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"POLYGNOSIS": the development of a thesaurus in an Educational Web Platform on optical and laser-based investigation methods for cultural heritage analysis and diagnosis

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Abstract

Due to their unique properties, laser and optical technologies hold today an important role in the protection and study of Cultural Heritage, since they are used in a wide range of demanding analytical and diagnostic applications. Considering the rapid and vast technological development of their methodologies and tools, it is necessary to make this new knowledge more reachable and comprehensible to heritage scientists. Towards this end, a web-based knowledge platform (Polygnosis) (http://politeia.iesl.forth.gr/polygnosis/) was designed by the Institute of Computer Science (ICS) of FORTH concerning the state-of-the-art light and/or laser-based techniques, which have been developed at the Institute of Electronic Structure and Lasers (IESL) of FORTH, for advanced imaging, analysis and diagnosis of Cultural Heritage objects. This educational digital tool seeks to highlight the efficiency and potentials of modern optical and laser technologies in Cultural Heritage documentation, as well as, promote the dissemination and deeper understanding of their applications to conservators, archaeologists, art historians, material and laser scientists. "Polygnosis" represents accumulated knowledge regarding the selection of the diagnostic tool and the suggested methodology, with simultaneous display of examples of actual experimental procedures. The model relates those examples with the relevant terminology of the Thesaurus, the information about the object under examination and the metadata resulting from those experiments. 'Polygnosis' thesaurus is a semantically structured vocabulary organized by a faceted classification, which serves the educational needs of the system. The current study concerns the definition and classification of terms for the development of the semantically linked Thesaurus, as well as, the presentation and review of the knowledge platform, with emphasis on the supportive role of the thesaurus in such an educational resource.

Keywords: Thesaurus system, Knowledge platform, Data curation, Laser technologies, Cultural heritage

Introduction

Cultural institutions, such as museums, art galleries etc. whose core activities include the management, protection and promotion of cultural objects, show an increase in the demand for specialized scientific knowledge that stems from the application of modern optical technologies and their methodologies in the study of Cultural Heritage. Nowadays, advanced investigation methods and instrumentation have been increasingly employed in archaeometry studies to determine the origin, date and authenticity of the objects, to detect

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material deterioration and if possible to understand its causes and mechanisms and to indicate the appropriate conservation and restoration methods or evaluate their effectiveness.

Many professionals from various scientific disciplines, such as curators, art historians, archaeologists, conservators etc., are involved in the examination process and diagnosis of Cultural Heritage, each using their own specialized terminology [1]. This, coupled with the fact that the domain of optics and lasers is rapidly growing and constantly improving and updating its methods, as well as broadening its application areas in the Cultural Heritage domain by employing more complex techniques, improved instruments and specialized terminology, makes the description of the methods and results confusing even for the most up-to-date professionals [2]. Consequently, a communication gap among cultural heritage professionals appears which sometimes may lead to misconceptions or misunderstandings. Also, newcomers to this field find it difficult to gain a deep understanding of the use of these technologies and their results, or to select the appropriate method to investigate an issue. Moreover, the variation in the field's technical vocabulary can be an obstacle for specialists or non-specialists to understand a text, find a proper term, conceptualize a topic or an information need. The latter is highly essential for the in-depth educational review or systematic research on the interdisciplinary domain of optical technologies used for the study of cultural heritage.

To resolve this situation, new Knowledge Organization Systems (KOS) are needed to enable the efficient cooperation of interdisciplinary working groups. They comprise of an attempt to support individuals in thinking and sense-making, serve both as a guide to other information, but also consist of information sources in their own right [3]. Their conceptual structure allows the effective organization and integration of data, so as to enable their users identifying an object of interest without prior knowledge of its existence [3]. Therefore their use is essential in the above-mentioned field, both for the documentation of the investigation methods and processes, as well as, the provision of related educational material.

The goal of this study is to present the supportive role of the semantically linked thesaurus in "Polygnosis" educational knowledge web platform regarding optical and laser-based techniques for advanced imaging, analysis and diagnosis of Cultural Heritage objects. Particularly, the benefits derived from the thesaurus deployment in such an educational context, are outlined.

The main contribution of this paper concerns the 'Polygnosis' thesaurus which consists of a method for analysing in depth this interdisciplinary field, acts as an educational resource and provides an effective concept space.

"Knowledge Organisation Systems (KOS): short overview" section gives a synopsis of the typology of such systems. "The 'Polygnosis' platform" section introduces the knowledge platform and illustrates its scope, design and content. "The 'Polygnosis' thesaurus" section describes the goals, role and concepts of the thesaurus and the methodology used for its construction. "Results and discussion" section reviews the resulting system and provides examples of its use, together with the "Evaluation of the 'Polygnosis' system" section which aims its assessment and proposes further developments. Finally, "Conclusions" section presents the main conclusions and contributions of this study, along with its future advancements.

Knowledge Organisation Systems (KOS): short overview

Over the past 20 years, many KOS have been developed for serving heritage professionals in the discovery and understanding of new knowledge, and therefore, the support of decision-making, good research and practice. Plenty of KOS with different degrees of vocabulary control, richness of semantic relationships and formality have been implemented so far; each serving slightly different purposes. As follows, they are usually grouped by their structure into three general categories:

Term lists, which comprise of lists of terms often with definitions, such as Authority Lists, Glossaries, Dictionaries, Gazetteers, Synonym Rings etc. Generally, they do not include a deep organization or complex structure, but they may encompass a limited monohierarchical structure[1] that allows simple navigation [4].

Classifications and categories, which emphasize the creation of subject sets, such as Subject Headings, Taxonomies and Categorization Schemes. They provide ways to separate entities into broad topic levels based on a particular characteristic, by employing either monohierarchical or polyhierarchical structure[2] [4, 5].

Relationship lists, such as thesauri, semantic networks, ontologies, which focus on the connections between terms and concepts [4, 5]. Particularly:

- *Thesauri* are based on concepts and have a restricted set of relationships among terms, includ-

[1] Monohierarchical structure is the hierarchical arrangement of concepts in which each concept can have only one broader concept and can occur at only one place in the hierarchy, while other broader term relationships have to be shown as related term relationships.

[2] Polyhierarchical structure is the hierarchical arrangement of concepts in which each concept can have more than one broader concept, thus a single concept can occur at more than one place in the hierarchy.

ing hierarchy, equivalence (synonymy), and association/relatedness [4, 5]. Most of them employ polyhierarchical structure. Both monolingual [6, 7] and multilingual thesauri [8] are developed according to extensive rules and guidelines, which are given by international standards.

- *Ontologies* are specific concept models that represent complex relationships among objects and include the rules and axioms missing from semantic networks. From all the systems discussed here, ontologies tend to have the most precise and formal definition of relationships [4].

To sum up, most of the above KOS types (such as classification systems, gazetteers, lexical databases, ontologies, taxonomies and thesauri) attempt to model the underlying semantic structure of a domain, and thus, they serve for the discovery and understanding of complex knowledge of interdisciplinary fields, such as art conservation.

