Integrating Non Destructive Testing Techniques data for cultural heritage monuments to CIDOC Conceptual Reference Model

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ABSTRACT

The cultural heritage artifacts Conservation Documentation is not universally agreed upon nor has it always been considered an important aspect of the conservation profession. Conservation records present major drawbacks, which are the fragmentary and incomplete description of the contained information and related processes. On the other hand, art works and monuments of great historical value are subject to examination only through Non-Destructive Testing and Evaluation (NDT&E) techniques. In this context, the present paper presents the DOC-CULTURE project approach to standardize the documentation of the conservation and the NDT&E methods and their output data through CIDOC-CRM extension.

INTRODUCTION

The present paper makes public part of the research work done at the DOC-CULTURE project [Development of an integrated information environment for assessment and documentation of conservation interventions to cultural works/objects with Non Destructive Testing and Evaluation (NDT&E) techniques, www.ndt-lab.gr/docculture], co-financed by the European Union NSRF THALES program, regarding the creation of an information system for accommodating metadata relevant to conservation interventions and digital documentation of non-destructive testing techniques (NDT&E), applied on cultural objects. The final outcome of the project is to develop an Integrated Information Environment (IIE), through the interdisciplinary collaboration of different research fields such as conservation activities, including NDT&E, computer and information science and documentation methods. The aim is to cover the following objectives:

1. NDT&E application methodologies for both decay detection and conservation interventions (both preventative or restorative conservation) assessment standardization.
2. NDT&E output data documentation through already established metadata/conceptual frameworks.
3. Implementation of the Integrated Information Environment for the documentation of NDT&E processes with actual cultural works/objects.

In order to accomplice the above mentioned objectives scientists and experts from three different departments are cooperating (Department of Chemical Engineering of the National Technological University of Athens, Department of Library Science and Information Systems of the Technological Educational Institute of Athens, and the Department of Computing Engineers and Informatics of the University of Patras), while they test their findings using as test bed the National Archaeological Museum of Greece.

Cultural heritage monuments decay detection and conservation innervations assessment new requirements

Conservation (preventive or restorative), before or after decay detection process, is considered as the absolute prerequisite for maintaining cultural artifacts of great significance in their initial/original form, as long as the laws of nature allow it [1]. Without or with incomplete or low quality conservation activities, cultural artifacts/objects are doomed to decay and finally to stop existing, depriving art admirers to enjoy and understand the creator's intentions. Apart from the case that no conservation effort is put, which might occur due to lack of funds, the incomplete or low quality case, is mainly happens because of inconsistent or total absence of information concerning the artifact. The long intervals between restoration/preservation activities (sometimes many years), usually from different professions and the total absent of any kind of common standardization methods in keeping data records (usually conservation intervention data are unstructured, handwritten, notes), intensify the fact that artifacts information are incomplete and sometimes inconsistent. Also, today a large number of modern conservation techniques and examination methods (destructive and non destructive) are used, producing a huge amount of data, in different formats, such as text, numerical sets and visual objects (images, thermographs, x-ray images, microscopy images etc.), in specific time periods or intervals (before or after conservation activities or for restoration assessment reasons or for decay detection reasons). The produced examination methods data are very useful during conservation procedures, as they provide the knowledge in order for conservators to choose the most appropriate restoration techniques, materials etc. The problem arises when the examination data (and other conservation data), from past interventions do not exist or they exist in a form that cannot be used directly and immediately from conservators and conservation scientists. The main reasons for this situation is (a) the absence of a globally accepted conservation data and metadata scheme that covers all possible information deriving from such activities and (b) consequently the low level of interoperability between different Information Systems used from culture heritage organizations and developed by software companies [2]. Apart from decay detection and conservation innervations assessment data (see Figure 1 *Conservation* and *Examination* sections), the object's identity or *Historical data* (including object's history and purpose, creator biography, bibliographic data etc.), object's physical *Description* and *Type* (dimensions, materials used, structure information), the environmental conditions (past and present), the *Owner* information, present and previous condition state reports, treatment reports, restoration proposals made by the conservator etc., are also pieces of information that need to be classified and organized in a standard way. All these data sources are forming what is known as Conservation Documentation [3] and are depicted in Figure 1 in a unified way.

It is also clear, that a common and widely accepted framework for creating, managing, storing, accessing and preserving the conservation data (and the other parts of the object's information) will enable easy information exchange between conservators, conservation scientists as well as other science disciplines experts such as material science experts, engineers, data analysts, image process experts etc. (*DOC-CULTURE research domains, see Figure 1*). Also, the high levels of interoperability during data exchange will allow the formation of a global conservation knowledge database where conservation methods, data process techniques, computer aided tools etc. created or invented by different people would be easily re-used and re-applied with minimum modifications to a variety of cultural objects.

