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ENVISION OF A DIGITAL FOUNDATION TO EMBED KNOWLEDGE AROUND RELEVANT ASPECTS OF CULTURAL HERITAGE

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KEY WORDS: Digital Spaces, Digital Maps, Representation of Knowledge, LBS, Identification, Unified approach, 3D representation

ABSTRACT:

Reviewing current results and applications in the domain of (digital) cultural heritage, such as virtual reality, digital information management, multimedia, makes evident that technologies and systems are nowadays pervasive in the investigation phases and in the analysis and exploitation of the scientific data. Applications of virtual reality by means of 3D representations of architectural and historical models are attracting a wide range of audience – especially in the tourist and multimedia sector. Typically, the emphasis is given to the visual representation and its impact to the user, giving less importance to the scientific accuracy and capacity of the platform to represent the whole "knowledge" associated to the cultural asset.

There is a demanding need to envision approaches to communize all the elements of such multidisciplinary knowledge. A data set of coherent, structured, multidisciplinary, multi-source, multi-media information (that can be physically distributed) - constituted by "markers" (i.e. pertinent to a specific domain such as architectural, technical, structural, historical, bibliographical, archive related, photographical, physical, chemical, ...) – should give the capacity to implement Cultural Heritage platforms around a sort of a "Digital Foundation" of assets to support different applications and user experiences. Current approaches and availability of digital libraries, the accessibility of distributed information (e.g. by internet), the capacity to model data and meta-data, the availability of instruments to accurately position objects in space and time (together with ontological representations) let us envision a novel model of representing a dynamical evolving multi-source "digital foundation".

The above model, as the result of a multidisciplinary approach coming from a long experience in research and technologies in various fields (ICT architectures, Digital Libraries, Knowledge representation, Distributed infrastructures, GIS and applications of Satellite Navigation) and projects (National and European) is now experimented around the UNESCO Villa Adriana in Tivoli (Rome, Italy). It constitutes the center of excellence that allowed the authors to preliminary build a digital foundation for the area, demonstrating the capability to generate (among other features) accurate 3D virtual reality representations, distributed multi-source/multi-target and multi-modal representation for virtual guides and to support archeological studies and excavations for professional users. It furthermore implements capacities to manage, to control and to develop the necessary knowledge for the safeguard and conservation of the immense material associated to archeological sites.

1. INTRODUCTION

Current results and applications in the domain of (digital) cultural heritage, such as virtual reality, digital information management, multimedia, makes evident that technologies and systems are nowadays pervasive in the investigation phases and in the analysis and exploitation of data.

Applications of virtual reality by means of 3D representations of architectural and historical models are attracting a wide range of audience – especially in the tourist and multimedia sector. Typically, the emphasis is given to the visual representation and its impact to the user, giving less importance to the scientific accuracy and capacity of the platform to represent the whole "knowledge" associated to the cultural asset.

There is therefore a demanding need to envision approaches to communize all the elements of such multidisciplinary knowledge. A data set of coherent, structured, multidisciplinary, multi-source, multi-media information (that can be physically distributed) - constituted by "markers" (i.e. pertinent to a specific domain such as architectural, technical, structural, historical, bibliographical, archive related, photographical, physical, chemical, ...) – should give the capacity to implement Cultural Heritage platforms around a sort of a "Digital Foundation" of assets to support different applications and user experiences. Current approaches and availability of digital libraries, the accessibility of distributed information (e.g. by internet), the capacity to model data and meta-data, the availability of instruments to accurately position objects in space and time (together with ontological representations) let us envision a novel model of representing a dynamical evolving multi-source "digital foundation" called "Digital Space".

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The approach elucidated in the present work was experimented in the course of European Project called CUSPIS in the framework of applications of Satellite Navigation for the Cultural Heritage sector.