The 'Polygnosis' platform

Aims and scope

In the framework of the NSFR Greek national project "POLITEIA" (Politismos-Technologia, New Technologies in the Research, Study, Documentation and Access to the Information for Cultural Heritage Objects and Monuments) [9], a web-based knowledge platform "Polygnosis" along with a semantically linked thesaurus, were designed and implemented with educational orientation concerning the state-of-the-art optical and laser-based techniques for advanced imaging, analysis and diagnosis of Cultural Heritage objects.

'Polygnosis' platform aims to facilitate access to specialized knowledge, serve as a reference tool, and possibly promote consensus on concepts and terms and the move towards a common language for the field. It focuses on assisting primarily art conservators, but also heritage researchers and practitioners with problem clarification on cultural heritage materials. Nonetheless, students in the fields of conservation, archeology or art history can be benefited from this advanced educational web-based resource.

The novelty of 'Polygnosis' platform lies in the fact that categorical and factual relationships are central to the intellectual structure of the subject space of this learning system. In this manner, the user is easily navigated from categorical to factual knowledge through the platform's 'Best Practice Guide', where accumulated knowledge regarding the selection of the diagnostic tool and the methodology is presented, with simultaneous display of examples of actual method applications on heritage objects. The model relates those examples to the relevant terminology of the thesaurus, the information about the object under investigation and the data extracted and processed from those procedures. Each of the platform's case-study presents, discriminates and explains all the knowledge arising from the described examination procedure, such as the documentation of the object, the recording of the evidence as well as the conclusions resulting from the evidence.

Design and content

'Polygnosis' system runs on a 3-tier architecture. This allows the separation of the application logic, the data and the user interface, while it ensures open architecture, expandability, adaptability and flexibility. The three major independent modules are the database, the functional components and the user interface. The general idea is that data are stored in a central database ('Synthesis') and users (curators, conservators, technicians, art historians, students, researchers, administrators etc.) can access them through the internet, using the system's functional components according to the type of access rights they are given [15].

The functionality provided by 'Polygnosis' is inspired by CREBITEL[3] system [16]. The infrastructure of 'Polygnosis' follows the latest research results of open systems and conceptual models. The system's authorised user may enter, change or delete all the data. The system uses native XML database and all the data are organized and stored in valid XML files following XML schemas [17, 18]. The XML schemas are based on international standards such as ISO 21127 [19]. In this way, the system secures the data preservation, scalability, exploitation and interoperation with others systems.

For data and knowledge organization, an ontology of categorical and factual knowledge about the conservation and diagnosis of heritage objects and the examination techniques based on laser technologies was created. This ontology is based on the CIDOC CRM (ISO 21127:2014) and its family models CRMsci and CRMdig.

The CIDOC CRM is a formal ontology designed to be used as a global schema for describing and integrating metadata about museum collections [14]. The term "museum collections" is intended to cover all types of material collected and displayed by museums and related institutions, as defined by ICOM.[4]

[3] CREBITEL is a bi-lingual Training Electronic Handbook, which was developed to convey the complex knowledge of using multispectral imaging techniques for conservation planning. It was a web-based information system (WBIS) that employed a model supported by a multilingual thesaurus and knowledge representation.

[4] ICOM: International Council of Museums.

'Polygnosis' is populated by organized and integrated data, collected from scientific examination methodologies and applications that are being conducted in the laboratory of 'Photonics for Cultural Heritage' of IESL-FORTH. The mentioned laboratory's investigation methods comprise of Multispectral Imaging, Raman Spectroscopy, Laser-Induced Breakdown Spectroscopy (LIBS) [10] and Digital Holographic Speckle Pattern Interferometry (DHSPI) [11, 12]. The platform's design and content mainly focus on:

- The interpretation and understanding of the possible applications of the described techniques, as well as, their methodologies and instrumentation.
- The various data and images that each technique may produce in pre- or post-processing stage.
- The correlation of the above documentation material with the physical features observed in the artwork along with the feature's causes or mechanisms.
- The investigation methods in relation to the object's detected features.

The platform's main concepts, as follows by the conceptual data model in Fig. 1, are [13]:

a. The implementation of an investigation method ('Method application' entity).
b. The particular "examples", which refer to specific measurement events, examination and diagnosis procedures [14] ('Example' entity).
c. The technical examinations, objects and primary data, as well as, the secondary data derived from processing the primary data ('Technical examination', 'Objects' and 'Data' entities respectively).
d. And finally, the bibliographic documentation and the relevant terminology ('Glossary terms' and 'Publications' entities).

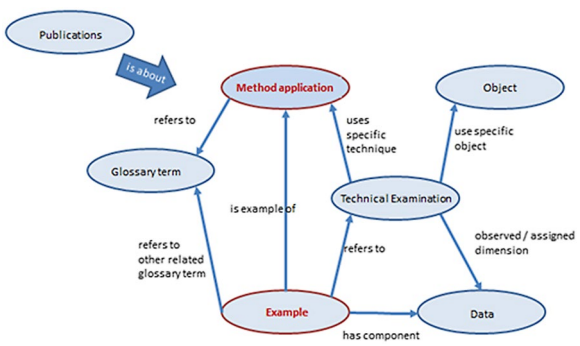

Fig. 1 The model and basic concepts of 'Polygnosis' knowledge platform

Figure 2 displays the homepage of the platform where the user can select his/her content page of interest. The 'Best Practice Guide' illustrates a table of the available examples classified according to the type of evidence that each examination method reveals. Thus, the user can select the case study that interests him either by the type of examination or the type of evidence. Thereafter, the user is provided with descriptive texts (categorical knowledge) regarding the examination type and evidence selected, as well as, a list of examples of related case-studies (factual knowledge) on different heritage objects. For instance, the learner can explore the feature 'overpaint' which consists of an evidence that Multispectral Imaging can detect, in case-studies that examine either a panel painting, a mural painting or a painting on parchment, among other. Therefore, the comparison of the applied methodological approaches, the tools used and the examination results between different material objects, is enabled.

Figure 3 demonstrates a case-study focusing on the identification of the composition of red pigments in a Byzantine mural painting. A brief description of the materials studied, the used methodology and tools, is given in the 'Examination' section [13]. Highlights of the procedure are introduced in the 'Documentation' section, along with the results' assessment of the 'Diagnosis' section. Here, the final conclusions, the produced spectra and a map of the analyzed spots are presented together with a commentary text. Subsequently, a list of terms related to this example, as well as, bibliographic and reference sources are displayed.

The 'Polygnosis' thesaurus

Scope, concepts and role

In order to support the platform's educational role, a set of related-to-the-discipline terms were defined and classified for the development of the semantically linked thesaurus. 'Polygnosis' platform contains domain concepts linked through a network of well-defined relationships and a rich set of terms identifying these concepts through its thesaurus, which is accessed and maintained via the thesaurus management system 'THeMaS'. It concerns an application specific thesaurus that aims to support diagnosis and conservation decision making, as well as, analyse in depth and map out the concepts of this multidisciplinary domain, through organizing them by a faceted classification. Therefore, it provides global subdivision of concepts through Broader-Narrower Term Hierarchy, as well as, it sets concepts and terms into context, relating concepts to terms, and giving definitions. As a result, it offers related concepts the user might not has thought initially, thus help him explore and clarify the information need and find useful related information.

