UNDERWATER ARCHAEOLOGICAL KNOWLEDGE ANALYSIS AND REPRESENTATION IN THE VENUS PROJECT : A PRELIMINARY DRAFT

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ABSTRACT:

One of the VENUS' objectives aims to provide underwater archaeologists with software for signal, data and information processing and management. In last decades, such tools have only focused on the geometric aspects; however, in order to integrate the archaeologist's knowledge and designing tools managing both data and knowledge, an appropriate formal representation is required. Our goal is to investigate how artificial intelligence methods and tools could be used to represent archaeological information and to formalize reasoning processes used within this context. The paper presents a preliminary underwater archaeological knowledge analysis performed after the first mission of the project on the wreck site of Pianosa in october 2006. It proposes a preliminary representation of underwater archaeological observations and related knowledge by means of an ontology, based on the CIDOC-CRM model.

1 INTRODUCTION

According to the general objectives of the VENUS project, we want to provide 3D surveys stemming from the archaeologist's knowledge to virtually represent new archaeological hypothesis, in the context of the analysis of an underwater experiment.

The overall objective of underwater archaeology, like its terrestrial counterpart, is to improve our knowledge of the past. Today underwater archaeology opens, from the deep past of the sea, a direct route to these shipwrecks, complex works that testify the wealth and the diversity of exchanges and of human beings (Wilkes, 1971), (Cleator, 1973). This objective can be achieved according to different ways : planned studies which are motivated by scientific interests, preventive studies mainly for prevention, emergency studies performed before works in order to keep a track of a site.

The underwater archaeology shares common techniques and standards with ground archaeology; however it differs from its terrestrial counterpart. The major differences are the technical conditions of operation, because the investigations take place under water, the nature of discovered sites, which, in most of the cases, are shipwrecks, and the absence of stratigraphy.

The works are performed in a hostile environment and require specific tools and techniques involving diving activities more often in open sea. In (Papini, 2006b) we presented the traditional underwater archaeology methodology for studying the archaeological sites. However, the VENUS project is oriented toward both kind of sites, those reachable by divers and those reachable only with submersible vehicles i.e., Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) (Gambogi, 2006). The use of such new technologies induces a change in the methodology for archaeological studies and provides the possibility of describing and representing new aspects of archaeological information and knowledge.

The underwater archaeological knowledge analysis presented in the paper stems from the first mission of the VENUS project on the wreck site of Pianosa (Tuscany, Italy) in october 2006 (Papini, 2006a). The choice of Pianosa Island was made by crossing different sources of information. Volunteer divers reported in (Totaro et al., 1991) the presence of amphorae on the site of "la Scola", illustrated in figure 1, and declared the site to the soprintendenza of Firenze in 1991. A preliminary visit of the site by the archaeologists of SBAT in 1994 confirmed the presence of around one hundred amphorae within an area of 35×38. The island was known to be the place where Marco Vipsano Agrippa Postumo, August imperor's nephew was sent into exile. An excavation of the remains of a roman villa witnesses this fact (Mastragostino, 2001). Since 1861 until 1998 the island of Pianosa was a jail, consequently the underwater sites have been protected from robbing which constitutes an exceptional site of investiga-

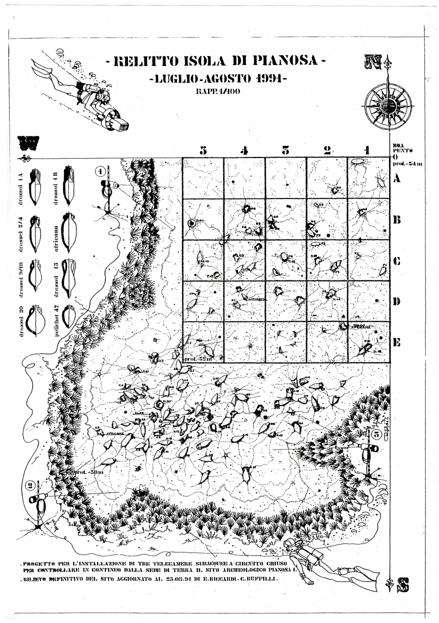

Figure 1: Map of the Pianosa by E. Riccardi, C. Ruffilli

tion for archaeologists. In the Pianosa case study we used various techniques of data acquisition both traditional and Remotely Operated Vehicle (ROV).