2. VILLA ADRIANA AS A CENTER OF EXCELLENCE

2.1 The UNESCO Site of Villa Adriana

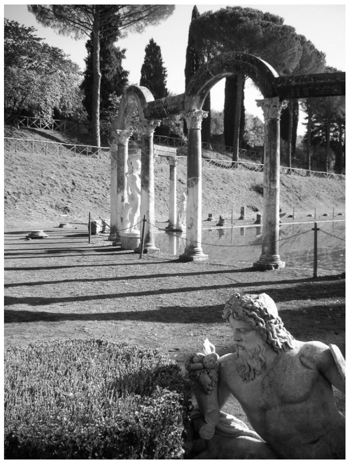
Figure 1: Villa Adriana, Canopo

Hadrian's Villa - **Villa Adriana**- close to Tivoli (Rome, Italy) - is one of the most important and well known monumental complexes of Roman antiquity. It is among the most visited cities and museums in Italy, reaching a maximum presence of about 400.000 visitors per year. The Villa was built by the emperor Publius Elius Adrianus between 117 and 138 C.E. In 1999 the archaeological area of the villa was acknowledged by UNESCO as one of the Human Heritage Monuments. According to UNESCO, it can be considered the symbol of the Roman Empire since it is considered among the highest forms of ancient culture and one of the main models for the study of the birth and development of modern architecture. This unique character is also emphasised by the many exhibitions that are dedicated to Adriano every year around the world. This uniqueness was clearly wanted by Hadrian for his Villa, since it was meant to be the place for personal leisure. This character expresses also his own cultural approach, as seen in other massive buildings in Rome (The Temple of Venus, The Mausoleum known today as Castel Sant'Angelo, Elio bridge and the Pantheon) and in the Roman provinces (Hadrian Wall, The Arches of Gerasa and Athen).

Such an important characteristic is immediately clear in all the structures of Villa Adriana. The Villa is a complex of building sprawled over some 120 hectares and consisting of several structures (some 28) each one variously shaped which can be singled out even if they belong to a global project, probably created in part by Emperor Hadrian himself (117-138 C.E.). The vastness of the project can be better understood from a comparison with Pompei, that covers an area of about 60 hectares only. Today only 770 rooms are open to visitors and these are connected by open spaces, gardens, and criptoporticoes and, especially by an extraordinary underground road network originally dedicated to pedestrians and carts and not yet completely known.

Villa Adriana has been excavated for more than five centuries and is famous worldwide, but it lives in a paradox since it is still scarcely known in its essence and structure – as many other Roman monuments. The reason for this partial and fragmented knowledge of the Villa can be traced to the nature of old excavations and studies, often limited to an antiquarian and humanistic perspective: most of them dealt with just one single building, without taking into consideration the Villa as a whole. Ancient sources, from Renaissance on, simply copied from each other the antiquarian information, and some were simple fairytales about its treasures. There are few comprehensive studies on Villa Adriana as a complex, sometimes outdated or incomplete and often providing limited and insufficient information. One major reason is the extreme difficulty encountered to gain a global perspective of each single structure, mainly due to progressive decay, restoration measures and excavations. Most of the research completed so far has been focused on archaeological aspects of single components or artefacts, without any general framework that could encompass the information that was progressively unveiled.

As an example, it shall be mentioned that most of the available surveys are affected by errors, and that they represent only a superficial image of the real geometry of many of the existing structures. The exact position of the different structures within the complex is presently unknown. At the same time, only a minor part of the entire complex is known in detail. Furthermore, the location and the general layout of the hydraulic and transportation systems are only in part known, even if this knowledge would be of great help when proposing hypotheses with respect to the original design of the Villa. Finally it should be noted that many structures are still buried in the ground; should they be unveiled, the information on their characteristics would add significantly to the general knowledge of the complex. This would certainly help in promoting the value of the Villa with respect to the management of tourist flow and in general its sustainability.

The need for a comprehensive study that stems from a multidisciplinary survey is strong. This comprehensive study would form a general framework and integrated layout to link new specialised information related to structural, architectural and physical aspects that could be unveiled using innovative techniques. Based on such framework, as an example, it would be possible to develop an economical model to manage tourist access and maximise a sustainable use of the Villa with great cultural benefits.

This aim is strongly supported in Italy by the **Soprintendenza ai Beni Archeologici del Lazio**, that has recently signed an agreement with University of Rome "Tor Vergata" in order to develop a modern tool to store survey data in a GIS form and that is supporting a whole set of projects around Villa Adriana to form a "center of excellence" to develop innovative projects at all levels - including a new technological perspective.

Specific activities have been defined in order to verify and check all the information that has been retrieved on the Villa in the past and that will be progressively unveiled in the future. This includes data on scientific areas that are quite different and even far apart from the fields pertaining to archaeology. Hence, the foundation will form a new starting basis, updated and corrected in future studies.