Fig. 2 The homepage of 'Polygnosis' knowledge platform

Specifically, 'Polygnosis' thesaurus conceptual structure and data interconnections are better interpreted below in Fig. 4.

Thesaurus construction methodology

Design process and challenges

The main challenge that we had to deal with when designing the thesaurus, was matching a user question against a semantic network at the categorical level since generalizations and specializations of concepts are unrestricted. The different scientific communities have different perceptions of the same terms and concepts that were to be incorporated in the 'Polygnosis' thesaurus. Thus, it was crucial to avoid the logical errors and idiosyncratic decisions, which may lead to inconsistencies and consequently would require backward-incompatible restructuring of the classification system and its application. Consequently, the demand for objectivity in designing and establishing the top-concepts of the thesaurus leads us to look for formal rules that would enable ranking the specific terms on the basis of typical criteria. As a result, we have turned our attention to the ontology of CIDOC CRM Model [14].

Accordingly, an ontology-driven faceted analysis method was used for the definition of the top-level concepts that consist of the backbone for organizing its

Fig. 3 Example of the application of Raman spectroscopy on a Byzantine mural painting

knowledge. It is critical to point out that it has not been used to define any of the terminology appearing on the thesaurus, but it has rather explained the logic of the documented terms. Due to its structure and formalism, this ontology has assured the ability to integrate terminology from different relevant scientific sources and it has enabled semantic interoperability.

The methodology followed for the construction of 'Polygnosis' thesaurus include the following main steps:

a. Data collection and analysis: collection and processing of related scientific sources, terminology and thesauri.

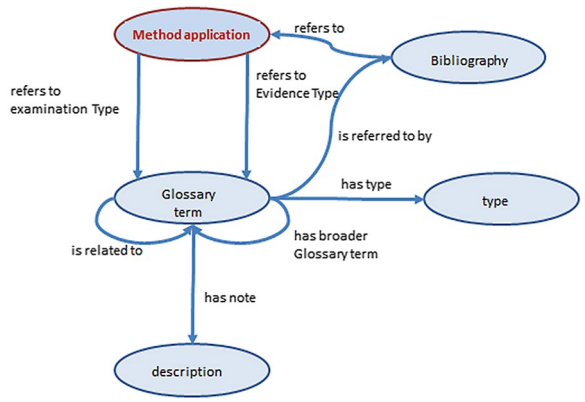

Fig. 4 The conceptual model and semantic structure of 'Polygnosis' thesauri

b. Thesaurus structure: (i) formation of semantic categories and facets of the thesaurus according to the main concepts of 'Polygnosis', (ii) building of hierarchies and finally (iii) formation of the semantic relationships between terms.

Below follows a more detailed description of the above mentioned methodological steps.

Collection and data analysis

Like most knowledge organization systems, the thesaurus is the result of processing documents and information resources. The first step is the collection and processing of a set of "content objects"[5] [20], which will be the primary material used for producing the subsequent homogenized indexing system [6].

The documented scientific terminology in 'Polygnosis' thesaurus is part of the expert languages of the disciplines of art conservation, technical art history, optics and lasers, among others. Thus, the process of selecting terms for inclusion in 'Polygnosis' thesaurus involved the consulting of various related sources. Each of the studied source, either describes experimental procedures performed for the study of heritage materials (e.g. spectroscopic material analysis), or includes terminology referring to the condition state, degradation processes, pathology, features and components of a heritage object (e.g. detachment, pentimento) or terminology regarding the object itself (e.g. acrylic paintings, murals).

Primarily, existing analysis/condition reports from past campaigns that were conducted by the 'Photonic for Cultural Heritage' laboratory of IESL-FORTH were studied in order to identify the terms and concepts that we aim to document in the thesaurus. The 'Ariadne' conservation documentation system's conceptual model [21] has also assisted in the identification of the conservation steps in our analysis/condition reports. In parallel, laser system's user manuals were analysed in order to collect technical terms regarding the equipment and the digital documentation data.

'Polygnosis' thesaurus has been based on the experience, structure and content of CREBITEL thesaurus [16]. CREBITEL thesaurus facets include "Material", "Evidence of Technique, Mark and Trace", "Alteration", "Intervention" and "Investigation Methods". Therefore, both thesauri share common scopes, notions and concepts regarding the examination and conservation methods of artworks, their evidences and the resulting data.

Furthermore, many terms were taken and defined from other thesauri and vocabularies such as the AAT[6] [22], NARCISSE[7] [23, 24], CRISTAL[8] [25] and EwaGlos[9] [26], which actually played a verification role in the final terms' selection. Finally, a high number of books, related journal articles, condition reports, etc. were studied in order to localize relevant terminology to be included in 'Polygnosis' thesaurus. The source(s) of each thesaurus term is/are documented as a reference on each term's identity card in the Thesaurus Management System (TMS) 'THeMaS'.

Thesaurus structure

After having collected a great number of terms, we had to deal with the challenge of organising them based on their content and meaning, in other words their intension. The process and method followed in designing and building our thesaurus is the same as the one adopted for the implementation of the backbone thesaurus of DARIAH EU[10] backbone thesaurus (BBT) [27]. This method exploits all the advantages offered by categorical semantics, in order to define the intentional properties[11] of the general concepts under which we can subsume more specific terms.

[5] A content object is any item that is to be described for inclusion in any information retrieval system, website or any source of information.

[6] AAT: Art & Architecture Thesaurus (1990).

[7] NARCISSE: Network of Research Computer Image SystemS in Europe (1990–1993).

[8] CRISTAL: Conservation & Restoration Institutions for Scientific Terminology dedicated to Art Learning Network (1999–2000).

[9] EwaGlos: European illustrated Glossary of Conservation terms for Wall-Paintings & Architectural Surfaces (2015).

[10] DARIAH EU: The Digital Research Infrastructure for the Arts and Humanities—a research infrastructure.

[11] Intentional properties express the essential characteristics, i.e. the "nature" of a concept.

Thereafter the categorisation of terms/concepts, we defined our facets and hierarchies through identifying the intentional properties of the concepts to be classified [27, 29]. The latter properties provide the necessary and sufficient conditions for a term to belong to a category and not to be replaced without loss of meaning. It is through the intentional properties of concepts that we can identify hierarchical relationships that will lead to broader categories (facets), which will be used for the classification of the terms [27].