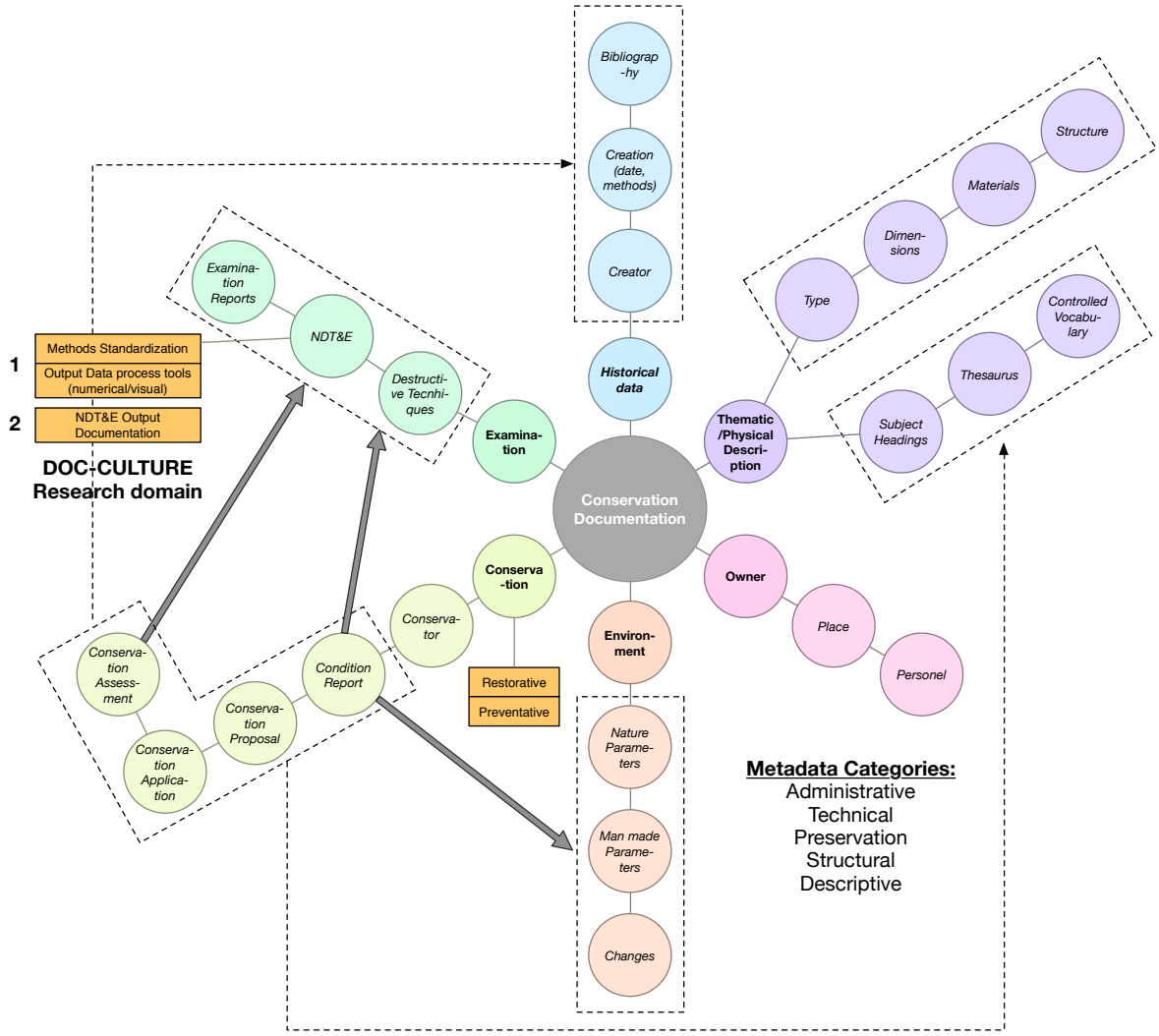


Figure 1. Cultural Object Documentation Map.