2.2 Studies cantered around Villa Adriana: the universal map

Several studies were developed under the request of the Soprintendenza per i Beni Archeologici del Lazio to obtain a comprehensive survey and therefore a sort of "universal" geo-referenced 3D map of the entire land upon which is built Villa Adriana. Such a "universal map" should then constitute a basis for all further developments of studies and investigations for scientific, archeological, historical and other studies around the area. In this respect, all management of the interventions, maintenance, restoration and even – tourist visits – should accomplish to use and rely on such a map. Villa Adriana major features, to include, among others, construction materials, decorations, hydraulic functions, soil-structure interaction, stability, resistance, typological solutions, construction details, were thoroughly investigated. In this respect it shall be pointed out that at the present state of knowledge Hadrian's Villa resembles a model of intense architectonical experiments. Different typological solutions have been adopted after several functional modifications; constructed volumes have been organised and arranged in such a way to form interacting and complicated spaces. The engineering aspects relate to the vast excavations aimed at reshaping the local terrain, to the specific solutions adopted to cover several complexes, to the extended network of underground constructions, dedicated to pedestrian and carriage pathways as well as to the numerous hydraulic conduits. It shall also be pointed out that the hypotheses and related model are compared with existing structures still surviving within other archaeological complex that have been traced to Adriano throughout the Mediterranean. In essence the models and the hypotheses pertaining to structures of the Hadrian's Villa that are no longer existent will be compared and validate against structures of the same period traced to Adriano.

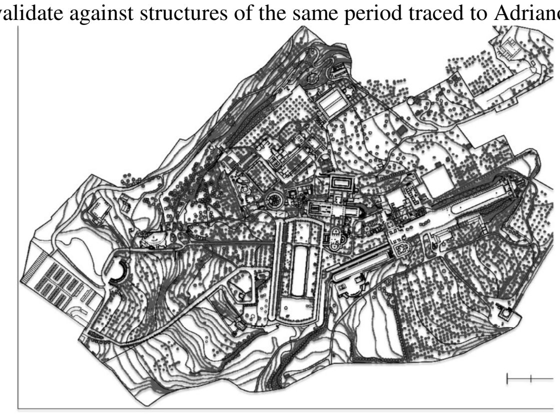

Figure 2: 2D projection of the Villa Adriana "Universal Map"

The planimetric complexity of the area, the existence of a rich set of underground features (including roads), the diverse attitude of buildings and houses with respect to their functional features, the complex shape of the terrain and the different states of conservation and their positional and geometric attributes requested numerous surveys with different and international experts. Different and up-to-date methodological and technological processes were applied to build the universal map – including:

- A completely new approach to the digital library archive structured in layers and linked to GIS facilities;
- The use of aerial photogrammetry, 3D scanners, reference stations:
- The use of suitable User Terminals to encompass GPS/EGNOS and storage models studies appropriately for the scope;

To the scope of the correct interpolation, extraction and reconstruction of geometrical features, link to the correct data stored in the digital libraries and data-bases and the need to use data for 2D/3D visualization and reconstruction lead the team (coordinated by the University of Rome Tor Vergata) to study new approaches for the cataloguing, storage and representation of the data.

In this respect, the need to comprehend data in all forms (geographical, geometrical, historical, reconstructive, …) is enclosing the whole background of knowledge around pieces, parts, whole of assets in the area. Such a representation constitutes a core to:

- Represent objects in diverse dimensional features;
- Allow dynamical reconstruction and representation of objects in diverse contexts and towards different users (tourist, archeologists, managers, institutions,…);
- Contains all relevant features to allow 2D/3D representation and management of data (e.g. in digital libraries).

As an example, a reference case-study is targeted to build the digital representation of a part of Villa Adriana –the building of Roccabruna – as a reference example to enclose 3D reconstruction in different time-frames, accurate modeling of parts and the whole building with accurate 3D scanner surveys and the successive intervention of the experts to models complex spaces and data.

In this respect, the approach pursued here is distinguishing for the following features:

- Easy extraction of features in both space and time frames;
- Accurate geometrical representation and compatibility with most common tools for rendering (incl. Revit);
- Capability to link objects with external databases and digital libraries (by means of standard identification and tagging);
- Capability for the model to be appropriate in different contexts (i.e. tourist, archeologist, …) by means of suitable meta-data layers;

Such a model encompasses usual 3D representation in both terms of quality as well as for the different perspective: it constitutes a way to construct the knowledge of the asset and not its representation.