The paper is organized as follows. Section 2 describes the knowledge analysis provided after the Pianosa mission in october 2006. It presents the archaeological information and knowledge which is described with traditional technology, it then shows the new aspects of archaeological information and knowledge that can be described using new technologies and shows which kinds of reasoning are possible. Section 3 proposes a preliminary representTion of archaeological information stemming from the conceptual model of the CIDOC. Finally, the paper draws some perpectives using representation based on ontologies formalisation which seems promising before concluding in Section 4.

2 ARCHAEOLOGICAL KNOWLEDGE ANALYSIS.

This section presents the objects managed by the archaeologists, their nature, their relationships, the constraints they have to satisfy. In the case of Pianosa site study the artefacts are amphorae.

2.1 Archaeological knowledge provided by traditional methodology

Traditional archaeology deals with objects which are characterized by several features that help the archaeologists for recognition and identification. These features are generally divided into two types, intrinsic and extrinsic features. Intrinsic features concern the object itself while the extrinsic features concern the object in relationship with its environment or other objects. Within a traditional study, the features are directly observable. For each feature, a domain of the possible values is stated. The value may be quantitative, for example the height, or qualitative, for example the color.

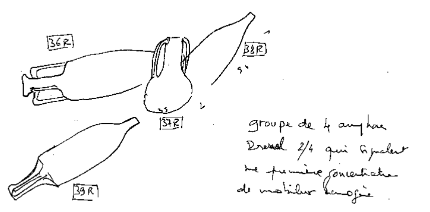

Figure 2: Homogeneous group of four amphorae of type Dressel 2/4. design L. Long

For the amphorae the intrinsic features concern the morphology, the technology used for their construction, the material they are made of, the typology, the signs they hold (stamps, decoration, etc.), the metrology (height, volume, weight, etc.), as well as other features, linked to the archaeological study, like numbers (survey number, documentation number). The extrinsic features are numerous: spatial features concern place where the object is found and its orientation, place of production, place of use, position with respect to the reference system, etc ...; temporal features concern absolute or relative datation; functional features (packing for specific goods); conservation features.

The features may be simple or complex. A simple feature gives a value, while a complex feature requires a more detailed description involving new features. Generally, the feature that describes the material used for the construction of the object, can be complex. For example, if the material is ceramics, several features describe it, i. e.: the color of the paste according to the cooking process (oxidative cooking gives a pink or a red color while

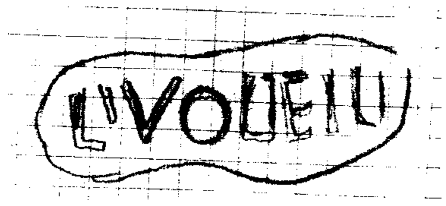

Figure 3: LUCIUS VOLTEILIUS'planta pedis stamp found on a Pascual amphora design L. Long

reducing cooking gives a grey or a black color), the temper, the surface (presence and color of the engobe), the decoration (that could be grooved, slipped, moulded or sandblasted).

The features can be independent or dependent. For example, the feature corresponding to the typology is linked to the one concerning the morphology, the one concerning the datation and the one concerning the origine. The value of a simple feature may be quantitive in case of measurement or qualitative in case of observation. The value of a feature may be not knwon and in this case it could be possible to define a default value. The features may be ordered according to a specific needs. In the identification process of the amphorae, for example, the archaeologists first look the lip, then the neck, then the general shape of the body of an amphorae.

Different kinds of relations may link the objects. Mereologic relations specify that an object may be composed of several parts, an amphora consists of a belly, a bottom, a neck, a lip and two handles.

Taxonomic relations refer to the classification of the objects according to a typology within a hierarchy. Within the classification of the amphorae. The amphorae Dressel 2/4 and Dressel 20 belong to the same typology which brings information on their morphology, their origine and their datation.

Dependence/independence relations express that dependence relations may exist between several objects.

The relative positions of the objects define spatial relations. The spatial relations are topologic relations (connected, disconnected, overlap, ...), qualitative or quantitative distance relations (close, at the distance of ...), orientation relations(at the north of, in the same direction, ...), spatial density statistics.

The relative datation of the objects describe temporal relations between amphorae.