Especially, the NDT&E are suitable for art works and monuments of great cultural value, where strict regulations prohibit invasive testing during the conservation. The development of the appropriate NDT&E application procedure/methodology on specific cultural artifacts categories is affected from parameters such as object's materials, structure and purpose of the examination. The variety that exists as far as concern cultural artifacts categories and the different approaches followed by conservators have issued great divergence on how NDT&E applications (procedures and methods) are performed urging also for setting a minimum level of standardization (*DOC-CULTURE research domains, see Figure 1*). On the other hand as mentioned before, these methods provide a large amount of numerical/text data as well as visual data like images, diagrams, histograms, thermographs, microscopy images etc. Also, there is a lot of ongoing research, concerning image annotation tools, multiple layers images, 3D representation and reconstruction, virtual restoration image plug-ins etc. that produce derivative data based on the NDT&E instrumental outputs, useful during conservation/restoration works. As before, there are no relevant standardized methodologies and procedures for image analysis, annotation and numerical data processes for NDT&E, so as to provide a wide range of potential applications, in a user-friendly way, for those involved in the conservation and preservation of cultural heritage (i.e. conservators, conservation organizations or bodies, restoration centers, etc.).

The new requirements that emerge from modern conservation activities are the reason that both

conservators and information scientists combined effort is necessary towards conservation data and metadata standardization. It is globally accepted standardization effort is the first step towards their inclusion to the Research Data Management (RDM) [4] activities and their sharing and re-use [5].
Before presenting the work that has been done in the context of DOC-CULTURE and the utilization of the CIDOC-CRM (International Committee for Documentation Conceptual Reference Model) as the basic ontology scheme "*for providing definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation"* [6], an overview of the documentation standards and related work is presented.

The documentation/metadata standards – Related work

The use and moreover the extension of metadata standards with the inclusion of NDT&E and other parts of conservation information is necessary in order to fulfill the aforementioned goals. As far as concerns the DOC-CULTURE project, Table 1 presents in brief the most popular metadata standards, which contain element sets describing cultural objects and conservation aspects.

Table 1. Metadata standards for cultural object and conservation documentation

Title of the standard	Responsible	Version/Web site - Short description
CIDOC-CRM (International Committee for Documentation Conceptual Reference Model)	CIDOC CRM Special Interest Group (SIG).	The current official version is 5.0.4 (released in December 2011). http://www.cidoc-crm.org/ The CIDOC Conceptual Reference Model (CRM) provides definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation.
VRA Core - Visual Resources Association	Library of Congress and Visual Resources Association	Version 4.0 was released in 4/9/07. http://www.loc.gov/standards/vracore/ The VRA Core is a data standard for the description of works of visual culture as well as the images that document them.
Dublin Core Metadata Element Set	Dublin Core Metadata Initiative (DCMI)	Dublin Core Metadata element set can be found in ISO 15836:2009. http://dublincore.org Dublin Core presents a simple and efficient structure, which creates a user-friendly framework for both museum curators and conservators. Its widespread use, offered a safe choice for an element set which is regularly updated.
CDWA - Categories for the Description of Works of Art (see http://www.getty.edu/research/publications/electronic_publications/cdwa/index.html)	Art Information Task Force (AITF)	Latest update: March 25, 2014. CDWA describes the content of art databases by articulating a conceptual framework for describing and accessing information about works of art, architecture, other material culture, groups and collections of works, and related images. CDWA includes around 540 categories/subcategories, discussions, basic guidelines for cataloguing, and examples.

In conjunction with the modern conservation new requirements many research teams have proposed similar approaches, but none has concentrated in exposing NDT&E data through their inclusion to standards. In this context, the European Research Open System (EROS) developed an information system, aiming to store museum objects and conservation processes metadata [7]. The EROS information system was based on the early versions of CIDOC CRM and Dublin Core.
On the other hand, the Conservation Space (http://conservationspace.org) aims to develop an open source software application for handling conservation metadata through digital documentation, as stated in their website: "*The conservation community has long recognized that a digital approach to*

managing its documentation would improve continuity in procedures, increase access, expand research opportunities, and better ensure the preservation of its documents." The project is funded by the Andrew W. Mellon Foundation Programs and is undertaken by the Office of Digital Assets and Infrastructure (ODAI) at Yale University. The Conservation Space project is promoting openness by sharing data through web.
Following, the TIVal project [8] aims at supporting the integration of different, distinct and heterogeneous multimedia contents into a comprehensive and accessible portal, in order to present information supporting a critical analysis of a piece of cultural heritage. To support their goals they adopt the domain ontology derived from CIDOC CRM in organizing their contents.
The importance of CIDOC CRM is also recognized by many others either as a metadata mapping guide or as the intermediate stage for crosswalks between other standards or by providing extensions to the core model. Specifically, in [9] NDT&E methods are used for to analyze Byzantine Iconography, while the results as mapped to CIDOC-CRM standard. In [10], [11], [12], [13] and [14] various metadata mappings and crosswalks are proposed between standards such us Dublin Core, Text Encoding Initiative (TEI), Resource Description Framework (RDF), while CIDOC-CRM remains the junction point. In [15] the art-E-fact ontology extension was developed, following the general trend where many communities (e.g. eLearning, telemedicine, cultural heritage) adopt the same methodology, in order to standardize their contents and data models facilitating the integration and exchange of content coming from heterogeneous data sources.

