ontologies are used to describe the entities in the virtual environment, while we see the virtual environment as an experienceable substitute for the semantic relations among the objects in the an external domain, namely a cultural heritage domain. For this reason, our proposal does not require a semantic model of the 3D environment: rather, it assumes that a semantic representation of the domain knowledge is provided, that is mapped onto the 3D environment as part of the visual design process. The representation through an ontology of the 3D environment onto which semantic relations in the domain ontology are mapped is not a necessary component of the framework we propose, although it may be beneficial to the clarity and soundness of the mapping.

## III. VISUALIZATION OF SEMANTICALLY ANNOTATED OBJECTS IN CULTURAL HERITAGE

Semantic annotation makes the description of cultural objects explicit and unambiguous through the use of formal languages rooted in description logics [20]. However, this representation cannot be exposed directly to the end users, since it is encoded in a machine readable form oriented at interoperability and formal reasoning. In some sense, the use of semantic representation exacerbates the need for intuitive tools for exploratory search. The visualization framework we propose aims at translating the information about the cultural heritage objects, expressed in a semantic format, into an executable visual representation where the relations among the objects are mapped onto the visual and spatial properties of the 3D environment and can be navigated as such.

In this section, we generalize our approach by describing the framework in terms of its abstract components. Based on past research described in [21], [22], we describe how these components are arranged in a reference architecture that maps semantic descriptions of cultural heritage onto visual metaphors. We also describe the content editing pipeline needed for bridging the semantic description onto visualization within the framework.

### A. Visualization Framework

The access to cultural heritage is the result of the interplay of three elements, namely the *cultural objects*, possibly represented by digital media resources, the *description of the objects*, or metadata, and the *visualization interface*, driven by project specific goals (dissemination, presentation, study, etc.). In traditional cultural heritage portals, the interaction with the user is structured according to a communication metaphor, which depends on parameters such as the intended audience and functionality. The chosen metaphor frequently mirrors the fruition of the actual cultural objects: the metaphor of the "archive", for example, is often employed for the access to cultural heritage archives, the metaphor of the 3D visit is more suitable to museum contents (see, respectively, the well known interfaces of Europeana and Google Art Project[4]).

---

[4]https://www.google.com/culturalinstitute/u/0/project/art-project

The classification of the items proposed to the user depends upon the description encoded in their metadata, such as date, authorship and content of the items. Beside authorship and editorial information, metadata usually contain information about the management and preservation of cultural objects, such as responsibility for the preservation, digitalization standards, etc. and only recently they are evolving toward the description of contents, suitable for content-based access (with categories such as iconography, event types, etc.) [23], [24].

Here, we assume that the description of a set of cultural heritage objects is provided in semantic terms, i.e., that they are described in one or more formal ontologies encoded according to the Semantic Web standards [25], and describe a visualization framework for these objects. The framework includes three main component, namely, visual components, control components and architectural components.

The **visual component** consists of a set of visual elements, whose type and appearance depend upon the metaphor which informs the user interface (the "labyrinth" for the Labyrinth project), which include:

- an *environment*, that provides the context of the visualization, where the iconic objects (see below) are located;

- a set of *iconic objects*, possibly characterized by behaviors triggered by the user interaction;

- a *scene layout*, i.e., the location of objects in the environment.

The **control component** consists of the *mapping* between the cultural heritage objects and the visual elements, which includes:

- the *mapping of the properties* of the cultural objects onto the visual features of the iconic objects in the interface (consider, for example, the use of color and shape to represent properties such as content type or relevance);

- the *mapping of the relations* among the cultural objects onto spatial relations in the virtual environment (for example, historical relations can be mapped onto linear spatial relations);

- a set of *interaction design* specifications (for example, the navigation paths and behavior of objects).

Finally, the **architectural component** consists of the architecture that, given the visual and mapping components, realizes the user interaction with the heritage objects in a 3D application. It describes the software elements that realize the visual and mapping components (which include specific software for semantic data storage and management, software for 3D graphics, etc.) and the interaction among them, achieved through APIs that allow the software elements to communicate among each others.

### B. Visualization Architecture

The ontology–based visualization architecture is structured according to a client server schema. The description of the cultural heritage objects is encoded in a set of ontologies,
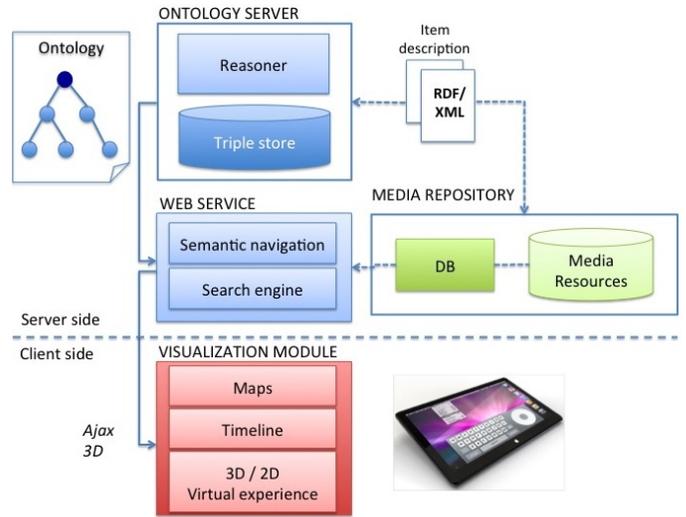


Fig. 1. The ontology-based visualization architecture.

stored in an ontology server. The information stored in the ontology server is dynamically extracted from the ontology and made available to the visualization client, which manages the 3D environment. Notice that the architecture abstracts from the actual implementation of the ontology server and requires only that the server provides an endpoint through which the ontological knowledge base can be queried. The 3D environment contains a set of visual elements which represent the cultural heritage objects, set and staged on the basis of their properties, as represented in the ontology server. In the 3D interface, the user can get information about the cultural objects and their relations by navigating the environment and interacting with the objects it contains.