Within this framework, four extensible facets relevant to the content of the platform were defined. These facets together with their scope notes are presented below:

a. "Material Objects": This Facet comprises types of things with a physical substance that constitute complete units and have a relatively stable form with identifiable boundaries in at least one dimension. Such units can be natural or man-made (with regard to the origin), simple or complex (with regard to composition) or consist of parts. In this latter case it is possible that the parts are either distinct and independent from the unit of which they are a part (e.g. a cave on a mountain) or that they have to be defined with reference to the sum of the parts (e.g. chess-chessmen). The definition of this facet is based on BBT [28].
b. "Investigation Methods": This Facet comprises systematic procedures designed to detect, identify and demonstrate the qualities and characteristics of an object. These methods allow the assessment of the object's condition state, the study of its structure, material, manufacturing technology, the nature and extent of its damage, as well as, the estimation of the deterioration factors. Often, the aim of these methods is to serve the development of the required conservation methodology and the determination of the type and extent of the necessary treatment. For example, spectroscopic methods, imaging methods etc.
c. "Identifiable Features": This facet consists of features that are inextricably linked with the objects on which they are found without being themselves autonomous objects. These features result from either forced or impulsive actions or procedures. They can be defined by physical characteristics (geometry, colour, etc.), and can be identified and determined by investigation methods. For example, a trace from a previous intervention, a signature, a sign, saturation of colours in a mural due to the existence of moisture etc.
d. "Data": This facet includes digital material that provides information relevant to the documentation of the object (material or information object) and the processes that take place during all stages from the acquisition of primary information, by recording or digitization, to the production of secondary and tertiary information, through studies, interventions, presentations, exhibitions and publications. This facet includes terms like interferogram, infrared reflected image, crack map etc.

The mentioned facets are organized in hierarchies according to the IsA relation which dictates that every subsumed term must belong to the same inherent category as its broader concept [30]. Using the IsA relation as the criterion for building hierarchies ensures that consistency is maintained since all narrower terms must possess all the fundamental properties attributed to the broader concepts of the hierarchy into which they are subsumed [29].

Apart from the hierarchies created by the IsA relation, terms are also linked through the associative relationship which covers associations between pairs of concepts that are not related hierarchically.

Based on this relationship, we achieved to relate an object with:

- The investigation methods that can most effectively examine it.
- The features that can be detected and identified on this object.
- The data resulting from the examination method applications.

All the above-mentioned relationships are reciprocal between all the associated terms. In this manner, a term acts as an entry node for viewing and understanding a large part of the knowledge in this area.

Even though 'Polygnosis' covers a wide range of concepts related to the study of cultural heritage by laser technologies, it still remains a specific application-based thesaurus. Although, DARIAH backbone thesaurus (BBT) consists of a coherent overarching thesaurus for the humanities [27], a metathesaurus under which 'Polygnosis' thesaurus can be aligned.

Polygnosis uses BBT's '*Material Object,*' which is common in the field of conservation/restoration of cultural heritage, archaeology, and history of art. The other three 'Polygnosis' facets: '*Investigation Methods,*' '*Identifiable Features*', and '*Data*' can be aligned to BBT's hierarchies and facets [27], as follows:

- '*Investigation Methods*' (Polygnosis) can be aligned to '*Methods*' (BBT's hierarchy) under '*Conceptual Objects*' (BBT's Facet). The latter 'Polygnosis' facet

according to the CIDOC CRM can also be classified under '*Conceptual Objects*' (E28) class. '*Conceptual Objects*' comprise non-material, man-made products and information, supported by the use of technical devices that may exist on more than one particular carrier at the same time [14].

- '*Identifiable features*' (Polygnosis) can be aligned to '*Physical Features*' (BBT's hierarchy) under '*Material Objects*' (BBT's Facet). This 'Polygnosis' facet includes the specific features that might be revealed and identified by the investigation methods, and therefore, it is important that they comprise of an independent facet.
- *'Data'* (Polygnosis) can be aligned to '*Information Objects*' (BBT's hierarchy) and '*Propositional Objects*' (BBT's hierarchy) under *'Conceptual Objects*' (BBT's Facet).

To sum up, the mentioned four facets of 'Polygnosis' thesaurus represent the basic conceptual schema of the domain of diagnostic processes and investigation methods on material cultural heritage objects.

Results and discussion

Comparing to the most sequential, alphabetical or through simple subject headings organization of contents, 'Polygnosis' concept relationships and faceted classification present multiple advantages and have contributed the most in the effectiveness of the thesaurus. Its semantic maps serve in the reorganization, enrichment and consolidation of heterogeneous thematic metadata. Moreover, they function as a base for the creation and maintenance of information. They provide the methodology for creating semantic networks through the interconnection of concepts of different information sources. By providing a standardized method for structuring the educational material, semantic maps support new navigation and retrieval methods, and as a result, new ways of organizing the information.

Subsequently, this is evident by the structure of the 'Polygnosis' thesaurus which is presented below:

1. *Facet*: Material Objects
   Hierarchies:
   a. Mobile Objects (e.g. panel paintings, easel paintings)
   b. Built Environment (e.g. complexes, infrastructure, residential areas, single built works)
   c. Structural Parts of Material Objects (e.g. pedestals)
   d. Physical Features (e.g. mural paintings, rock paintings).
2. *Facet:* Investigation Methods
   Hierarchies:
   a. Material Analysis Methods (e.g. elemental analysis methods, qualitative analysis methods, spectroscopic methods)
   b. Examination Methods (e.g. laser interference methods, multispectral imaging)
   c. Non-invasive Methods (e.g. Holographic Interferometry, Raman Spectroscopy)
   d. Micro-invasive Methods [e.g. Laser-Induced Breakdown Spectroscopy (LIBS)].
3. *Facet:* Identifiable Features
   Hierarchies:
   a. Construction Features (e.g. paint layer, ground, support)
   b. Deterioration phenomena (e.g. crack, detachment, cavity, bulge)
   c. Evidential Features (e.g. fingerprint or handprint, imprint of a previous support)
   d. Conservation-Restoration Features (e.g. inpaintings, remains of consolidation material).
4. *Facet*: Data
   Hierarchies:
   Documentation data (e.g. spectral images, interferograms).

The thesaurus facets allow the coherent and self-explanatory organization of terms. For instance, the hierarchies of '*Objects*' Facet (Mobile Objects, Built Environment, Structural Parts of Material Objects and Physical Features) cover the whole range of cultural heritage objects and components. Accordingly, an example of the use of the thesaurus is presented on Figs. 5 and 6. Figure 5 illustrates the card of the term 'overpaint' (including Scope Note, Hierarchy, Broader Term, Related Terms and sources), as well as, Fig. 6 presents the tree representation of the 'Construction Features' hierarchy from the Thesaurus Management System 'THeMaS', in a way that acts complementary.