CIDOC-CRM EXTENSION WITH NDT&E OUTPUT

According to AIC (American Institute for Conservation of Historic and Artistic Works, http://www.conservation-us.org) "*The conservation professional has an obligation to produce and maintain accurate, complete, and permanent records of examination, sampling, scientific investigation, and treatment. When appropriate, the records should be both written and pictorial. The kind and extent of documentation may vary according to the circumstances, the nature of the object, or whether an individual object or a collection is to be documented*". Following this directive the next five steps are obligatory, namely (i) Documentation, (ii) Documentation of Examination, (iii) Treatment Plan, (iv) Documentation of Treatment and (v) Preservation of Documentation.
Apart from the artifact documentation that refers to the so-called descriptive metadata (information used for identification and tracking) that can be drawn from various metadata standards the question here was how to include the documentation pertaining to the examination and testing, the planning of the conservation treatment and the treatment itself. This documentation consists of data that may be conveniently presented in a structured and repeatable manner, such as dates, names, materials, equipment etc., but also of natively unstructured data included mainly in reports authored by the conservator(s) and the other technicians and scientists involved in the examination and testing. Since the main target of the present project is to accommodate information produced by NDT&E, the answer to this question is crucial for the advancement of the project. After much discussion, it was proposed that three new second level entities should be created. They would be directly linked to the first level entity *Artifact* (hence the second level). These three entities are: ***Conservation***, ***Measurement*** and ***Digital Documentation***. The relations between them and the minimum set of metadata for each one are depicted in Figure 2.