The system encompasses four main modules (see Fig. 1):

- the **Ontology Server** maintains the ontology (or the ontologies) – where the cultural heritage objects are described – and provides the reasoning services that allow the system to infer further object properties from the declared ones. Also, it provides the endpoint for querying the ontology, necessary for the visualization client to access the data encoded in the ontology (typically, a SPARQL endpoint);

- the **Media Repository** contains the media objects (digital equivalents, documentation, etc.) related to the cultural heritage objects which constitute the domain of the system and is indexed by a relational database (typically, a mySql database);

- a **Web Service** (written in Java in the current implementation) implements the API the visualization client relies on to query the Ontology Server (Ontology-to-3D API). Depending on the project, the RDF triples extracted from the ontology can be serialized in different ways, typically as Json or RDF/XML data;

- the **Visualization Module** supports the interaction with the user through 3D navigation, as standalone application or embedded in a web browser.

The *visual component* in the visualization framework cor-

responds to the 3D environment embedded in the visualization client, where 3D models representing the cultural heritage objects are set into a given environment according to a given layout. The 3D environment and the objects it contains possibly respond to the user's input with predefined behavior, in accordance with the communication metaphor embedded in the interface. The navigation in the 3D environment is normally constrained to certain paths, and achieved through predefined camera movements.

The *control component* is distributed between the APIs that extract data from the ontology server and the visualization client, which is programmed to realize the interaction flow with the user. The Ontology-to-3D API fetches the semantic data from the ontology server (the properties of the cultural heritage objects and their relations) and passes them to the visualization client for it to transform them into visual properties in the 3D environment. Basically, the methods in the Ontology-to-3D API need to include commands for managing sessions, setting the user parameters (preferences, defaults, etc.), and querying the ontology. The interaction with the user is achieved by client side programming via specific scripting languages (such as JavaScript 3D libraries).

### C. From Ontology to Visualization

Each of the elements of the framework described above requires specific professional roles, arranged in a production pipeline. The pipeline can be roughly divided into three phases: **visual design**, the **software development** and the **editing phase**. The conceptual modeling of the domain is not required, since the framework assumes that a repository of cultural heritage objects is already available (for example, as part of some annotation project or as a by product of a digitalization initiative). It is possible, however, that, for specific projects, an ad hoc ontology is developed to satisfy this requirement: if this is the case, an *ontology engineer* designs and implements an ontology to describe the cultural heritage objects.

The **visual design** phase is aimed at bridging the gap between the conceptualization of heritage objects and the users through the use of visual and spatial metaphors. As argued by [7], the choice of the metaphor is crucial to communicating the conceptual model. This phase is usually conducted with the help of a sample repository, where a few objects have been inserted to support the design process and the subsequent development phase. Also when a semantically described repository is already available, it can be beneficial to focus the design on a small set of paradigmatic cases. After the domain has been encoded in the ontology and employed for describing the heritage objects, the *interaction designer*, in cooperation with a *visual designer*, i) devises a suitable metaphor for conveying the description of the objects through the 3D environment (by mapping of the object properties onto the features of the environment, and onto specific objects – the iconic objects – in particular), ii) designs the interaction flow (specifying how the user can interact with the 3D environment and what responses he/she should get in each phase of the interaction) and iii) establishes the visual properties of the 3D, such as its mood and appearance. A *game designer* may be involved in this phase to insert elements of playability into the interaction. As shown by [26], in fact, the use of game in tandem with visual metaphors increased the levels of learning.

The **software development** phase translates the interaction design into 3D assets, orchestrated and manipulated by set of software elements. Once a metaphor has been established, the 3D models the constitute the environment are created and arranged in a set of layouts by a *3D production team*, together with animations and camera movements (in case the navigation is achieved by constraining the user to predefined movements). In parallel, the *semantic web developer* implements the queries that extract the object descriptions from the ontology (previously uploaded onto an ontology server) and makes them available through the web by programming a web service available though an API. Finally, the *3D developer* programs the 3D environment so that it implements the interaction flow established in the visual design phase.

In the **editing phase**, cultural heritage objects are collected and annotated with semantic metadata before adding them to the repository. Metadata may include, for example, the relations of heritage objects with locations, artists, historical events, etc. Although professional *annotators* are preferred, metadata may be also contributed by amateurs through crowd sourcing, as recently proposed by [27], or may be created through semi-automatic annotation as proposed by [28], [29], [30].

## IV. THE LABYRINTH SYSTEM

The Labyrinth system[5] allows the user to *explore* a repository of media resources through the conceptual mediation of an "archetype" of narrative nature. Targeted on the general audience, the project is aimed at encouraging the users to explore the repository in an immersive, engaging way, as a way to promote cultural enrichment and cultural heritage dissemination. In the next years, thanks to the advent of the paradigm of Linked Open Data [31], information about cultural heritage, including events, performances, collections, etc. will be available on the web from different sources, making heterogeneity the standard situation rather than an exception. So, Labyrinth is not targeted on a specific type of cultural heritage objects or media types: the assumption underlying the project is that cultural archetypes, being pervasive in Western culture, can be employed as a compass to help the user navigate a heterogeneous repository of cultural heritage objects.