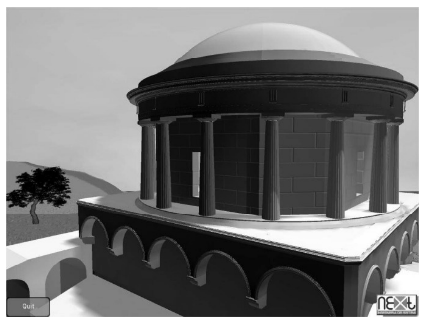

Figure 3: 3D representation of Roccabruna at Villa Adriana

2.3 From visualisation to representation

Digital reconstructed models (2D/3D) of the various constructions will be first arranged in a specific catalogue and will provide a base for further developments to embrace its **Digital Space foundation**. The following objectives will be pursued:

1) Structuring of the (digital) library and the information representation in the fields pertaining to the following areas: historical documentation, census and typological classification of structures (with particular reference to the vaults and the domes), characteristics of decay and damages, degree of structural safety. The inventory will be, afterwards, functional to the realization of the "universal map".

2) Draft of a "map of the risks" in which the results of the comparison between survey data, analyses on static and

characterization of the parameters and building materials, executed with technologies of pertinence of the unity of nuclear physics, will converge. In particular the territory of the Villa will be assigned different risk levels and priorities of safeguarding measures will be assessed together with related guidelines for consolidation and restoration; a careful comparison between technical data and cultural, social and economic evaluations will be carried out to supply required suggestions and indications to accomplish the last objective.

3) Identification of "fruition models" and "plans for economic improvement" that consider all the potentials of the Villa. Such a plan shall stem from and combine available experiences related to the “theme parks " and "open air museum structures"; it shall allow to verify the sustainability (economic, financial, institutional), in relation to a cultural project able to involve not only the occasional visitor, but the entire user community.

The possibility to attain the proposed objectives is depending on the methodological and procedural coordination of the synergy from different scientific expertise, on the possibility to direct them towards the expected results and to results which are more favourable from a cultural and economical perspective in the area of ancient monuments. Finally, all the expected results should be included in a web accessible portal since the beginning of the first investigations, in order to allow the many existing users in the world to keep up to date information in real time.

In this respect it is worth remembering that, as an example, many parts of the Villa Adriana are still unknown and that several others have never been carefully investigated; also knowledge of a very high percentage of the complex is spoiled by restorations which have not been fully documented or are described in dispersed and fragmentary documents. With particular reference to the retrieval of archive data, a fundamental part of the work will be developed together with personnel of the Authorities that will be involved in the research; such work will be carried out in addition to the acquisition of information in other archives and libraries.

Also, the collection of data in situ can be organized to obtain information without heavily interfering with the administrative and tourist daily activities. Therefore techniques of indirect survey are best suited to obtain initially:

- Precise and certified geographic positioning of all structures included in public property areas and identifying of a realistic extent at a given time.
- Location of underground structures (or still uncovered).
- Geo-referenced location of every complex in relationship to the general map of the area.
- Realising supporting topographic survey and photogrammetry of visible and underground structures.
- Identification of assets to enable authentication and certification of objects.
- Classification and use of digital information towards standardised identification of objects and their relation to Digital Libraries and/or data bases.

Test of the methodology focuses on qualitative control of digital data obtained by the use of GPS/EGNOS[1] where Information will be processed through specific software and will be arranged and used to help develop an IT platform for management and (graphic) representation of all available data. This software is basically constituted by a Location Based - LBS - platform extended by the interoperability with Digital libraries tools.

Expected results of the construction phase can be divided in two specific interacting branches; the first concerns the upgrading of knowledge of the area to obtain:

- three-dimensional graphic restitution of survey in CAD environment
- Location of the areas with underground structures.
- Zoning of open and restricted areas in the villa.
- Classification of the images and the alphanumeric data in a relational database.
- Design of geographic database and some implementation procedures in GIS environment.
- The appointment of the necessary LBS platform composed of User Terminals (usually PDAs) equipped with GPS/EGNOS and communication to a Service Control Center (as the front end to the IT back-end system).

The following results are expected instead from a second group of activities, addressed to the qualitative control of techniques for data collection:

- Refining of technical procedures for survey data exchange.
- Alignment of geometrical data entries by heterogeneous techniques.
- Functional validation of the informative system architecture.

The second phase will be essentially completed in the laboratory and targeted at the realisation of the "universal map" for the archaeological area, being a product where finding objective information about sector analysis and researches. Information will be arranged to achieve the following objectives:

- Building typologies classification
- Building phases determination
- Diachronically identifying of the structures
- Analysis of building techniques and use of materials
- Typological classification of static behaviour of the structures
- Test of nuclear techniques in dating and characterizing materials
- Analysis of structural decay characteristics: fissures, collapses, detachments of pictures
- Classification and physical chemical characterization of materials
- Location and classification of materials decay phenomena
- Identification of areas to be valorised

Resulting data will allow also managing and programming all the excavations, conservation, restoration and tourist flows (and activities).