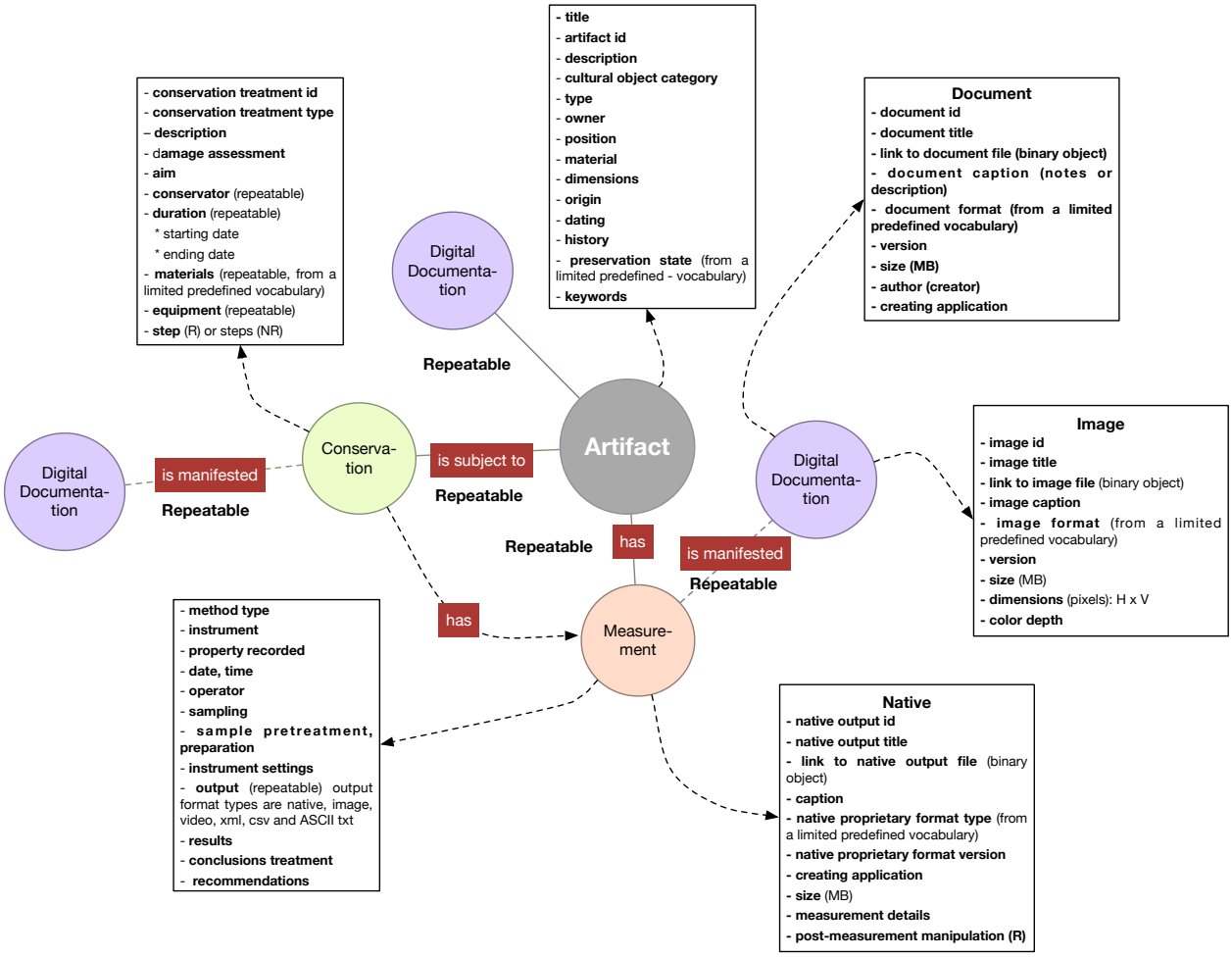


Figure 2. Artifacts and second level entities model – Minimum (or initial) set of metadata

The relations between these four entities of metadata are analyzed as follows:

- **one artifact** could relate to many conservation "*events*", measurements and digital documentation instances (one to many),
- **one conservation** could relate to many measurements and digital documentation instances (one to many),
- **one measurement** could relate to many digital documentation instances (one to many),

and also,

- **one conservation** could be applied to many types of artifacts (one to many).

Note that conservation is defined as an "event" that includes data such as time, duration, type of event, description etc. Measurements also is defined as an "event" that encompasses data as time, main body of responsibility, type of event, description etc. The values of the entities presented in our model are considered to act as "properties". Finally, digital documentation is an entity to all other three primary entities depicting any type of digital representation (document, image, video, data set, native measurement file, post process data results etc.).

It should be stressed here that the concept of conservation, in this extend and to a level that meets the new requirements analysed before, is not included in the CIDOC CRM.

The upcoming section presents the parts of the CIDOC-CRM chosen for modification and extension as well as an initial attempt for mapping the proposed model.

DOC-CULTURE entities mapped to CIDOC-CRM

After an in depth examination of the schema' s structure the concept of "curation" was identified as an activity that holds the same properties with conservation. It was decided to treat 'conservation as an event. Subclass of "event" according to the treatment of "curation" within CIDOC-CRM is the entity of "activity". We propose then to incorporate the entity of "conservation" within "activity" and as a subclass of "event" at a new element this being E91.
Furthermore, one more addition is proposed, as E92: Frequency which is a subclass of E4: Period and has the Property P8 "took place on or within" and connects to the E19 Physical object (see Figure 3 below).