Polygnosis thesaurus has a clear and easily understandable structure, and thus, it provides a novel approach and path to knowledge through its semantic connections and linking with examples of real examination procedures. The combination of terms' identity cards which indicate all its relationships, meaning and intent, along with the hierarchical views via tree representations, act complementary for the comprehension of the thesaurus. For instance, the term 'overpaint'—which one can easily search and find a description in several glossaries and

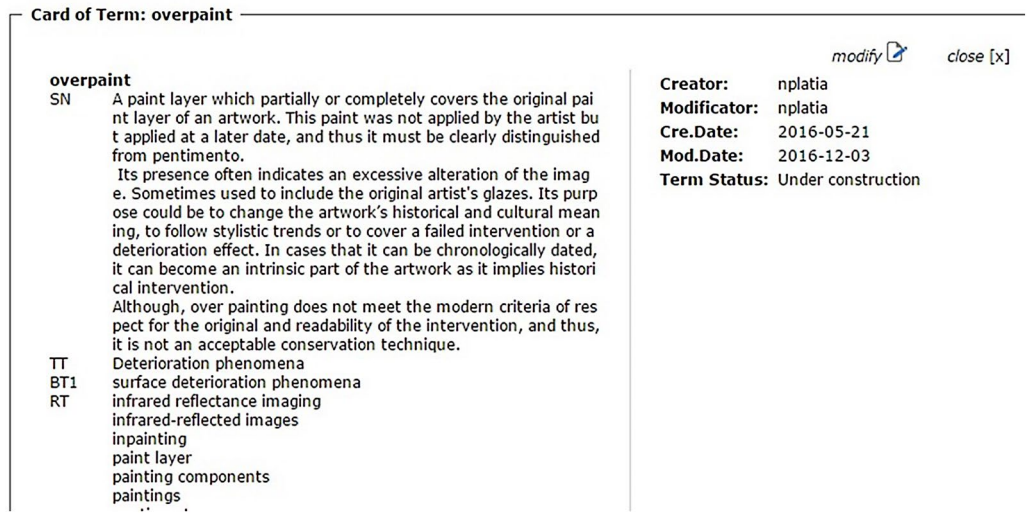

Fig. 5 The identity card of the 'overpaint' term, presenting its scope note, information about its hierarchy, broader term (BT), related terms (RT) and sources

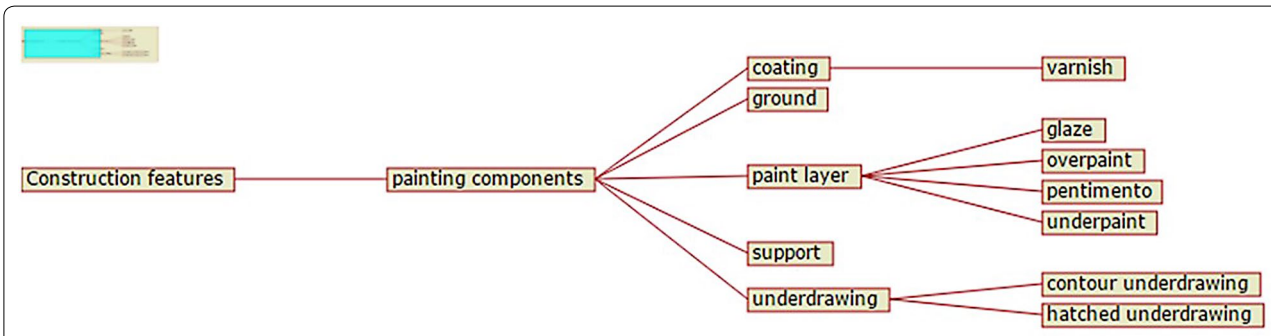

Fig. 6 Graphical representation of the top-term of the 'Construction features' hierarchy from Thesaurus Management System (TMS) 'THeMaS'

thesauri- may produce new knowledge in 'Polygnosis' via the system's semantic connections. The graphical representations of the concepts' relations support the understanding of a concept, and thus, highlight the thesaurus's self-explanatory structure that a glossary cannot have. Figure 7 shows an example of such a graphical representation of the term ''overpaint".

Due to the fact that different scientific communities have different perceptions of the same terms and concepts, it was crucial to avoid the logical errors and idiosyncratic decisions when constructing the thesaurus. Therefore, the demand for objectivity in designing and establishing the top-concepts of the thesaurus leads us to look for formal rules such as the CIDOC CRM Model.

A projection of Polygnosis thesaurus's conceptual model on the CIDOC CRM Model reveals interesting correspondences and limitations. To the degree possible, concepts are taken from the CIDOC Conceptual Reference Model (ISO 21127) entities:

- 'Material Objects' facet maps to E70 Thing,
- 'Investigation Methods' facet maps to E29 Design or Procedure,
- 'Identifiable Features' facet maps to E26 Physical Feature,
- 'Data' facet maps to E73 Information Object.

However, there is no "right" approach for planning contextualization strategies of knowledge systems, since based on the scope of each case and the system's designer, different perspectives will be established. Along these lines, this system imposes its own view and perspective on structuring the concepts regarding the experiments and methodologies described. We regard a link pointing to a relationship or relation as sufficient to imply the domain and range class or domain and range value, as symbolized in Fig. 8.

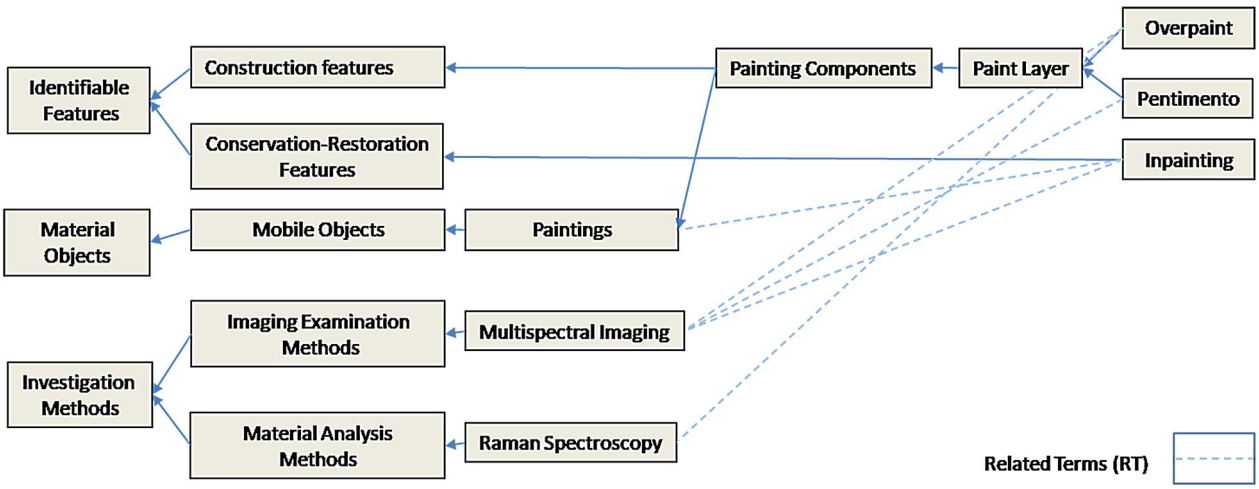

Fig. 7 The self-explanatory structure of the thesaurus supports in understanding the concept of a term. For example, 'overpaint' is a paint (layer) on a painting, but it is also related—although different—to pentimento and inpainting. Moreover, 'overpaint' is related to (examined by) Multispectral Imaging, and (analysed by) Raman spectroscopy

Figure 8 indicates the transition from the categorical to the factual knowledge in the 'Polygnosis' platform, as well as, the coverage of the information range of the domain by the facets of the thesaurus. The user knows in advance that by using investigation methods, one can identify physical features on material objects, which can be declared through the data resulted from the whole examination procedure. Through 'Polygnosis' semantic network and the display of actual examination procedures, the user now knows that overpaint on mural paintings can be detected by Multispectral Imaging and documented through a series of spectrum graphs.