Data included in the "universal map" will be functional to the development of researches and to improve available knowledge of the area for diverse applications (including geo-archaeology, management and tourist related services).

[1] EGNOS is the Satellite Augmentation System managed by the European Space Agency to complement GPS signals in order to extend the accuracy of position and to provide initial services (such as integrity) in view of GALILEO.

3. THE USE OF LOCATION BASED SERVICES

3.1 Background on Location Based Services

Location-based services are any service that takes into account the geographic location of an entity. Even though location-based services (LBS) were predicted to become the "killer application" of mobile commerce, their dominance has not yet materialized— but is predicted to do so soon. The LBS market size has been predicted to grow exponentially from 2006 to 2010. Within this four-year time span, for example, Asia's LBS market is expected to increase from $291.7 million to $447 million, Europe's market from $191 million to $622 million, and the U.S. market from $150 million to $3.1 billion. Generally, the slow adoption of LBS has been explained by the following causes.

First, the implementation of accurate localization techniques through providers has taken longer and has been more costly than expected –in this respect and demonstrated by the experiences of several solutions in the Cultural Fruition services, EGNOS adoption, as a **Global Navigation Satellite Systems** (GNSS) European solution to support the United States GPS, will play the expected differentiator role. One of the major challenges of the European GNSS is in effect to develop new markets for services and products, using EGNOS as precursor of Galileo. Second, the few available LBS applications display difficulty to adapt to user willingness and behavioral orientation that mostly depends on human factors that are not fully taken into account by the actual systems (mostly with predetermined contents and without any model of behavior instilled in the system). And third, users are concerned about privacy issues that are an inevitable side effect of LBS.

A LBS platform is usually composed of a **Service and Control Center level**, a **User Terminal level**, a **Service** and a **Content level**. The following are examples of services enabled by LBS in the Cultural Heritage domain.

3.2 Cultural Fruition Services (CFS)

The cultural tour/visiting guide are supported by accurate positioning service allows receiving Location Based cultural data content visiting city historical centres or archaeological areas. The cultural information should be geo-referenced and customized for the user; the data retrieval process should take into account the proximity to a cultural asset (every cultural asset is associated to its spatial coordinates associated to other attributes in a point of interest), the user profiling information and the user preferences. The tourist should experience an interactive multimedia cultural content in which the right information is accessed at the right time and in the right place. The cultural asset fruition scenario is basically composed of two capabilities:

- The outdoor (open sky) visit (such as archaeological areas with located assets such as statues and complexes).
- The indoor visit (museums, art galleries).

These capabilities are distinguished from different factors:

- <u>The satellite signal availability</u>. In fact the satellite signal is not available in indoor environments. In consequence of that the user localization could be done with different technologies (such as RFID or Wireless).
- <u>Different communications mean availability</u>. In large outdoor environments is not usually expected to have broadband communication mean such as WiFi which is easily possible to have in indoor environments.
- <u>Different concept of maps</u>. In the outdoor environment is expected to have a territorial map (in vector or raster form). In the indoor environment is expected to have a building map composed by different floors and topological structure.

3.3 Geo-Asset management services (GAMS)

Geo-asset management is the concept of identifying, collecting, cataloguing and disseminating geo-tagged information for assets. This approach, seen in cooperation with Geo time authentication (**GTA**) services using GNSS, should allow archaeologists and expert users to use geo-related information about assets for excavations, studies and research (in view of **geo-Archaeology** and **landscape-archaeology**).

Basis of this approach is the availability of an "**identity**" of an asset. A cultural asset identifies a work of art (e.g. sculpture, picture, etc) that is catalogued into a system. Each cultural asset should associate with a unique ID. Such unique code (to be defined at national or international level) is usually assigned by public organizations.

This unique listing code can be furthermore associated to the GNSS signals. The longitude and latitude coordinates (i.e. the geographic coordinates) are the ones provided by GNSS to identify the place where the cultural asset has been catalogued. A GNSS timestamp could be then added to build a unique identifier for each cultural asset for a specific location. Suppose that two cultural assets are catalogued in the same place (i.e. they have the same coordinates). Then the timestamp generated by the **GNSS** system will allow discriminating among them. Such "certified" coordinates (as enabled by EGNOS and in future GALILEO, and not enabled by GPS) can additionally provide a mean to address the problem of a global standard that permits to catalogue different cultural assets residing in different places and to "certify" the authenticity of the asset itself. The additional use of physical tags (e.g. RFIDs) can be also support in tangible identification also for management purposes.