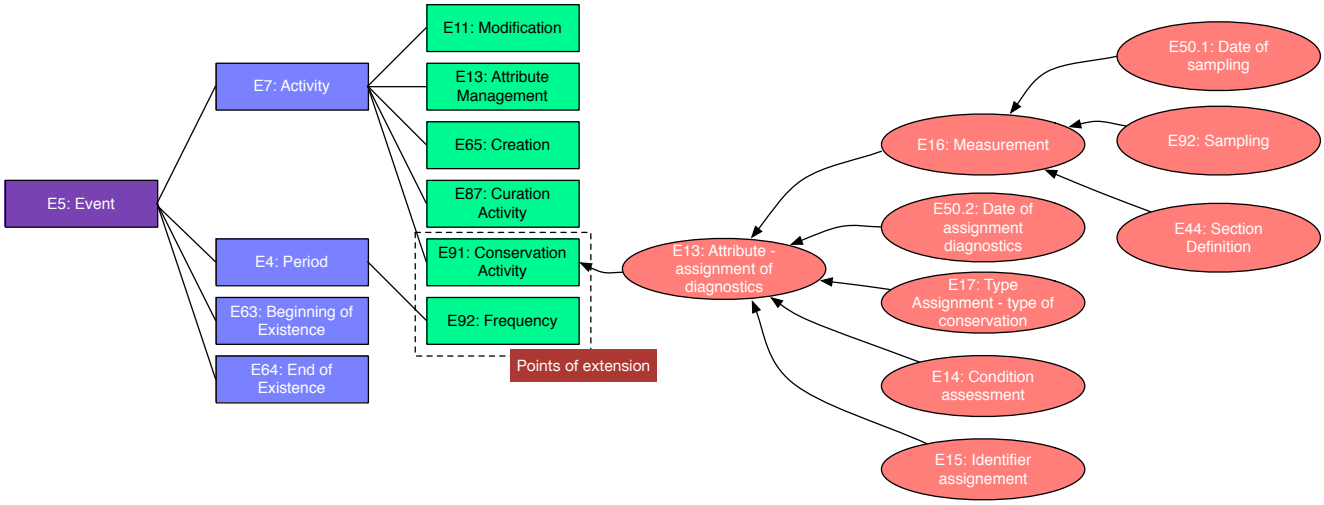


Figure 3. Points of extension in CIDOC-CRM

Following Figure 2 & 3 presented concepts the Table 2 lists the most important database fields elements and types of terms for each entity. Note that wherever *ddlist* is used implies that user should choose a value from a drop-down list, which constitutes a controlled vocabulary. In the current state of DOC-CULTURE projects *ddlists* are being defined.

Table 2. Elements and types of terms for each entity

Artifact	Conservation	Measurement	Digital Documentation
Identifier/ Object identification Number	Event /Conservation	Measurements (*ddlist*)	Electronic re-production manifestation
Date	Identifier/ Priority (*ddlist*)	Type (*ddlist*)	Format (*ddlist*)
Title	Event/ Previous conservation interventions	Operator (creator) (*ddlist*)	Date (captured)
Alternative title	Date modified (conservation interventions)	*is affiliated with/ Institution* (*ddlist*)	Date created
Creator	Description of Preservation state (*ddlist*)	Media type (instrument) (*ddlist*)	Title/caption
is referenced by	Policy (preservation) (*ddlist*)	Media type or extent (instrument settings)	Extent / file size
Temporal coverage	Date of conservation	Samples (agent class)	Identifier / fixity/ file format (*ddlist*)
Spatial coverage	Duration (of conservation)	Sample location (Location)	Description

Date created	Type of conservation (*ddlist*)	Sample period (location period or jurisdiction)	Subject (*ddlist*)
Subject (*ddlist*)	Alternative name of conservation type (*ddlist*)	Sample format (file format) (*ddlist*)	Creator
Description of item	Description of technique		*is affiliated with/ Institution* (*ddlist*)
Description of item. Notes	Frequency		Extent
Description of item. Metadata history	Conservator (*ddlist*)		*is version of*
Location	*is affiliated with/ Institution*		
Relation	Bibliographic citation (conservation)		
has part of	Software (*ddlist*)		
is part of	Physical object (conservation equipment) (*ddlist*)		
Rights (*ddlist*)	Alternative name of physical object (equipment) (*ddlist*)		
Rights holder	Production statement (equipment) (*ddlist*)		
License	has location of item (equipment) (*ddlist*)		
Provenance/ origin	Physical Description (*ddlist*)		
Source	Applied material (*ddlist*)		
Type/ cultural object category (*ddlist*)	Unit of measurement (*ddlist*)		
Extent/ dimensions			
Physical medium			

Following the above-presented methodology the upcoming paragraph presents an example of how the application of two NDT&E examination techniques in Artifact "5583" and the produced data are structured with the proposed model.

Example – Artifact "5583"

The cultural object chosen is a part of a wall painting depicting eight life-size women in ceremonial procession possibly towards a goddess, found in acropolis of Tiryns West slope rubbish deposit, at Argolid, Peloponnese (Artifact "5583"). As far as concern conservation only a few attributes apply as no actual conservation event has been initiated (still in phase of examination). Figure 4 depicts the entities and their relation. Consequently, Table 3 contains artifacts metadata, Table 4 the conservation metadata, Table 5 the two NDT&E techniques measurements metadata (one set of data concern the X-Ray Fluorescence – XRF technique and the other the VIS-NIR Fiber Optics Diffuse Reflectance Spectroscopy – FORS technique) and finally Table 6 has the data of four digital documentation objects, which are images (artifact photograph, two post process images depicted results from the application of NDT&E techniques and a modified photograph of the artifact pointing the spots that measurements took place).