### A. Overview of the system

Mainly inspired by the research in iconology and narratology [32], [33], the term "archetype" is employed in Labyrinth to refer to a conceptual core, set at the intersection of narrative motifs, iconological themes and classical mythology (the system itself is named after a well–known archetype). Common examples are the archetypes of the "journey", the "hero", etc. The core of the Labyrinth system is the Archetype Ontology (AO). Archetypes are described as set of related stories, characters, locations and objects which share some symbolic meaning. A detailed description of the ontology is provided in [30]. The AO contains the description of a set of archetypes (the journey, the labirinth, the hero) and describes how the artworks are related with them via the representation of places, stories, objects, etc. The AO was aligned with the conceptual reference model established by the International

---
[5]http://app.labyrinth-project.it:8080/LabyrinthTest/

```
1  <!-- http://www.AO.org/labyrinth#Minotauromachia -->
2  <owl:NamedIndividual rdf:about="&www;labyrinth#Minotauromachia">
3      <rdf:type rdf:resource="&www;labyrinth#Manifestation"/>
4      <hasResourceType rdf:resource="&www;labyrinth#Image"/>
5      <ma-ont:hasCreator rdf:resource="&www;labyrinth#Pablo_Picasso"/>
6      <hasGeographicalLocation rdf:resource="&www;labyrinth#NewYork"/>
7      <evokes rdf:resource="&www;labyrinth#KnossosLabyrinth"/>
8      <displays rdf:resource="&www;labyrinth#Minotaur/>
9      <displays rdf:resource="&www;labyrinth#Theseus/>
10     <describesAction rdf:resource="&www;labyrinth#killing"/>
11     <hasPart rdf:resource="&www;labyrinth#Minotaur_Story"/>
12 </owl:NamedIndividual>
```

Fig. 2. The metadata of the artwork "Minotauromachia" by Pablo Picasso, as described in the AO ontology.

Council of Museums (ICOM), the CRM-FRBR model [34], a standard in the description of cultural heritage. Automatic reasoning tools allow tracking the connections that a set of artworks hold with the archetypes represented in the ontology, thus letting the shared narrative elements emerge among the artworks. The representation of cultural heritage in AO was aligned with the conceptual reference model established by the International Council of Museums (ICOM), the CRM-FRBR model [34], a standard in the description of cultural heritage. Automatic reasoning tools allow tracking the connections that a set of artworks hold with the archetypes represented in the ontology, thus letting the shared narrative elements emerge among the artworks. The resulting framework lends itself to the creation of personalized navigation paths in cultural object repositories, represented in digital form, for the sake of exploration and study.

The system is web based and it integrates a standard hyper textual interface [22] and a 3D environment. In the standard interface, the interaction exploits the top level elements of the archetype (related stories, characters, locations, etc.) and their subcategories (story types, characters types, etc.) to let the user select increasingly smaller sets of artworks, according to a top down strategy; in the 3D interface, the use navigates from artwork to artwork based on the relations among them, following a personal path through the artworks. For example, by choosing the archetype of the "labyrinth", the user may follow a path from a Greek vase representing the fight between Theseus and a Minotaur to a XVIII the century Italian painting depicting Ariadne, going through different representations of the labyrinth contained in Gothic cathedrals across Europe.

In order to illustrate how a repository of heritage objects can be navigated by using this ontology, we will resort to an example, the painting "Minotauromachia" by Pablo Picasso, The description of this artwork in the ontology is illustrated in Fig. 2 (serialized in the XML/RDF format).[6] The *hasResourceType* property (line 3) describes the media type (image) of the resource; the *hasCreator* property connects the painting with its author, "Pablo Picasso". As for the archetypal meaning of the subject, the property *evokes* (line 7) relates the painting with the "Labyrinth" archetype. A set of specific

[6]Each line represents an RDF triple, composed of a subject (all triples in this fragment have the same subject, i.e., the named individual "Minotauromachia" referred to in line 2), a predicate (for example, *hasResourceType*, line 3) describing a property of the subject or a relation with another entity, and an object (for example, the media type Image, line 3) which constitutes the value of the property or the second term of the relation.

properties describe the relation with the archetype in greater detail, focusing on its narrative aspects: *displays* (lines 8-9) refers to the characters which appear in it, i.e., Theseus and the Minotaur; *describesAction* (line 10) refers to the event type it depicts ("killing"). Finally, the painting is related with the Minotaur Story (*hasPart*, line 11). Notice that the description of the artwork illustrated in Fig. 2 was partly derived from the manually inserted artwork metadata (e.g. title, creator) and partly derived from them by running reasoning processes on the ontology (e.g. archetypal relations such as related stories and characters).

Given this description, several relations can be detected with other artworks. Beside standard relations based on author or resource type, the archetype provides content relations with other artworks that display the same characters (Theseus and the Minotaur), depict the same action type (killing), refer to the same story (the myth of the Minotaur) and its related stories (Ariadne and the thread). Notice that the latter relation, not displayed in the figure, is inferred by the reasoner running on the ontology server – since the Minotaur Story has the Story of Ariadne as one of its episodes.

### B. Visual Design

The visual design of the Labyrinth project is inspired by the metaphor of the labyrinth, a theme that is deeply rooted in Western Culture, as witnessed by several archaeological locations across Europe [35]. This metaphor was chosen both for its ability to convey the graph like nature of the relations among the cultural heritage objects and for its immediacy of use, providing an immediate *mapping* for artworks (labyrinth nodes) and relations (connections among nodes). The visual design was aimed at accounting for the main requirement posed by the project, i.e., stimulating the users to explore the repository though an engaging experience and making the system usable by the large majority of uses by integrating information giving and entertainment in a visual environment. The intuition behind the choice of the labyrinth for the visual design was to stimulate the user's curiosity for the unknown, and using the labyrinth as a device to add serendipity to the navigation experience. Moreover, the labyrinth or maze is a genre of video games most users are familiar with, thanks to classic 2D games such as Atari's Pacman and more recent 3D titles such as Imangi's Temple Run or PlayFirst's Dream Chronicles. The user is encouraged to explore the repository by following the artwork–to–artwork relations, in the same way as the visitor of a hedge maze explores it in its way

to the exit. The interaction metaphor underlying navigation is "finding one's way": here, however, the user does not simply gain the exit, but the creation of a personal path in artworks' meaning, represented by a virtual "red thread".