4. A ENVISION OF A DIGITAL FOUNDATION: A PERSPECTIVE

To enable a unified approach to different applications and platforms – based on a homogenised representation of assets - including geo-graphical attributes, data and its representation (in space and time) lead us to introduce the novel definition of a "**Digital Space"** as a foundation for representing archaeological areas and its constituents objects.

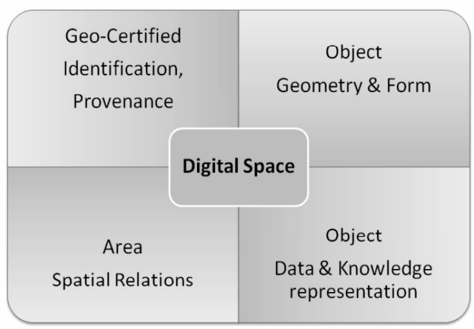

Figure 4: The Digital Space foundation constructs

This digital representation is an innovative instrument since it would constitute the basis for any informative system to supplement the data represented in diverse dimensional forms:

- The **physical form** – will be identified univocally by the **Global Asset Identifier** – complemented by the geo-position (particularly suited for open archaeological areas). This identification can be used for authentication, referencing and provenance purposes and can be easily stored in RFID tags.

- The **virtual form** (to be visualised in both in 2D or 3D forms) can be identified, referenced and stored as a digital data object. It has to be noted that the virtual representation objects can be:
    - Representation of areas with its relevant spatial structure of containment (e.g. a statue within a temple);
    - Representation of objects within a time-frame;
    - Geometrical representation;
    - The link to the actual instance in a defined digital library;
    - The description of the object (in form of data and meta-data);
    - The actual piece of art;

- The **digital library representation** in order to obtain the necessary platform for storage, handling and fruition. Within a coherent framework, the informative system will contain all the data already available in the existing literature and also those one that will be unveiled in different areas of study during the progress of the research.

- The **Spatial structure of areas,** to include relationships among objects in physical spaces (i.e. areas) to help digital representations to be located, related in space and topologically assembled.

The outline of the process to unveil digital space data can be then described with respect to investigation areas and steps to incrementally form "knowledge" of the area and objects contained in it:

- Survey and graphical restitution via 2D/3D dimensional models, area and point models (including Point of Interest POI) and relations between entities on the ground and virtual space-time reconstructions
- Storing of data and of information pertaining the fields of history and provenance, archive, references; classification and analyses of the structures existing above and below ground, with respect to their use and essential characteristics; classification, analyses and survey of decorations along walls and floors; classification and analyses of the hydraulic and transportation infrastructures
- Construction of the digital space by linking the different dimensional levels and the data base; this representation can be interrogated and navigated at different level on interest, in order to allow further analyses and also to arrange for different types of information to different types of fruition (i.e. tourist/experts) – maintaining the invariance of the supporting IT infrastructure

In essence, this methodology will provide a basis to convey the different scientific and methodological contributions and expertise towards the common objective of the construction of Digital Spaces.

Appropriate IT platforms should be appointed to let the digital construction be successful and usable to users and experts[2]. In fact, assets/objects can used to drive actions of the supporting platforms using relationships, proper ontologies and concepts structured around the "Digital Space Foundation".

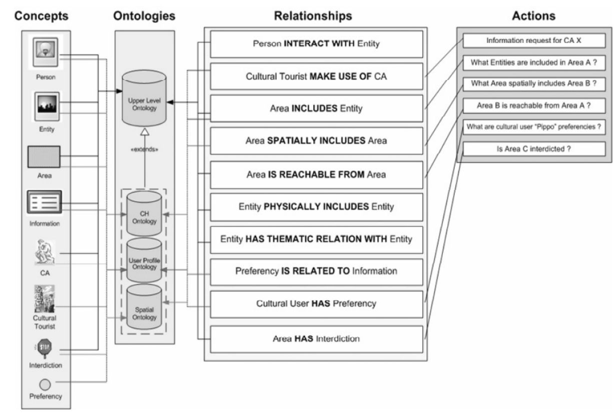

Figure 5: The Digital Space supporting capabilities

4.1 Authentication of assets and the Global Asset Identifier

The idea of authentication is based on the availability of a mean for authentication, as sort of electronic signature on the signal itself that can enable a number of applications and cases where the "trustworthy" and "authentication" of the location and time is considered an added value.