2.2 Archaeological knowledge provided by new technologies

Within a traditional study, the features are directly observable, while using new technologies, like photogrammetry or laser, the features may be directly, indirectly observable or deduced. The directly observable features are selfcontained, they are directly observed or measured by suitable devices or processes, for example, the color, the weight, the volume. The indirect observable features require a computation based on other directly observable features and on rules of computation. For example, the diameter is directly observable using a caliper square within a traditional study while it is indirectly observable within a photogrammetric process since it requires a computation according to a mathematical formula involving several points from the object. Deduced features are features that cannot be observed nor measured, for example, in case of incompleteness, the height of an amphora is deduced when the neck is visible but not the bottom (Drap and Long, 2001).

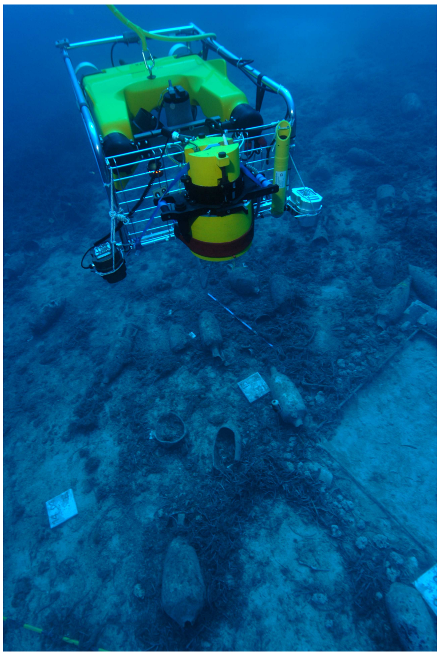

Figure 4: Data acquisition with ROV at Pianosa. Photo R. Graille

The archaeological information involves a huge amount of data. In the Pianosa wreck site study, one hundred amphorae have been identified at the end of the campaign. An amphora is characterized by numerous features, each feature belonging to a domain of several values. Moreover, these items often are uncertain, inaccurate or imprecise which increases the size of the data. Therefore, this aspect has to be carefully tackled from a computational point of view.

By nature, the archaeological information is incomplete (Borillo, 1977), (Borillo, 1978). In most situations, we face partial ignorance. Moreover, some features are not observable and require inference rules, often vague for deducing their value. Archeological knowledge is structured, since objects, specifically amphorae belong to typologies that are structured within a hierarchy. From these hierarchy partial pre-orders or total pre-orders may be defined on the features of the objects.

All these aspects have to be considered in order to define suitable archaeological knowledge representation. The structured nature of archaeological information leads to study how ontologies could be used to represent such information taking into account the uncertainty, inacuracy and incompleteness.

The VENUS project aims to produce a consistent representation of the acquired data during the survey of the underwater site. This representation would be used for the construction of a virtual model of the archaeological site. In a computational context, we are in a finite case which leads to specific integrity constraints on the features. A first constraint is that a value of a feature has to belong to a finite range of possible values called domain. A second constraint is that a feature may only have one value at the same time. Other constraints may be defined according to the specificities of the managed objects, to their use and the context of it, and to general real-world laws, for example, a third constraint is the unicity of name of the objects. A fourh one is that two distinct objects may not be at the same place, etc ...

The constraints on the features that characterize the objects, the relations between objects and the integrity constraints may conflict. Moreover, in the context of survey the same features may be measured at different times or several times by different persons which leads to inconsistency.

Constraints between relations may exist. For example, spatial and temporal relations or taxonomic and temporal relations may be linked. Moreover usual integrity constraints on the relations have to be taken into account like, for example, on exclusive relations. For example, constraints between taxonomic and temporal relations may be specified since amphorae of a given typology belong to the same period of time. The Dressel 2/4 and Dressel 20 amphorae found on the site belong to the same roman period.

In order to provide a consistent representation of the underwater archaeological knowledge a special attention has to be paid to consistency checking. Focusing on reasoning processes, archaeological knowledge consists of facts involved by observations and measures and by generic knowledge like rules and classifications. Since archaeologic information is by nature incomplete, uncertain, inaccurate and evolutive, nomonotonic reasoning has to be performed : revision when new evidences contradict previous hypothesis, update when the archaeological site evolves according to weather conditions or the evolution of the excavation process, fusion in case of different sources of information.

The formalization of non monotonic reasoning depends on the chosen formalism that represents the archaeological knowledge. Defining change operations on ontologies will be investigated next, with a special attention to computational aspects in order to provide effective and efficient algorithms.