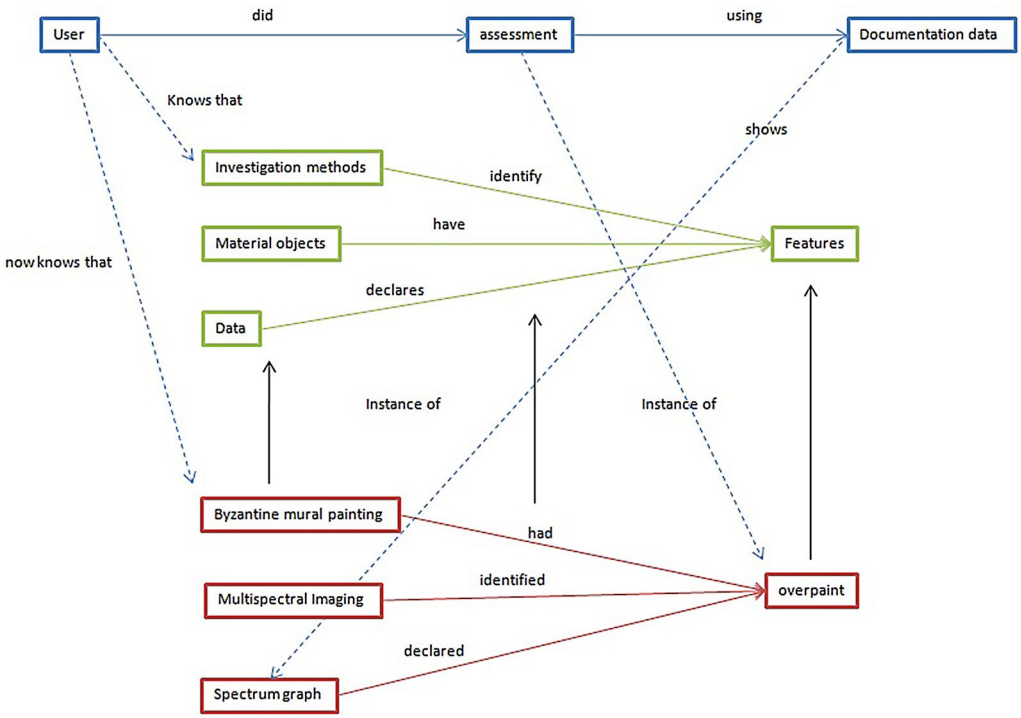

Fig. 8 Model for a Case Knowledge Acquisition by Investigation

The interpretation of the picture in combination with background knowledge allows for creating knowledge. This example is quite characteristic for a wide class of scientific knowledge acquisition. Knowledge is produced in an assessment activity, using some investigation method that provides evidence. A categorical theory is used to interpret the actual process that caused the evidence. In 'Polygnosis' platform, we aim to address a quite similar methodology and concepts on the application of investigation methods for the study of material cultural heritage objects.

'Polygnosis' intends to make the amount and distribution of content completely visible to the user. This is critical for giving the user an understanding of the coverage and completeness of the content provided, and the security that all relevant contents for his/her problem are at one comprehensible place. Fundamental role to that has played the indexing of general knowledge as a specific relationship of individual concepts, the assumed instantiation relationship of actual assessments to the general knowledge implemented by the subject index, and the inferences, together with a careful construction of the hierarchical relationships of the thesaurus.

In Fig. 9, an indicative content structure of the platform accompanied by its content pages is displayed. Either path the user will choose to take, will lead him to the same information pages and provide him with the same amount of knowledge. For example, as depicted here, two case-studies (Examples 1, 2) of different investigation methods (Method Applications 1, 2) can study the same material object (Object 1) and have various data (Digital Objects 1, 2, 3) as results. Accordingly, all former pages are linked with the glossary terms' pages, through which the passage of 'Polygnosis' system to TMS 'Themas' is enabled for better understanding and exploring the thesaurus.

Evaluation of the 'Polygnosis' system

There is no question that in order for a knowledge platform as 'Polygnosis' to be evaluated, it takes a lot of time of being used by the field's experts. Nonetheless, there have been already some initial efforts to evaluate the system with the expectation to give a preliminary view of how 'Polygnosis' is perceived. This evaluation also aimed towards making decisions for further platform development. Its objectives were as follows:

- to identify the strongest and the weakest elements of the platform from the perspective of use by learners,
- to identify typical scenarios of platform usage in terms of time and place,

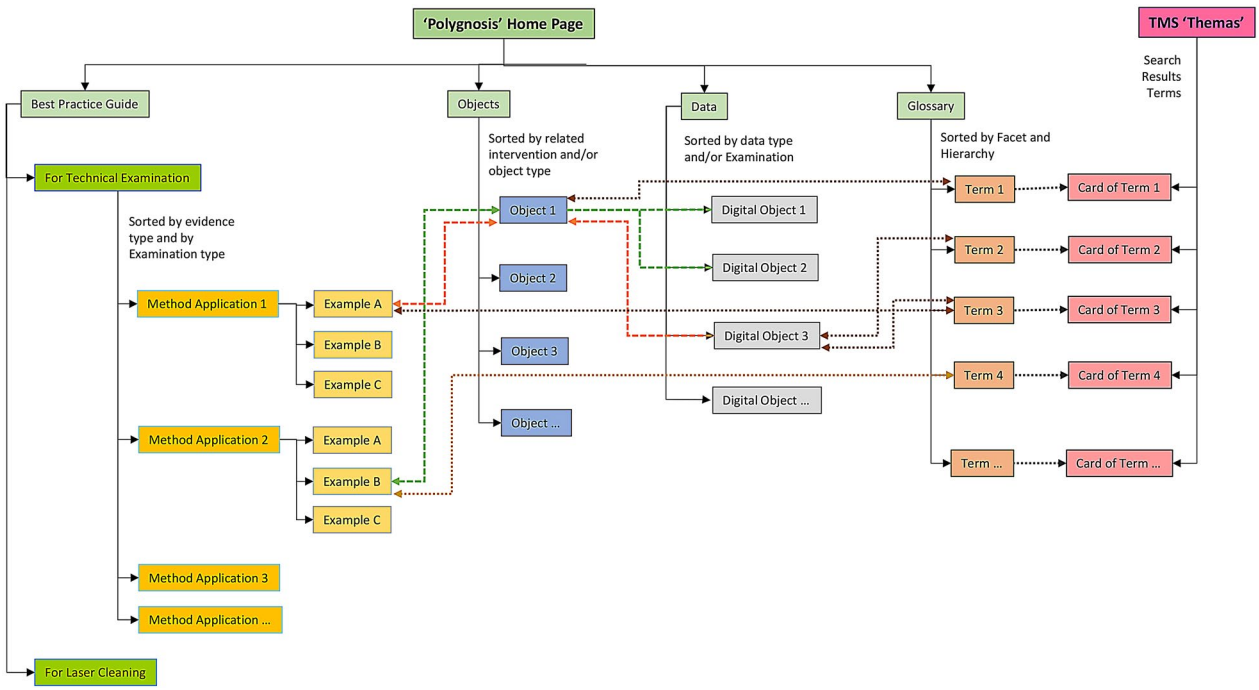

Fig. 9 Above is presented a detailed content structure of the platform along with its content pages. This has been an attempt to describe a possible user's scenario of 'Polygnosis'. Any path that the user will decide to follow on the introductory page will enable him to be navigated in every related information page

- to collect information and know-how on the subjects corresponding to the most useful platform elements,
- to judge the value of the platform and to prepare the guidelines and suggestions for further platform development,
- to collect information about the practical integration of web-based information systems into common issues and challenges of newcomers, students, professionals and researchers in the field of conservation science.