The authentication is based on the following elements:

A) **GEO-TIME authentication and tagging equipment/s**

These equipments are to be used on surveys to record geo-time data that are considered important to "certify" and authenticate assets (i.e. constituent objects in a physical space). A receiver (usually a PDA equipped with GPS/EGNOS for geo-tagging and communication device to link to external data bases) is needed. This receiver will store a local database of the recognised geographical areas linked to other specific data such as text/picture or video.

B) **GEO-TIME authentication tag**

The authentication tag could be then encapsulated/embedded in the asset (with a combination of visual readable information for customers and RFID based information for automatic check). The visible readable information is easy to be forged by malicious actors while the RFID tag could store cryptographic information. Such tag constitutes both the Geo time Identifier as well as the storage of provenance data.

Actually, a geo-time stamp is composed of the following fields (as did for the Villa Adriana assets in the universal map):

1. **User**: identifies the user that generated the ID;
2. **Starting time (i.e. year-month-day / hour-minute-seconds)**: defines the time in which the ID validity is activated;

[2] See the CUSPIS project as a reference platform in this respect.

3. **End time (i.e. year-month-day / hour-minute-seconds)**: defines the time after which the ID validity will expire. Time frame can be unlimited;
4. **Identifier:** identifies the asset ID in relation to a specific library and/or a standard (e.g. using DOI – the Digital Object Identifier).
5. **Type:** identifies a museum, an exhibition, maps service information, routing service information and points of interest service, ...;
6. **Area:** Identifier, in its topological structure, of the area (or sub-area) where the timestamp is valid.

The literature points out the need of developing an international standard to identify assets (ASSET ID or more recently the DOI structure), moreover it suggests the GNSS technology use as an added value to address the problem. A large number of cultural assets share the problem of identification over the world. The proposed unique marking (as the Global Asset ID) is indeed crucial to cataloguing and protecting a cultural asset so that public institutions and stakeholders can manage assets and objects in complex areas. The GAID can be associated to new objects found in a site both in archaeological events and when new discoveries are unexpectedly made (road constructions and so on). The GTA system can support these archaeological discovers and geo-referencing for mapping in order to uniquely identify every new CA and for precise and accurate positioning. Moreover, the GNSS signal can enhance security services in all data related applications for:

- **Authentication**: the ability to grant that the subject X is the subject X without any doubt.
- **Confidentially**: the ability to grant that what subject A is saying to subject B is not listened from an unwanted subject C.
- **Integrity**: the ability to grant that what subject B is listening from subject A is exactly what subject A is saying to subject B.
- **Non-repudiation**: the ability to grant that what is confirmed from subject A cannot be undone.

<u>Usage of Cultural Asset Identification within Digital Spaces</u>

The Digital-Space enabled platform should allow identifying **univocally** a cultural asset by:

- Assigning **GAID** (Global Asset Identifier) with the complement of **geo-time stamps** (**hash functions** are used to generate univocal keys)
- **Certifying Identity** by an Institution/authority using appropriate mechanisms and process related platforms. The certified data are saved in the Authority database and stored on the CA RFID.

  Support the verification of the **authenticity** of assets reading the (RFID) identity and checking it though the application and the certification authority

Additionally:

- The Digital-Space enabled platform application can generate "certified" **POI** from asset data, linking geo-time to identification and enabling IPR management (e.g. using GAID for watermarking);
- Institutions can issue **certificates** by using global GAID and geo-time data (certificates can be used in various applications such lending, insurance and transportation). Secure functionalities are therefore based on **certified data** (e.g. using **Crypto-keys**);

<u>Spatial data structures for Digital Spaces</u>

The spatial and cultural asset data must be organized in an abstract conceptual model to allow the semantic organization of spatial and relational concepts. The first step is to discretize the environment in areas essentially by means of two kinds of relationships – the Spatial inclusion and the Reachability

The reachability relation is an equivalence relation, in fact:

- Area A is reachable from area A.
- If area A is reachable from area B then area B is reachable from area A.
- If area A is reachable from area B and area B is reachable from area C than area A is reachable from area C.

The spatial inclusion relation is based on geometric considerations in fact the area A is spatially included in area B if the bounds of area B contains the bounds of area A. It is possible to see that this relation is asymmetric, in fact if area A is included in area B then are B cannot be included in area A. Each area may contain several entities, each entity is directly linked with:

- Its relational attributes
- Its spatial representation as a point (Point Of interest).
- The children entities: the entities which are physically contained in the father entity

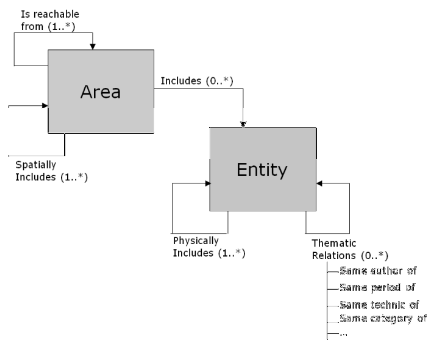

Figure 6: The Digital Space spatial data structure

Each entity could be in relation with other entities for physical inclusion or for other thematic relationship. In the same way the areas could be in relation for spatial inclusion or reachability. These relationships go to create a graph based structure that will be use to manage all relations and containments in the archaeological areas.