A relevant constraint to the design was given by the representation of semantic relations in the ontology. Formally, the labyrinth is an undirected graph [36], where vertices have a variable degree.[7] The nodes correspond to the graph vertices, the corridors to the edges. The direct transposition of the graph-like structure of the relationships among the artworks from the ontology to the 3D labyrinth, however, leads to a proliferation of the edges that would be confusing for the user. Take, for example, the similarity relation "displaying the same character" among artworks. Representing this relation as artwork to artwork relations implies that, for each artwork, an edge should be added from the artwork to every other artwork that displays the same character (and this should be done for each similarity relation). In order to alliviate this problem, in Labyrinth, semantic relations such as "displaying the same character" are represented by special nodes (called relation nodes) that represent the relation itself, thus obtaining a more compact representation.

As a result of the constraint described above, there are two types of nodes (iconic elements in the terminology of the framework) in the labyrinth, connected by "corridors": *artwork nodes* and *relation nodes*. Artwork nodes are connected with both relation nodes and artwork nodes. Relation nodes are connected only with artwork nodes. The user navigation starts from an artwork node: the user has to choose one of the corridors exiting from the node, labeled either with the name of a different artwork (in this case, the corridor, leads directly to an artwork node) or with the name of a semantic relation (in this case, the corridor leads to a relation node, that in turn leads to a set of different artwork nodes). Notice that design choice is in line with the type of presentation users are accustomed to in web recommendations, where the user is usually recommended with a set of similar items with respect to the current one, categorized according to the type of relations they have with the current item ("same author", "users who bought also bought", etc.). Finally, since the semantic relations are symmetric, corridors can be walked both ways.

As for the 3D *environment*, the setting of the labyrinth is inspired to the classical hedge maze, with architectural elements that are intended to remind of some distant but not well specified past, so as to prepare the user for the possible appearance of ancient and remote artworks. This choice was primarily due to the constraint posed by the heterogeneity of the repository that is assumed by the project. The floor is partly tiled, partly covered with grass. Corridors differ in length and form: some are longer and they bend, so that their end is not visible, in order add some thrill to the experience. As for the *scene* definition, artwork nodes contain a low circular balustrade in the middle, open in several points, so as to invite the user to step into the inner part of the node. In order to mark the difference with artwork nodes, relation nodes are empty. The entrance to corridors is marked by doors. Each node has a fixed number of doors/corridors: depending of the number

of semantic relations that connect the node with other nodes, some doors may be closed, or hidden by greenery.

A major element of the *interaction design* is given by the user navigation. The navigation in the system is inspired to the paradigm of constrained navigation [38], with the aim of making it usable also for non expert users of 3D applications. The user moves by clicking on small circles of light posited on the floor, in front of the doors of the nodes and along the corridors. Circles of the same type also mark the presence of an artwork in the middle of artwork nodes and must be clicked to get information about the artwork. Smaller circles of light appear inside the circles when they are clicked, so that they eventually form a sort of "red thread" that marks the path made by the user so far. The metaphor of the red thread, aimed at improving self orientation, is enforced also by a small console, posited in the lower part of the screen, that shows the list the nodes visited by the user. By clicking on a node in the list, the user is brought back to that node. The console also contains buttons for ending the session and turning off the sound. The user is free to explore the labyrinth, going back to previous locations and clicking on the control posited in artwork nodes to receive information and experience them via the appropriate plugins: depending of the media type of the resource associated with the artwork, an image is displayed, a video is played, etc. A short description of the artwork, with title, date and creator, is always provided.

In order to make the experience more engaging, when the session begins, the user is given a target node. When the user reaches the target node, or when the user decides to exit from the labyrinth, the session ends and the user is shown the statistics about her/his own path: number of visited nodes, elapsed time, backtrackings, etc.

### C. Software Development

Given the size of the knowledge base[8], it would have been impractical to create a full representation of the labyrinth. In case the knowledge base were modified, then, this representation would not be valid anymore. For these reasons, in Labyrinth 3D, only one node at a time is created: each time the user selects a path leading to an artwork node, the 3D visualization client queries the ontology server to get information about the artwork, including the list of artworks it is connected to, so that the portion of the labyrinth that surround the selected node is created on the fly just before the user get there. The new node is then generated and rendered, along with the set of corridors that connect it with the other artworks. In the following, we describe the algorithm executed by the visualization module to manage the interaction with the user. The visualization module queries the ontology through the ontology-to-3D API (see Section III-B). In summary, the functioning of the system is the following:

**Initialization**. When the session starts, the client queries the ontology to get the list of the available archetypes through the *startLabyrinth()* command.

**Archetype selection**. After the user chooses an archetype (*setArchetype()*), the client invokes an initialization command

---

[7]For usability reasons, the maximum number of edges per vertex has been limited to the arbitrary threshold of 7, given the well known limitations of short term memory first shown by Miller [37].

[8]The ontology currently contains 1211 triples.

that selects a random pair of artworks (*initialize()*), that provide, respectively, the start and target nodes.

**Node generation**. At this point, a loop is repeated to create the next node, until either the user reaches the target node or he/she exits the labyrinth by clicking the exit button. When the navigation starts, the next node is the start node selected by the system in the previous step; otherwise, the next node is the last node (i.e., artwork) selected by the user (see step 3, Generation of the labyrinth).