Towards this end, the first systems' evaluation was conducted during the workshop '' Laser SYNTHESIS and POLYGNOSIS; The POLITEIA Documentation System and Knowledge Platform" that took place at FORTH in November 2015. The workshop's participants were young researchers, scholars, graduate students and professionals with a background in optics, material, computer and conservation science disciplines. The course lasted for 5 days including 2 days of hands-on sessions and 3 days of lectures related to 'Polygnosis', TMS 'Themas' and 'Synthesis' systems. The participants had also the opportunity to curate data for inclusion in the systems from analysis and conservation reports. At the end, open-ended questions were being asked to the participants through questionnaires and an extended discussion took place regarding the systems' aim, functionality and use.

After analyzing participants' feedback, the evaluation emphasized the importance of semantic presentation forms and design as the key issue for a good learning platform with the relatively smaller importance of material quality and amount at this initial stage. Furthermore, the need for easier data curating and uploading in the central data base ('Synthesis'), as well as, a more straightforward and clear structure for its entities was highlighted. After all, the whole idea of such a system for creating a common language in this field was appreciated.

Thereafter at a more mature state, another evaluation workshop was conducted in the Department of Conservation of Antiquities and Works of Arts in TEI of Athens on May 2017 and was accumulated by 19 participants that were conservation students, graduates and professionals. The basic principles governing the knowledge platform and the thesaurus along with the project's aim and results, were discussed. Moreover, both the 'Polygnosis' platform and the 'Themas' TMS were presented and explained in one-to-one person, and everyone engaged at least 2 h in hands-on use of the systems. Moreover, the evaluation methods for the given conditions were questionnaires, interviews, and observations.

To begin with, the first chapter of the given questionnaires is focused on the evaluation of the content and the presentational aspects of the platform. The educational content assessment includes material completeness, exactness, relevance, clarity, scientific value and length of material, acknowledgments/references, and illustrative richness. The presentation aspects include screen design quality, easy access to learning objects, proper structural organization, presentation simplicity, proper headlines and titles, quality of illustrations. The criteria are evaluated by five quality ratings: poor, marginal, acceptable, good and excellent. Quantitative summary of some of the given questionnaires' results is presented in Fig. 10.

The evaluation indicated a good level of presentation and navigation simplicity. Among the advantages reported were its structure and the coverage of a broad area of knowledge related to laser technologies for the study of heritage objects, while the most popular elements of the content in use included: the glossary, the objects page and the best practice guide. The drawbacks reported were software instabilities and interface inconsistencies and the need for a more complete and detailed presentation of materials and data.

The quantitative summary of the results in Fig. 11 indicated the positive impact of 'Polygnosis' in a personalized learning environment. The system's semantic structure has assisted participants in comprehending knowledge in a centralized way. Nonetheless, some participants pointed out that multimedia interactivity is needed for advancing the learning experience.

One of the reported difficulties referred to the understanding of the interface of the TMS 'Themas' due to the excess of information. Also, 90% of them complied that the thesaurus's concepts tree representations presented in TMS 'Themas', helped them to better understand the platform's structure and content.

In this respect, it is evident that the overall contribution of 'Polygnosis' system in the field was appreciated. The majority of participants found its content relevant to their background and agreed that they would be able to use knowledge derived from the platform in their professional and educational activities. On the question related

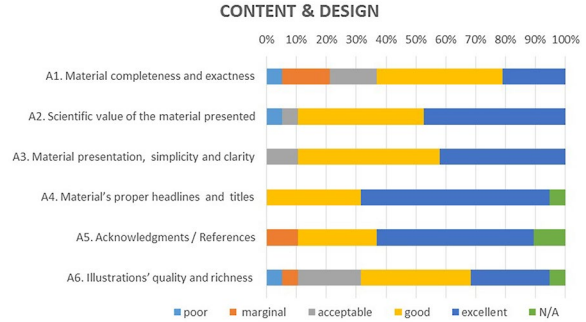

Fig. 10 Quantitative summary of the given questionnaires' results regarding the platform's content and design