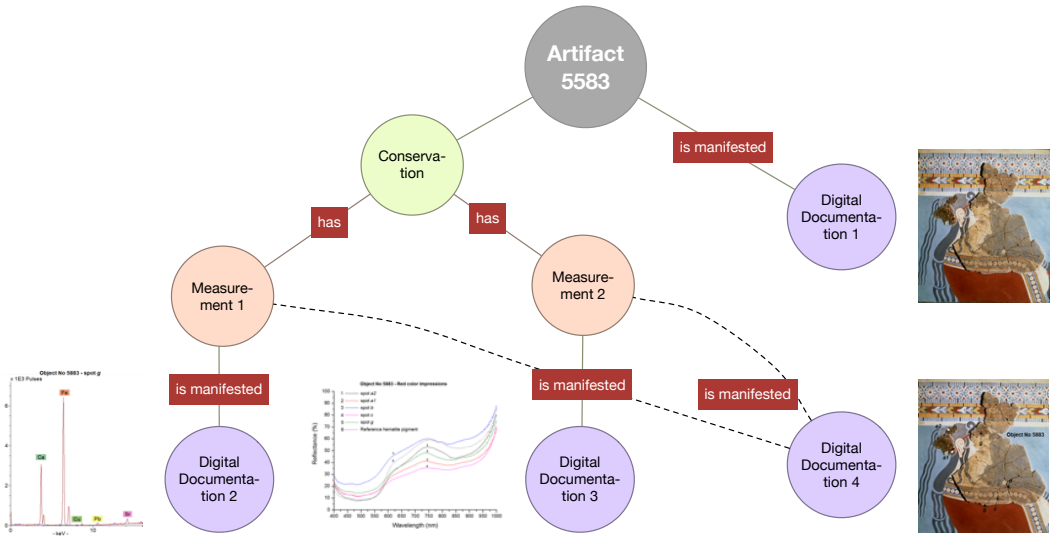


Figure 4. Instantiation of proposed model – Artifact "5583"

Table 3. Artifact 5883

Artifact	Description
Identifier/ Object identification Number	"5883"
Date	LH IIIB period (second half of 13th century BC)
Title	Ceremonial Procession of the eight life-size women, Acropolis of Tiryns West slope rubbish deposit.
Alternative title	"None"
Creator	Unknown
is referenced by	• Rodenwaldt G., Tiryns II. Die Fresken des Palastes, Athen 1912, 69 ff, nos 71-111, fig. 28, pl. IX. • S. Immerwahr, *Aegean Painting in the Bronze Age*, The Pennsylvania State University Press, University park & London 1990, 114-117, 129, 148, 165, 202, figs. 26g, 32g, 33b, pls. 55-56. • Peterson S., *Wall paintings in the Aegean Bronze Age: The Procession Frescoes, Dissertation*, Univ. of Minnesota 1981, 69-77, 206-218.
Temporal coverage	Ancient Greece
Spatial coverage	Peloponnesos (Greece) [http://lccn.loc.gov/n2012043551]
Date created	LH IIIB period (second half of 13th century BC)
Subject (*ddlist*)	Mural painting and decoration [http://lccn.loc.gov/sh85088531]
Description of item	Part of a wall painting depicting eight life-size women in ceremonial procession possibly towards a goddess. The part preserves, on a blue background, the figure of a woman in profile facing right. She wears an open-chest red bodice with embroidered white rosettes on the yellow-blue border. Her hair fall on her chest and back in rich locks, which are held by a red ribbon with white dots, possibly beads. The interior of the eye is painted red and a rather shy smile gives liveliness to the figure. The scene is framed in the upper part by horizontal bands of yellow, blue, red, white and black stylized ivy leaves and rosettes.
Description of item. Notes	"None"
Description of item. Metadata history	"None"
Location	*National Archaeological Museum of Athens*
Relation	"None"
has part of	"Not applicable"
is part of	"Not applicable"
Rights (*ddlist*)	*National Archaeological Museum of Athens*
Rights holder	*National Archaeological Museum of Athens*
License	"None"

Provenance/ origin	Athens, Greece
Source	*National Archaeological Museum of Athens*
Type/ cultural object category (*ddlist*)	Fragment of wall painting
Extent/ dimensions	Preserved maximum height: 0.38 m. Preserved width: 0.33/0.40 m.

Table 4. Conservation 1

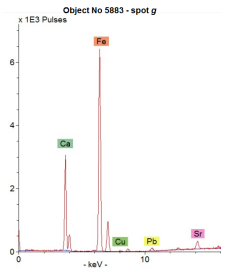
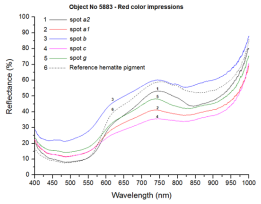
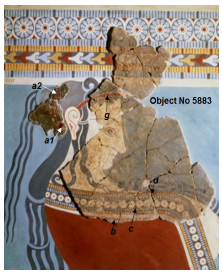
Artifact	Description
Event /Conservation	Conservation
Identifier/ Priority (*ddlist*)	"5883"
Event/ Previous conservation interventions	Cleaning of the painted surface mechanically and with acetone. Consolidation of the painted surface and the substrate with Paraloid B72 solution in acetone. Retouching with aquarelle colors to a *limited extent.*
Date modified (conservation interventions)	Not started yet
Description of Preservation state (*ddlist*)	Cleaned fragments positioned and rendered with a new mortar.