1) *Retrieval of relations*. The client queries the ontology to get the information about the chosen artwork (or the start node when the labyrinth is initialized) through the command *getNodeInfo()* of the ontology-to-3D API. This command is the key to the mapping of the semantic relations encoded in the ontology onto the structure of the 3D labyrinth: given an artwork, it returns the information about its creator, title, etc. and the list of the semantic relations (such as character-based, story-based, location-based relations and so on) between the artwork and the other artworks.
To retrieve these data from the ontology, *getNodeInfo()* executes a set of SPARQL queries on the ontology, one for each possible type of semantic relations. For example, the following query extracts from the ontology the set of artworks $?a$ that are evocative of the archetype of the labyrinth (: $evokes$) and display the character of Theseus ($displays$):

```
}
SELECT  ?a
WHERE{
?a :evokes :Labyrinth
?a :displays :Theseus
}
```

2) *Computation of topology*. The method *getNodeInfo()* returns an XML document describing the selected artwork and its related artworks; the XML contains a section for each semantic relation type (*agent*, *story*, etc.). For example, consider the following fragment, returned by invoking the command *getNodeInfo(MinotauromachiaPicasso)*:

```
<story>
    <rartifactstory>
        KnossosPalace
    </rartifactstory>
    ...
    <rartifactstory>
        ElLabirintoGriegoMontalban
    </rartifactstory>
</story>
<agent>
    <rartifactagent>
        AriadneMuseiVaticani
    </rartifactagent>
    ...
    <rartifactagent>
        GreekVaseTheseus
    </rartifactagent>
</agent>
```

The artworks tagged as *rartifactstory* (the Knossos Palace, the book "El Labirinto Griego" by M.V. Montalban) and *rartifactagent* (an anonymous statue of Ariadne at the Vatican Museums, a Greek vase
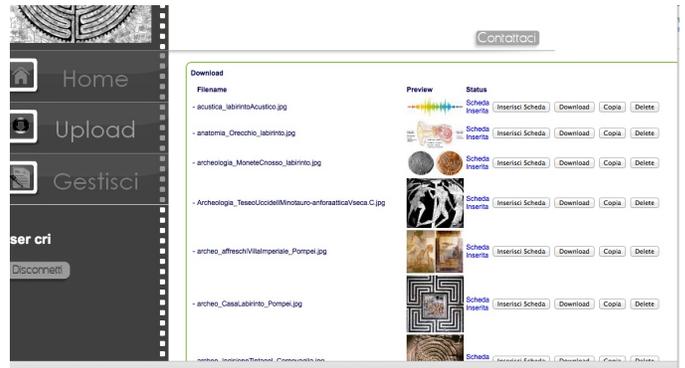


Fig. 3.   A screenshot of the back-end of the system.

representing Theuseus) all are artifacts (a generic term for artworks employed in AO) related to the painting Minotauromachia by Picasso by different relation types, "same story" (*rartifactstory*, i.e., related artifact for story) and "same agent" (*rartifactagent*, i.e., related artifact for character) respectively.
At this point, the topology of the labyrinth is computed. For each semantic relation:

– if it contains a *single artifact*, an artwork node is created to represent it and a corridor is added from the chosen node to the new artwork node;

– if it contains *multiple artifacts*, a relation node is created and a corridor is added from the chosen node to the relation node; for each artifact, then, an artwork node is created and a corridor is added from the relation node to each new artwork node.

3) *Generation of the labyrinth*. Based on the topology computed above, the next node of the 3D labyrinth is created and added to the 3D environment, together with its exiting corridors. When the user chooses a new artwork (either directly connected to the current one or indirectly, via a relation node), the loop is repeated.

**End of session**. When the user either reaches the target node or clicks on the exit button, the client executes the *endLabyrinth()* command to visualize the statistics of the session (time elapsed, visited nodes, etc.) and closes the session.

## V. LABYRINTH AT WORK: CONTENT EDITING AND EVALUATION

In the Labyrinth system, the editing phase was conducted through a back-end interface[9] the allows content editing professionals to describe and upload new items to the system repository (see Figure 3 for a screenshot of the back-end). When a new item is added to the repository its description is inserted through a web form, so as to alleviate the annotator from the use of a formal language. The system then, internalizes the description of the new item in the ontology through a built in procedure that converts the input data into RDF triples. The internalization procedure (described in [22]) also adds connections between the new items and the archetypes contained in the system based on a set of rules triggered by

---

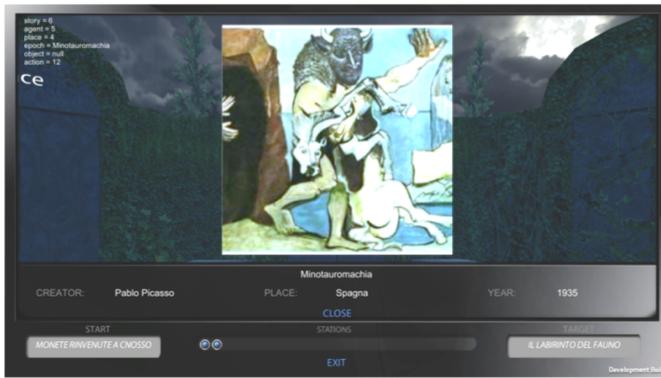[9]The interface and the contents are in Italian.

Fig. 4. Example: start node, Minotauromachia by Pablo Picasso.



Fig. 5. Example: doors from start node, labeled with semantic relations (same place, same epoch, same object).