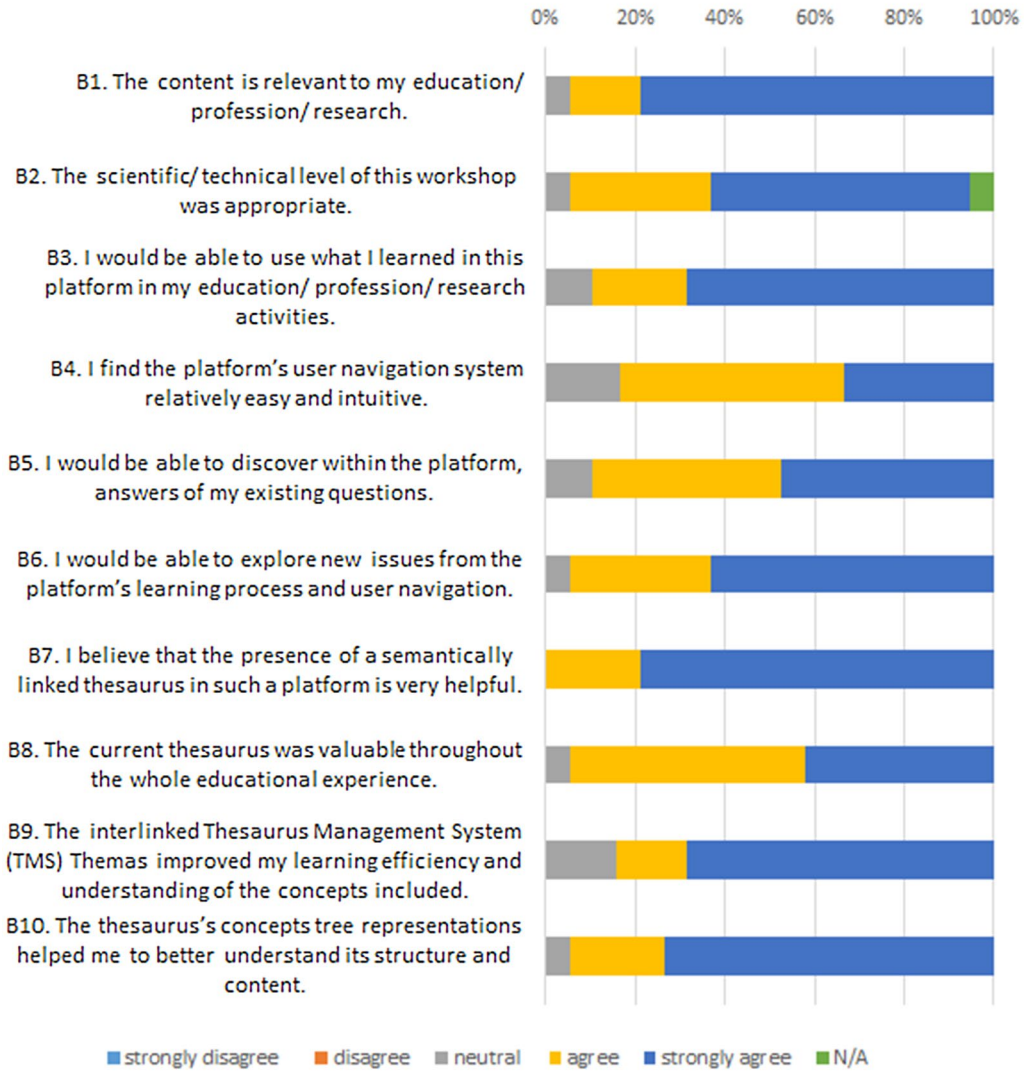

Fig. 11 Quantitative summary of the questionnaires' results for assessing individual learning aspects

to easiness and intuitiveness of navigation, 85% of the participants claimed that the platform is easy to navigate. Few of them suggested the inclusion of a tutorial (such as a tool 'Help' functionality) for facilitating their navigation.

Furthermore, the evaluation indicated that another strength of the platform is the way of integrating its diversified knowledge by using structured meta-information and formal knowledge description. Specifically, this functionality is served by the thesaurus system that defines the top-level-concepts (facets and hierarchies) -under which the specific terms are subsumed- based on a formal ontology, the CIDOC Conceptual Reference Model ("CRM"). In this sense, the definitions of the facets and hierarchies are not closely dependent on the specific terms of a particular field and so they can be valid regardless of the subject conducting the classifications or the scientific domain to which they refer. Moreover, it was agreed that the current thesaurus was valuable throughout their whole educational experience since its presence was very helpful. After interviewing participants and analyzing their feedback, a clear distinction has been achieved between concepts (meanings) included within the platform and their lexicalizations (terms).

The users appreciated the structured and logically arranged information that was available for easy access.

A major part of the students declared the high value of 'Polygnosis' in facilitating the exploration of new issues, complementary to existing questions, from the platform's learning process and user navigation. The majority of the unfavorable opinions concerned content quality, which directly related to weaknesses of the content production and review process. Thus, some students recommended introducing a crowdsourcing model for enriching the platform's content by a wider community of professionals and experts.

In terms of time/situation use, 'Polygnosis' evaluation indicated a high potential for individual learning as well as a potential for use during other learning activities (e.g. lectures and seminars in the form of reference material). Depending on context, the material can be used as defined by multiple educational scenarios (e.g. lecture, home-study, search for illustrations etc.). The richness of the presentation contexts serves to simplify learning platform usage in multiple situations. Since many of the critical comments about platform user experience concerned content quality, there was an opportunity to explain why it is often difficult to develop high-quality educational material.

The evaluation also considered aspects of functionality from the user point of view. The general conclusion for practical use of multimedia tools in education was that high usability and simplicity of information access should be the focus point of any chosen approach in this direction. The 'Polygnosis' evaluation suggested that after thorough content review, the platform can successfully deliver rich learning content. To conclude, thesaurus design and content so far cover the main conceptualizations of the domain, since it consists of a sufficient information source for understanding the domain without the need of prior knowledge. However, there are many more facets and terms to be included in the thesaurus, such as a 'Materials' facet.

Conclusions

The 'Polygnosis' platform provides reliable access to highly specialized knowledge. It has the ability to constantly update and merge new knowledge, since its contents are dynamically enriched and semantically organized. It creates a comprehensive environment with respect to a scientific issue. The system enables the comprehension and assessment of knowledge in a centralized, yet personal, way.

Moreover, the thesaurus' faceted classification brings to light hidden connections between the terms and relates concepts. Thus, each term acts as an entry node for viewing and understanding a large part of the knowledge in this area. In this manner, the user can easily explore the learning material following his/her interests, professional needs and pace. Moreover, the faceted classification and hierarchies assist the navigation and querying of categorical relationships through generalization/specialization of concepts. Therefore, the users' research inquiries can be analyzed and clarified through access to adequate generalizations.

'Polygnosis' thesaurus is a never-ending, ongoing project and its development depends on its evaluation and on the involvement of its users. Thesaurus terms can be dynamically enriched and each new term can be classified under the appropriate facet. The method of faceted classification that was selected for the design of the thesaurus allows users to add new terms and hierarchies in a way that will not force us to modify the structure of the thesaurus. Furthermore, this method permits the addition of new facets, as well as new hierarchies in existing facets. Up to now, 4 Facets, 13 Hierarchies and 140 terms have been created and archived in both 'Polygnosis' and TMS 'THeMaS' systems.

The networked knowledge organization via hierarchical relationships answer questions and makes paths which leads to new relationships, interpretations and results. Therefore, 'Polygnosis' thesaurus architecture and semantic relationships lead to a knowledge representation approach which has a major educational role. Graphic views act as a great educational tool since they reveal the higher and narrowed terms and give an easy understanding of the thesaurus structure by guide terms criteria. The thesaurus also offers a self-explanatory structure which is language independent.

In conclusion, the system focuses on diagnostic knowledge—specifically on cases where investigation methods are applied to detect features on an object. However, we intend to upgrade its structure and enrich its contents with case-studies related to conservation methodologies that include applications of laser cleaning. Finally, after analyzing the evaluation results, the main future development aspects concern:

- Optimizing of content production, review, and management process with respect to cost and educational efficiency.
- Expanding 'Polygnosis' thesaurus content by adding more facets, as well as, terms in existing facets.
- Advancing user's learning experience with the inclusion of multimedia interactivity and the upgrading of illustrations quality and richness.
- Involving more partners in content production and directing 'Polygnosis' to become a portal for international e-learning resource exchange center in the conservation science field. Towards this end, it is necessary to develop mechanisms that would allow

the exchange of users' assessments, opinions and concepts through an experts' forum.

Authors' contributions
All authors collaborated on the development of the 'Polygnosis' Educational Web Platform. NP undertook the development of the thesaurus as part of her undergraduate thesis at the Department of Conservation of Antiquities and Works of Art, Technological Educational Institute (T.E.I.) of Athens, under the supervision of MCh, and wrote the present paper. KD, LH and ChB were responsible for building the educational platform on the basis of the team's previous experience on related projects. KM, KH and PP provided information on laser analysis, diagnosis and conservation concepts, terminology and case-application data. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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Not applicable.

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