<u>Including Provenance data</u>

The concept of *Provenance* is already well understood in the study of fine art where it refers to the trusted, documented history of some work of art. Given that documented history, the object attains an authority that allows scholars to understand and appreciate its importance and context relative to other works of art. Objects that do not have a trusted, proven history may be treated with some skepticism by those that study and view them. This same concept of *Provenance* may also be applied to data and information generated within a computer system; particularly when the information is subject to regulatory control over an extended period of time. Today's digital libraries architectures suffer from limitations, such as lack of mechanisms to trace results and infrastructures to build up trusted networks. *Provenance* enables users to trace how a particular result has been arrived at by identifying the individual and aggregated services that produced a particular output. This support includes a scalable and secure architecture, an open proposal for standardizing the protocols and data structures, a set of tools for configuring and using the provenance architecture, an open source reference implementation, and a deployment and validation in industrial context.

The impact of the use of Provenance aware infrastructures (such as the one developed by open-source by the FP6 GRID Provenance project) is to provide mechanisms that allow information generated and managed within a grid infrastructure to be proven and trusted. By this we mean that the information's history, including the processes that created and modified it, are documented in a way that can be inspected, validated and reasoned about by authorized users that need to ensure information controls have not been altered, abused or tampered with.

5. RESULTS AND EXPERIMENTATION OF THE CONCEPTS

5.1 The CUSPIS VIth FP project results

In the context of the 6th Framework Programme and under the developments of the GALILEO calls, the Galileo Joint Undertaking launched a specific call reserved to the Special User Communities (Call 2-1A) to facilitate the introduction of GNSS and in particular of EGNOS and Galileo in the community of Cultural Heritage. The project **CUSPIS – Cultural Assets Space Identification System** (see http://www.cuspis-project.info) was a response to the call with a Consortium that comprehended all actors in the value chain and whose objectives were the following:

- Establish and focus on proper User Community Groups in the Cultural Asset context, enhancing their awareness of the potentiality of the Satellite Navigation toward the problems related to the Cultural Heritage domain;
- Analyse Cultural Assets issues related mainly to security, management and fruition;
- Identify all potential applications enabled by GALILEO services in the Cultural Asset sector;
- Analyse the potential applications, examining all the elements that can affect the final services; this activity will involve the key actors of the value chain, including the User Community related ones, and will assess the associated market potentiality. Throughout a trade-off analysis, some of the identified application were selected to be implemented and demonstrated,
- Perform a business and cost benefit analysis,

Although the project were focused on the User Community groups, fostering on analysis and penetration activities (in a field where navigation and communication technologies are of a novel application), a set of proof-of-concepts were demonstrated successfully to the Users with a character of innovation. The realisation of the CUSPIS platform that deployed the Authentication and Identification services (based on the concept of GAID), the demonstration of the geo-archaeology, management and fruition services at Villa Adriana allowed the authors to experiment successfully the concept of Digital Spaces in concrete applications. CUSPIS were disseminated in several events both at National as well at International level, demonstrating the innovative concepts behind the peculiar ideas envisaged in the design of mobile Cultural Fruition and the innovative models behind the Cultural Heritage domain.

CUSPIS studied and implemented a set of applicative services as a first experiment to exploit the concept of "Digital Spaces". Further experimentation is now to be launched to extend the work around Villa Adriana and also to export the model in other important excavations such as Pergamon in Turkey.

6. CONCLUSIONS AND FURTHER WORK

The considerations above and the promising results of successful implementations part of FP6 projects such as CUSPIS – together with the studies around Villa Adriana, managed and supported by key institutions, universities and industries, have helped to advance at both scientific and technological levels in several areas with a strong accent on validation of key technologies for the use and structure of digital spaces to enable a technology-enhanced learning and a knowledge construction process called "Digital Space".

The capability to experiment and advance on developed technologies and/or open-source tools constituted a key success factor for the present work and in-kind value to construct a reference platform for Cultural Heritage scenario as experimented around Villa Adriana.

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