Table 5. Measurements 1 and 2

Digital Documentation	Description	Description
Measurements (*ddlist*)	X-Ray Fluorescence (XRF)	VIS-NIR Fiber Optics Diffuse Reflectance Spectroscopy (FORS)
Type (*ddlist*)	NDT&E	NDT&E
Operator (creator) (*ddlist*)	Eleni Cheilakou	Eleni Cheilakou
is affiliated with/ Institution (*ddlist*)	National Technical University of Athens	National Technical University of Athens
Media type (instrument) (*ddlist*)	Bruker-AXS Tracer III-V portable XRF	Portable Ocean Optics, USB4000-VIS-NIR Fiber Optic Reflectance Spectrometer (FORS)
Media type or extent (instrument settings)	Rhodium tube from which X-rays are emitted, and a peltier-cooled, silicon PIN diode detector, operating at 40 kV and 15 μA from an external power source for 200 live seconds using a filter composed of 1 mil titanium (Ti), and 12 mil aluminum (Al)	The instrument features a high-performance 3648-element linear CCD-array detector, installed with a multi-bandpass order-sorting filter to cover the 350-1000 nm wavelength range, and a 25 μm entrance slit for optical resolution to 1.5 nm. It is equipped with a QR400-7-VIS/NIR reflection bifurcated ……
Samples (agent class)	6	6
Sample location (Location)	Spot a2, a1, b, c, g	Spot a2, a1, b, c, g
Sample period (location period or jurisdiction)	"Not applicable"	"Not applicable"

Table 6. Digital Documentation 1, 2, 3 and 4

Digital Documentation	Description	Description	Description	Description
Identifier	1	2	3	4
Electronic re-production manifestation	Artifact 5883	Measurements 1	Measurements 2	Measurements 1,2

Format (*ddlist*)	Jpg	Jpg	Jpg	Jpg
Date (captured)	23/3/2014	23/3/2014	23/3/2014	23/3/2014
Date created	23/3/2014	23/3/2014	23/3/2014	23/3/2014
Title/caption	Img_5883	XRF spectrum Post Process Artifact 5883	FORS Process Artifact 5883	Artifact 5883 Spots of Examination
Extent / file size	1,4 MBytes	500 Kbytes	450 Kbytes	1,4 MBytes
Description	"None"	XRF spectrum of the red painted area revealing high Fe and lower Ca contents. The identification of red ochre with the form of Hematite (Fe_2O_3) and the presence of Calcite ($CaCO_3$) coming from the substrate is suggested.	FORS spectra obtained from the red color impressions verifying the presence of red ochre with form of Hematite (Fe_2O_3) as the main component of the pigment producing the red color.	Post process with Adobe Photoshop
Subject (*ddlist*)	Image	Image	Image	Image
Creator	Dimitrios Kouis	Eleni Cheilakou	Eleni Cheilakou	Dimitrios Kouis
is affiliated with/ Institution (*ddlist*)	Technological Institute of Athens	National Technical University of Athens	National Technical University of Athens	Technological Institute of Athens
Dimensions	5Mpixes	1000x1000 pixels	1000x1000 pixels	5Mpixes
Colour depth	True Colour	True Colour	True Colour	True Colour
Image binary file				

CONCLUSIONS

The importance of NDT&E methods during cultural heritage objects conservation and restoration process is well known. Through NDT&E it is feasible to perform in depth condition evaluation of the under examination artifacts without any impact to their physical form. Nowadays, all modern examination methods produce enormous sets of data like numerical, text and images (diagrams, spectrum figures, thermography images etc.). On the other hand conservation techniques and methods are perfected and produce outstanding results. The lack of standardization during restoration and examination procedures is a major drawback in the conservation world as it makes more difficult the information exchange.

The DOC-CULTURE project provides a standardization framework not only for NDT&E methods application, but also for conservation procedures in general. Based on CIDOC-CRM standard (and in the future on Dublin Core) a complete model and methodology for creating, managing, storing, accessing and preserving the conservation data was/is developed. The adoption of standards during the implementation of Information Systems for cultural objects data and metadata storing is vital

and helps the information flow between organizations, scientists, conservators etc. The example presented in this paper illustrates the potential that organized information through CIDOC-CRM presents as the structure form helps both retrieval and re-use. This is an ongoing research work and more accurate and complete results are expected in the nearby future.

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