3 ARCHAEOLOGICAL KNOWLEDGE REPRESENTATION

The underwater archaeological knowledge can be represented by data models called *'ontologies'*, following the usual definition of this word in the Semantic Web community (Berners-Lee et al., 2001). This is the way that most researchers follow today, and the previous background of the partners of VENUS is aligned with this option (e.g.: the object-oriented framework of Arpenteur software). When considering the state-of-the-art literature in the domain of cultural heritage, or of marine and coastal information, we notice a tendency to promote the systematic use of *metadata*. Moreover these metadata are proposed precisely in the ontology framework, and with an implementation in one of the W3C representation languages: RDF, OWL, ...

3.1 The CIDOC Conceptual Reference Model

The CIDOC *Conceptual Reference Model* (hereafter refered as *CRM*), which now has the international status of ISO21127, is based upon recent work developed for Semantic Web ontologies. It distinguishes **Entities**, which are classes of physical or immaterial instances, and **Properties**, which are binary relations between classes, possibly quantified by cardinalities.

The *CRM* model is more generally dedicated to the representation of any kind of archive, or heritage piece of work, in particular for museum collections. Using the *CRM* at early stages of an archaeological experiment is probably less frequent. However, we do believe that it is able to represent not only the objects, but also the way they are collected, and identified, and assigned with various more or less imprecise measurements, and hypothetical attributes concerning their age and origin. When these assignement are made concurrently by different observers, mixing human people and artificial devices, it becomes very important to track and mark the data collection process all along.

Let's start recalling some aspects of the *CRM*, then we will see how to use it for representing the archaeological knowledge extracted during an underwater experiment, in the traditional case and with new technologies as well.

3.1.1 Some CRM basics According to the version 3.0 of the *CRM* (Crofts et al., 2001), this model has been formulated as an object-oriented semantic model, with the intention that this presentation should be both natural and expressive for domain experts, and easily converted to machine readable formats such as RDF and XML. The following terminology has been selected for ease of understanding by non-computer experts:

Entity for anything that may be called $class, entity$ or $node$. There is a finite number ($i = 1$, about 80) of entities, named E_i, and the first one is E1, the basic CRM-entity

Link for anything that may be called $attribute, reference$, or $property$. There is a finite number ($k = 1$, about 100) of links that relate entities, in the relational form $P_k(E_i, E_j)$, where E_i is the entity domain, and E_j is the entity range. For many links, the inverse link holds, simply by exchanging domain and range, for instance: " this physical stuff consists of such material ", and " such material is incorporated in this physical stuff ", can be translated by, respectively: $P45((E18 :' this'), (E57 :' such'))$, and $P45((E57 :' such'), (E18 :' this'))$. But some links have no inverse: $P91((E54 :' diameter_i'), (E60 : 18))$ means only that $diameter_i = 18$ (in the associated *Measurement Unit*). For links which are properties, the cardinality constraints are deliberately omitted.

inheritance 'Superclass - Subclass' relations refer to 'isA' relations, 'subclass superclass', 'parent class - derived class', 'generalization - specialization', etc. The inheritance is controlled through this hierarchy.

Example: " a piece p_k, discovered at location A(x, y, z) is identified as part of an amphorae of type Dressel20 ", can be translated into a set of formulas in the following (simplified) style:
P55[has location] ((E19-Physical Object: p_k), (E53-Place:A)),
P87[identified by] ((E53:A), (E47-spacecoordinates: (x, y, z))),
P48[meets in time with] ((E19:Pk), (E52-timespan:$Dressel20$)) etc ...

Though fastidious, it is a very rich environment for recording every action that many different people can take about every single object. Then, it will always be possible to add new statements, even contradictory, and to check them against external constraints. CRM relies on some modelling principles that allow a consistent accumulation of possibly different beliefs: it imposes *Monotonicity* (nothing will be removed nor modified, once recorded) together with an Open World assumption (no negation by Closed World). Hence, everything is cumulative, and there is no room for inconsistancy or contradiction, but we will discuss this in the "uncertainty" section below.

3.1.2 CRM representation for traditional methodology . The hierarchy of the CRM entities allows to manipulate any archaeological piece at different possible levels of abstraction, according to the degree of investigation has been brought to the piece.