Fig. 7. Example: backtracking to "same object" relation: door to Ariadne and the thread.

the keywords contained in the metadata of the items. Since the 3D labyrinth is dynamically created node by node, when new elements are added it is possible to verify how they are integrated in the 3D environment immediately after, and to assess how they affect the user experience.

### A. Navigation Example

In order to exemplify the navigation in the 3D labyrinth on real data, consider the artwork Minotauromachia, a painting by Pablo Picasso (see Section IV-A). When posited in the artwork node that contains the Minotauromachia (Fig. 4), the



Fig. 6. Example: relation node of type "agent" (same character).

user is surrounded by a set of doors that represent the available semantic relations connecting it with other artworks. Fig. 5 shows a partial view of the node, with doors for the "same character" relations (labeled as "agent"), the "same object" ("object") and same location ("location").

Fig. 6 shows the relation node the user reaches by choosing the door "agent" (same character), where doors are labeled with the titles of the artworks that display the same characters as the previous node. Once here, by choosing the door surmounted by the title "Teseo uccide il Minotauro" (Theseus killing the Minotaur"), the user will enter a corridor leading her/him to the artwork node which contains the artwork with that title, an ancient Greek vase representing Theseus in the act of killing the Minotaur (not shown).

Choosing a different door from the initial node (for example, the one labeled as "objects", i.e., artworks displaying the same object), the user may get to the relation node represented in Fig. 7. The figure shows in particular the door leading to a XVIIth century Italian painting (not shown in figure) whose title is "Il filo di Arianna" (Ariadne and the thread).

### B. Evaluation

In September 2014 we carried out a preliminary evaluation of the 3D interface of the Labyrinth system, in order to gather information about the users' liking of the system and their expectations about its use.

In the occasion of a scientific fair open to the general public, small groups of 3 to 5 people, chosen among the attendants, were given a demo of the Labyrinth system. After a short introduction (they were told simply that the system could be used to navigate in a repository of cultural heritage objects), the users were asked to choose a path in the labyrinth from an initial random node, with the experimenter clicking on the navigation controls corresponding to the user's choices. This procedure was motivated by the fact that, given the high inflow of visitors, we decided to exclude the usability of the system interface from the evaluation, in favor of a more coordinated execution of the testing protocol. Some users, however, explicitly asked to interact directly with the system and were allowed to, thus enabling the experimenters to make ethnographic observations about their navigation. The preliminary evaluation was conducted on a corpus of

51 media objects, which included images, text excerpts and video clips, described according to 3 archetypes (labyrinth, hero and journey). The archetypes contained 38 stories, 40 characters, 30 actions, 39 locations, 19 objects and 40 epochs. After each session, users were asked to answer individually a short questionnaire in an anonymous form.

The questionnaire was designed to test the acceptance of the 3D visualization, its immediacy of use and appeal for the average media users, in order to assess the achievement of the design goals of the system, i.e., stimulating the users to navigate the repository through an engaging experience. Inspired by the notion of *participatory design* in heritage [39], some specific design choices, like the setting of the labyrinth, were also tested. We also asked users to express preferences about the use of the system, aimed at gathering information for the design of new similar applications within the proposed framework.

The questionnaire included 7 questions. Question 1 grouped 6 sub–questions, aimed at investigating the general *acceptance* of the system: by using Likert scales (with 5 points from $-2$ to $+2$, mapped onto values from 1 $(-2)$ to 5 $(+2)$ in the subsequent data analysis), we asked testers to what degree the system was:

1) intuitive
2) interesting
3) engaging
4) useful
5) appealing
6) straightforward to use

Then, through multiple answer questions, we asked the testers to indicate their *preferred devices* (Question 2) for using the system (tablet, pc, smartphone, etc.) and to indicate what *use* (Question 3) they envisaged as suitable for the system (teaching, entertainment, cultural dissemination, etc.). In order to investigate the similarity of the proposed system with other paradigms of media use, we also asked the testers what types of applications were *similar* to the proposed system (Question 4). Finally, we asked some specific questions about the acceptance of the metaphor of the labyrinth and of the visual design. In particular, we asked the testers (Question 5) to select adjectives to describe the 3D labyrinth ("confusing", "intriguing", "ordinary", "challenging", "playful" and "unpleasant"), then we asked them whether they liked or disliked the proposed *setting*, ancient ruins, (Question 6) and what *other settings* they would like to have implemented (Question 7) through multiple choices (historical palace, modern building, museum, etc.).

41 testers took part in the evaluation, males and females, with ages ranging from 10 to 67 years old. The results were encouraging under all perspectives, i.e. the acceptance of the system, its immediacy of use, the understanding of the metaphor of the labyrinth and the suitability of the setting. However, these results are only preliminary, due to the fact that the testers were selected among the users that showed more interest about the application by approaching the demo booth. The average value of the answers to the questions concerning the acceptance was 4.5 (Question 1, subquestions $i$ to $vi$, all 5 point Likert scales), with "interesting" as the highest average value (4.7) and "straightforward" as the lowest average value

TABLE I.     PERCEIVED PROPERTIES OF THE SYSTEM

| SYSTEM PROPERTY | AVERAGE VALUE | ST. DEV. |
|---|---|---|
| intuitive | 4.35 | 0.72 |
| interesting | 4.7 | 0.57 |
| engaging | 4, 41 | 0.74 |
| useful | 4.48 | 0.61 |
| appealing | 4.5 | 0.74 |
| straightforward | 4.32 | 0.68 |

(4.32), indicating that the application was appealing but of its use was not entirely clear. The values are illustrated in Table I. As it can be noticed, the standard deviation is not high, since the testers generally agreed on a positive evaluation.