Let's follow the "stuff" hierarchy path $E1 \rightarrow E18 \rightarrow E19$:

1. CRM Entity (E1): anything that can be individualized from context, and identified by an Appellation (E41) under the form of Object Identifier (E42), and attached to some Type (E55);

2. Physical Stuff (E18): some piece that has dimensions (one or several), which can be composed of several Physical Stuff parts, etc.;

3. Physical Object (E19): the piece can be taken and moved up to the surface for further investigation, receiving an Object Identifier (E42), being assigned a number (E60) of parts, attached to a current, or former, or permanent location (E53), etc.

Let's follow the "temporal entity" (action) hierarchy path $E1 \rightarrow E2 \rightarrow E5 \rightarrow E7 \rightarrow E13 \rightarrow E16$:

1. CRM Entity (E1): anything that can be individualized, hence it can be also a process that materializes in space and time, and receives an Appellation under the form of a Conceptual Object Appellation (E75);

2. Temporal Entity (E2): has a Time Span (E52);

3. Event (E5): to which participated the Actor (E39);

4. Activity (E7): which takes into account a Conceptual Object (E28), like a Procedure (E29), see below (cf 3.1.3);

5. Attribute Assignment (13): to attach any attributes among them any Measurement;
or Modification (E11): which uses a particular Procedure;

6. Measurement (E16): to perform a measurement on a physical stuff.

In section 2.1 we distinguish between *intrinsic* and *extrinsic* features. The *CRM* allows to distinguish between:

- typical intrinsic features, such as Material, Measurements, etc.,
  Physical Stuff ($E18 :' p'_k$) has dimension ($P43$) Dimension ($E54 :' height'$) writes $P43('p'_k,' height')$, etc.
  and we can attach a Unit (58:'cm') and a Value (E60:'12.8') to the Dimension, meaning: [height = 12.8 cm], what writes:
  $P90('height',' 12.8') \cap P91('height',' cm')$!

- typical extrinsic features, such as Place, Period, Appellations, etc. Physical Object ($E19 :' p'_k$) has former location ($P53$) Place ($E53 :' A'$), and Place $'A'$ is identified by the space coordinates (x, y, z), altogether writes:
  $P53('p'_k,' A') \cap P87('A',' (x, y, z)')$;
  note that the same entity p_k can be E18 or E19, depending of the abstraction level used by the link.

The creation of complex features is made possible by the binary link mechanism. Let's illustrate this from the VENUS first experience.

During the Pianosa experiment, archaeologists were almost exclusively confronted to amphorae. Hence there are three main concepts to represent: the archaeologist, the amphora and the activity of performing an amphora discovery.

- The archaeologist can be represented as an *Actor* (E39), to which we can possibly attach some data if the identifier is not enough.

- The activity of diving and browsing around is necessary for keeping track of the exact time, duration and external condition (light, turbidity). It can be done through the *Activity* (E7) entity, with properties like *Time-Span*(E52), etc.

- The amphora can be managed through the *Type* (E55), let's name it: 'ampho'. Then we can attach several characteristics to this *Type*, starting with the *Appelation* (E41) "amphora", what we can read:
  $P33((E55 :' ampho'), (E41 :' amphora'))$, and we can add that this Type can be measured along several *Dimensions* (E54), such as a height, a diameter etc.

Now, consider what is the data collection process in itself.
At first glance, the archaeologist can see a *Physical Object* individualized from its environing context, then she can decide that it is a *Physical Man-Mde Stuff*, rather than just a rock for instance.
A *Physical Man-Made Stuff* (E71), can be used for representing a particular amphora, let's name it $amph_1 2$, either as a single piece, or as a group of several parts, broken apart, but believed to belong to the same amphora. $P44(E71(), E70())$ says that such physical man made stuff is an amphora, and $P62$ says that it is composed of *Physical Stuff* (E18) parts p_1, p_2 etc.:
$P62((E71 :' amph_1 2'), (E18 :' p_1'))$ etc.

3.1.3 CRM representation for new technology.

In section 2.2 we distinguish between *directly observable*, *indirectly observable*, and *deduced* features.

Each sensor, camera or any other device, as well as an algorithm (e.g.: interpolator, statistical approximation), can be represented as a *Man-Made Stuff* (E71) and be considered as an *Actor* (because E39 is a superclass of E25) acting in an *Activity*.
Therefore, the CRM allows to record the origin of any observation, allowing to distinguish a direct sensor measurement, as a computed measurement, or as a deduction from a more complex processing, involving several other features. Though it cannot provide any direct means to propagate uncertainty, it allows a further processing to be correctly informed on every intermediate step. This is what we will use in the next section.

Let's consider the "procedure" hierarchy $E72 \rightarrow E71 \rightarrow E28 \rightarrow E73 \rightarrow E29$:

1. Stuff (E72): has a general use Type (E55);
2. Man-Made Stuff (E71): has a Title (E35) and is intended for Type;
3. Conceptual Object (E28): refers to concept Type;
4. Information Object (E73): can be composed of several Information Objects;
5. Design or Procedure (E29): was used by Modification (E11) which is a subclass of Activity (E7).

Example: instead of performing some direct Measurement, we can apply some software Procedure:
- the definition of some interpolation software, can be done considering that the particular algorithm is a Procedure, hence, as a Man-Made Stuff receives (P102) this Title:"interpolate", and is a Conceptual Object, hence can be taken into account (P15) in an Activity, performed by some Actor, on some Physical Object that has some permanent location, identified by some space coordinates; - the execution of the algorithm is then recorded as an identified Activity, occurring during a particular Period, hence, falls within a Time-Span, and on some particular Physical Object, such as p_k, and consists in modifying the original coordinates (x, y, z) and proposing (x', y', z').

The development of the **Arpenteur** software, initiated by the coordinator of the VENUS project, as an object-oriented software, allows to 'map' its internal classes onto CRM objects. This mapping will be one part of our next effort, in order to build the bridges between what the CRM representation permits, and what the **Arpenteur** software allows to compute and implement.

3.2 Representing uncertainty together with the CRM

The Conceptual Reference Model can be considered as an Ontology: two important aspects follow.
Share and Agreement: the ability to record every facet of the knowledge building process, allows to further discuss any such record, thus providing a solid background to elaborate hypothesis.
Structure and Control: the CRM allows to build complex structures, controlled by several possible constraints: we discussed briefly the assignment of space and time information, that entails classical time and space topological consequences. We can also use the CRM to propagate information through a hierarchy that can be built by the creation of intermediate nodes, which can group together several entities, for some explained reason.
Example 1: pieces p_k, ... p_{k+l}, are grouped into the group G_k, which inherits as "location", the average location of the various pieces (x_m, y_m), and as "time span", the same as of these pieces (e.g.: Dressel20), etc.
Then it becomes possible to check some constraints between the properties of this group G_k and those of its parts. This allows to define several constraints as in any "*is_a*-relation".
Example 2: the piece p_k, already used in the example of the previous section, has received an original space place, identified by coordinates (x, y, z), and some -possibly different- coordinates $x', y', z')$ have been computed by interpolation. We can now check if the two values (x, y, z) and (x', y', z') are compatible against some specified constraints, like: confidence interval, topological consequence, etc.

CRM choices provide an easy way to represent "positive knowledge", but the previous section has mentioned that we need also to represent constraints between features, and any negative knowledge that can be explicitl: forbiden values, forbiden relations, etc. We must also ask: How to manage the information about data quality ? how to manage the uncertainty in this overall context ? Hence, the representation of constraints, of differing data quality, of preferences, etc. is left to the user responsability. Restauring consistency by accepting or refusing parts of the registered knowledge, is left to further reasoning processes.

This is precisely what we intent to bring in the VENUS project. We have already investigated several tracks in previous projects: belief revision, possibilistic logics, etc. that we will adapt to these representations. The formal conceptual languages that we are presently investigating are, the Description Logics and the Conceptual Graphs. Bridges exist between these languages and RDF or OWL languages.

4 CONCLUSIONS AND FUTURE WORK

This paper presents a preliminary underwater archaeology knowledge analysis stemming from the results of the first mission of the

Venus project on the wreck site of Pianosa. This analysis focused on archaeological knowledge provided by traditional archaeology and as well as by new technologies like photogrammetry or laser.

A first representation stemming from CRM model was proposed, which takes into account the various aspects of the traditional process of building the knowledge base associated to an underwater archaeology experiment. It enables also the smooth integration of data acquired by automatic devices, and of data derived by most of the algorithms used in the VENUS consortium software. It is briefly exemplified on the Pianosa experiment.

Since archaeological information is by nature incomplete, uncertain, inaccurate and evolutive,future works will investigate how artificial intelligence methods and tools (Leber et al., 2007) could be used to represent archaeological knowledge and to perform non monotonic reasoning. This paper provides some hints on how to further develop representation and reasoning mechanisms for stepping up from the cumulative CRM representation to a non-monotonic approach of reasoning.

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