As for the *preferred device* for using the system (Question 2, multiple choice), the "pc" was the most frequently selected choice (25 users), followed by "tablet" (17) and "smart phone" (17). As for intended *use* (Question 3, multiple choice) "cultural enrichment" was the most frequently selected choice (31 users), followed by "teaching" (18 users). As for the most *similar* applications (Question 4, multiple choice), the "video game" and the "encyclopedia" were not surprisingly the most frequently selected choices (18 and 14 users) - since the the application was designed with the goal in mind to disseminate cultural contents with an immersive, game-like interaction style in mind. The *labyrinth* (Question 5, multiples choice) was perceived as "intriguing" by 31 users, and "challenging" or "playful" by only 13 of them. Finally, most users (31, 75.6%) liked the proposed setting (Question 6, yes/no question) and the most preferred *alternative settings* (Question 7, multiple choice) were the museum and the library (15 users each), in line with the reception of the content as cultural by the testers.

The ethnographic observation of the testers who interacted directly with the system showed that the navigation was generally easy, with some problems in clicking the navigation controls when they were located far away along the corridors, because the controls became small due to the perspective. Some users uttered their bewilderment at finding themselves in a node they had already visited, but were ready to accept the explanation that this is typical of labyrinths. The users tended to read carefully the information displayed about the single items, reasoning aloud about their connection with the archetype and with the previously visited nodes.

## VI.  CONCLUSION

In this paper, we presented a framework for visualizing semantic data in 3D environments in the field of cultural heritage. The framework includes a set of abstract components, a reference architecture and a pipeline, that we illustrated with the help of a case study, the Labyrinth system. After describing the design and implementation of the 3D interface of the Labyrinth system, we illustrated the results of an evaluation of the system, conducted in the spirit of participatory heritage innovation envisaged by [39].

The results of the evaluation show a good acceptance of the visual design of the 3D interface and provide the basis for developing other applications based on the same framework. By applying the framework to the design of other applications and testing them with users in a deeper way, it will possible to refine and improve the framework itself, taking advantage of

the full range of devices that support real time 3D to develop innovative cultural heritage applications.

REFERENCES

[1] H. Jenkins, *Convergence Culture: Where Old and New Media Collide.* NYU Press, 2008.

[2] R. Villa, P. Clough, M. M. Hall, and S. Rutter, "Search or browse? casual information access to a cultural heritage collection." in *EuroHCIR*, 2013, pp. 19–22.

[3] E. Hyvönen, "Semantic portals for cultural heritage," in *Handbook on ontologies.* Springer, 2009, pp. 757–778.

[4] M. Doerr, "Ontologies for cultural heritage," in *Handbook on Ontologies.* Springer, 2009, pp. 463–486.

[5] M. Doerr, S. Gradmann, S. Hennicke, A. Isaac, C. Meghini, and H. van de Sompel, "The europeana data model (edm)," in *World Library and Information Congress: 76th IFLA general conference and assembly*, 2010, pp. 10–15.

[6] C.-c. Chen, H. D. Wactlar, J. Z. Wang, and K. Kiernan, "Digital imagery for significant cultural and historical materials," *International Journal on Digital Libraries*, vol. 5, no. 4, pp. 275–286, 2005.

[7] C. Ziemkiewicz and R. Kosara, "The shaping of information by visual metaphors," *Visualization and Computer Graphics, IEEE Transactions on*, vol. 14, no. 6, pp. 1269–1276, 2008.

[8] K. Dylla, B. Frischer, P. Mueller, A. Ulmer, and S. Haegler, "Rome reborn 2.0: A case study of virtual city reconstruction using procedural modeling techniques," *Computer Graphics World*, vol. 16, p. 25, 2008.

[9] L. Calori, C. Camporesi, A. Negri, and S. Pescarin, "Virtual rome," in *SIGGRAPH Posters.* ACM, 2008, p. 101.

[10] A. Guidazzoli, L. Calori, F. D. Ponti, T. Diamanti, S. Imboden, A. Mauri, A. Negri, G. B. Cohen, S. Pescarin, and M. Liguori, "Apa the etruscan and 2700 years of 3d bologna history," in *SIGGRAPH Asia 2011 Posters.* ACM, 2011, p. 2.

[11] V. Lombardo, A. Valle, J. Fitch, K. Tazelaar, S. Weinzierl, and W. Borczyk, "A virtual-reality reconstruction of poeme electronique based on philological research," *Computer Music Journal*, vol. 33, no. 2, pp. 24–47, 2009.

[12] H. Rua and P. Alvito, "Living the past: 3d models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage–the case-study of the roman¡ i¿ villa¡/i¿ of casal de freiria," *Journal of Archaeological Science*, vol. 38, no. 12, pp. 3296–3308, 2011.

[13] N. Smith, K. Knabb, C. Defanti, P. Weber, J. Schulze, A. Prudhomme, F. Kuester, T. Levy, and T. Defanti, "Artifactvis2: Managing real-time archaeological data in immersive 3d environments," in *Digital Heritage International Congress.* The Eurographics Association, 2013, pp. 363–370.

[14] G. Pavlidis, A. Koutsoudis, F. Arnaoutoglou, V. Tsioukas, and C. Chamzas, "Methods for 3d digitization of cultural heritage," *Journal of cultural heritage*, vol. 8, no. 1, pp. 93–98, 2007.

[15] E. Kalogerakis, S. Christodoulakis, and N. Moumoutzis, "Coupling ontologies with graphics content for knowledge driven visualization," in *Virtual Reality Conference, 2006.* IEEE, 2006, pp. 43–50.

[16] C. Bogdan and D. M. Popovici, "The use of domain ontologies for the virtual scenes management," *WSEAS Transactions on Computers*, vol. 9, no. 8, pp. 868–877, 2010.

[17] T.-H. Trinh, P. Chevaillier, M. Barange, J. Soler, P. De Loor, and R. Querrec, "Integrating semantic directional relationships into virtual environments: a meta-modelling approach," in *Proceedings of the 17th Eurographics conference on Virtual Environments & Third Joint Virtual Reality.* Eurographics Association, 2011, pp. 67–74.

[18] K. Rodriguez-Echavarria, D. Morris, and D. Arnold, "Web based presentation of semantically tagged 3d content for public sculptures and monuments in the uk," in *Proceedings of the 14th International Conference on 3D Web Technology.* ACM, 2009, pp. 119–126.

[19] L. Pecchioli, M. Carrozzino, F. Mohamed, M. Bergamasco, and T. H. Kolbe, "Isee: Information access through the navigation of a 3d interactive environment," *Journal of Cultural Heritage*, vol. 12, no. 3, pp. 287–294, 2011.

[20] I. Horrocks, P. F. Patel-Schneider, and F. Van Harmelen, "From shiq and rdf to owl: The making of a web ontology language," *Web semantics: science, services and agents on the World Wide Web*, vol. 1, no. 1, pp. 7–26, 2003.

[21] L. A. L. V. Damiano, R., "Ontology-based visualisation of cultural heritage," in *Proc. of Complex, Intelligent and Software Intensive Systems 2014 (CISIS).* IEEE, 2014, pp. 558–563.

[22] A. Lieto and R. Damiano, "Building narrative connections among media objects in cultural heritage repositories," in *Interactive Storytelling - 6th International Conference, ICIDS 2013, Istanbul, Turkey, November 6-9, 2013, Proceedings*, ser. Lecture Notes in Computer Science, H. Koenitz, T. I. Sezen, G. Ferri, M. Haahr, D. Sezen, and G. Catak, Eds., vol. 8230. Springer, 2013, pp. 257–260.

[23] L. Aroyo, N. Stash, Y. Wang, P. Gorgels, and L. Rutledge, "Chip demonstrator: Semantics-driven recommendations and museum tour generation," *The Semantic Web*, pp. 879–886, 2007.

[24] C. Van Den Akker, S. Legêne, M. Van Erp, L. Aroyo, R. Segers, L. van Der Meij, J. Van Ossenbruggen, G. Schreiber, B. Wielinga, J. Oomen *et al.*, "Digital hermeneutics: Agora and the online understanding of cultural heritage," in *Proceedings of the 3rd International Web Science Conference.* ACM, 2011, p. 10.

[25] P. Hitzler, M. Krotzsch, and S. Rudolph, *Foundations of semantic web technologies.* CRC Press, 2011.

[26] L. P. Rieber and D. Noah, "Games, simulations, and visual metaphors in education: antagonism between enjoyment and learning," *Educational Media International*, vol. 45, no. 2, pp. 77–92, 2008.

[27] J. Oomen and L. Aroyo, "Crowdsourcing in the cultural heritage domain: opportunities and challenges," in *Proceedings of the 5th International Conference on Communities and Technologies.* ACM, 2011, pp. 138–149.

[28] M. Cataldi, R. Damiano, V. Lombardo, and A. Pizzo, "Lexical mediation for ontology-based annotation of multimedia," in *New Trends of Research in Ontologies and Lexical Resources.* Springer, 2013, pp. 113–134.

[29] V. Lombardo, A. Pizzo, C. Battaglino, R. Damiano, and A. Lieto, "Coupling conceptual modeling and rules for the annotation of dramatic media," *Semantic Web Journal, Spec. Issue on Web Reasoning and Rule Systems*, forthcoming.

[30] R. Damiano and A. Lieto, "Ontological representations of narratives: a case study on stories and actions," in *2013 Workshop on Computational Models of Narrative, CMN 2013, August 4-6, 2013, Hamburg, Germany*, ser. OASICS, M. A. Finlayson, B. Fisseni, B. Löwe, and J. C. Meister, Eds., vol. 32. Schloss Dagstuhl - Leibniz-Zentrum fuer Informatik, 2013, pp. 76–93. [Online]. Available: http://dx.doi.org/10.4230/OASIcs.CMN.2013.76

[31] C. Bizer, T. Heath, and T. Berners-Lee, "Linked data-the story so far," *International journal on semantic web and information systems*, vol. 5, no. 3, pp. 1–22, 2009.

[32] A. Warburg, *Der Bilderatlas Mnemosyne.* Akademie Verlag, 2008, vol. 1.

[33] S. Thompson, "Myths and folktales," *The Journal of American Folklore*, vol. 68, no. 270, pp. 482–488, 1955.

[34] E. T. O'Neill, "Frbr: Functional requirements for bibliographic records," *Library resources & technical services*, vol. 46, no. 4, pp. 150–159, 2002.

[35] H. Kern and J. Saward, *Through the Labyrinth: designs and meanings over 5000 years.* Prestel New York, 2000.

[36] P. Rosenstiehl, "Labirinto," *Enciclopédia Einaudi*, vol. 13, pp. 247–273, 1988.

[37] G. A. Miller, "The magical number seven, plus or minus two: some limits on our capacity for processing information." *Psychological review*, vol. 63, no. 2, p. 81, 1956.

[38] S. Burigat and L. Chittaro, "Navigation in 3d virtual environments: Effects of user experience and location-pointing navigation aids," *International Journal of Human-Computer Studies*, vol. 65, no. 11, pp. 945–958, 2007.

[39] R. C. Smith and O. S. Iversen, "Participatory heritage innovation: designing dialogic sites of engagement," *Digital Creativity*, vol. 25, no. 3, pp. 255–268, 2014.