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MANAGEMENT AND COMMUNICATION OF ARCHAEOLOGICAL ARTEFACTS AND ARCHITECTURAL HERITAGE USING DIGITAL IS. WHAT TODAY? WHAT NEXT?

1. Introduction

The conservation of a monument or archaeological object or site today is a process including its whole lifecycle, i.e. the related processes of knowledge, conservation, management, communication, exploitation. It's a complex process, driven by multidimensional data and approaches, fragmented, high-costly, producing large amounts of heterogeneous data (3D models, images, photos, drawings, texts) (Gaiani 2012). A Cultural artefact usually involves different research, conservation and maintenance activities, but also arrangement for the visitors. Moreover, these works are based on an ongoing collaboration between art historians, archaeologists, architects, scholars, conservators, managers and specialists who work together to solve the same problem. This implies the need of a real collaborative work between all parties involved. Finally, the process of conservation and restoration requires an increasing degree of automation.

More than 40 years ago the Charter of Venice well bounded the need of documentation for all steps of the conservation process already introduced since the end of the 18th century: «In all works of preservation, restoration and excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs». Following this general recommendation, documentation has grown in importance and evolving computer-based technologies offered continuously new possibilities of recording and managing information, requiring an increasingly close cooperation of professionals from disciplines involved and not formerly involved in the heritage field, such as documentation and computer specialists.

Today applications collect and make available on the Internet several information on the most different aspects, allowing to combine large amounts of data and their relational analysis with other sources of information. The most usual solution is the use of Information Systems (IS) aiming at the managing of the processes, to support the integration and the automation of the different processes, to organize the discovery and the knowledge, to drive the restoration and the maintenance, to improve the collaboration between subjects involved, and to communicate to city users.

As ISs, you can identify all technological systems that manipulate, store, process and distribute information that has or is expected to have an impact on human knowledge and behavior organized within real-world contexts.

From this point of view, IS can be considered powerful cognitive artefacts (Norman 1993) supporting humans in higher cognitive activities such as: encoding, decoding and storage of information; research; information retrieval and sharing; reasoning; learning; problem solving; and decision-making.

In recent times and in disciplines where information and knowledge are not directly literary, the problem of accumulation and cataloging has been complemented by the technique in which information is returned, so that bibliographic strings or apparatus texts are required to come up with images, drawings, photographs, models, articulated according to a structure that organizes the ways and forms of this transmission and of this fruition. This led to two new issues: how to convey information through specific media; how to retrieve information not from textual but visual indices.

To provide a comprehensive solution to the problem, a specific line of research has developed techniques for building 3D-based IS. The guiding idea behind it is the concept of 3D database as an operating tool exploiting the fact that a digital model can be seen as a vast, cognitive spatial information system that can be edited and implemented over time (Gaiani, Alessandri 1999). These 3D-based ISs represent a fundamental change in our cognitive model of archaeological artefacts and architectural heritage (AH): in order to capture and visualize the artefacts; in the technique of archiving them; in the method of illustrating the knowledge (Gaiani 2003), in the techniques to navigate through the cognitive corpus. We could learn not only how to examine the objects but also how to recognize and create new relationships between them.

Between 2000 and 2001 my research group developed the application *La via Appia antica archeologia e restauro* (Gaiani, Gamberini, Tonelli 2001), a naive 3D web-based IS capable of delivering on client-side three-dimensional, two-dimensional and textual information via structured query, and navigation and visualization of both current state and thematic analysis of eight Roman tombs along the ancient Appian Way in Rome. Although designed to be accessible to the general public over the Internet, the final system also had to be a tool for professional operators, with data collected in a hypermedia 3D network database available for use during the conservation and restoration process. The application was built using the paradigm of knowledge by vision today a must for the archaeological and heritage IS development.

In this paper, we present a short review of the subsequent development along a 20 years path by my research groups, focusing the features related to the knowledge by vision concept.

Starting from the consideration that a lack of adequate understanding of the purpose and technical requirements of documentation in general has created a sense of uncertainty amongst conservation professionals, especially with regard to matching the type of documentation and the level of detail to specific project needs, then we present problems emerged after 20 years of experimentation with 3D-based IS. We could briefly summarize main issues observing that in lifecycle process requirements and in the growing abilities of Information Technology based systems, the accessibility to the entire corpus of information that should be shared by the specialists remains limited and the process is broken down into discontinuous isolated parts. The main reason of this deficit lies not only in the large amounts of heterogeneous data that the process requires and which prevents both the immediate usability and an easy information transfer, but also in complexity and narrowness of systems developed.

A new vision potentially able to give more powerful strategies to preserve, manage, and communicate archaeology artefacts and AH is then illustrated. From a theoretical point of view, it is based on a model of global knowledge shared and available at any time, in any place, to any user: researchers, professional operators, students, and city-users. From a technological point of view, it exploits of the paradigm of the Internet of Things (IoT) with the aim to transform Cultural Items in Smart Cultural Objects (SCO), sources and recipients of advanced information. This is a fundamental revolution in the way we conceive not only the heritage system but also how to generate, acquire and transfer the knowledge related to it, and in the management, conservation and communication process.

2. Twenty years of solutions based on knowledge by vision

Today 3D based IS basically uses three-dimensional representation with the aim of visualization of the object descripted. This is one of the goals of our development started 20 years ago. This focus on knowledge by vision, largely motivated by the inherently 3D nature of archaeological and AH items, is largely inspired by the works of Semir Zeki and David Marr.

To understand the theoretical background of this line of development we just recall a couple of Zeki and Marr sentences. Zeki defined the function of seeing as: «the acquisition of knowledge about the world» (Zeki 1999). This sentence presents the corollary: «the brain is only interested in obtaining knowledge about those permanent, essential, or characteristic properties of objects and surfaces that allow it to categorize them» (Zeki 1999).

Ten years before David Marr in his book (Marr 1982) stated: «Vision is a process that produces from images of the external world a description useful to the viewer». One of the central, best-known ideas and key-point in our path is in his book, with the suggestion that the visual system generates a sequence of increasingly symbolic representations of a scene, progressing from a "primal sketch" of the retinal image, through a "2D sketch" to simplified three-dimensional models of objects. The three-dimensional model is an object-centered representation of objects with the goal of later allowing manipulation and recognition. This representation must be initially related to and derived from the two-and-a-half-dimensional sketch, which means that there must be a relationship between the schema of an object and the way in which the organization of its surfaces appears to the perceiver. This is a central observation allowing to introduce a property of 3D-based IS, remained largely unexplored by the developments of the last 20 years: the research of an appropriate way to organize and retrieve information using specific media.

Recently the concepts of semantic organization of the information (TER BEKKE 1992) and of semantic 3D modeling (DE LUCA 2013) received great attention, but nobody related correctly this research paths with the Zeki and Marr observations, not allowing a true computational approach to the use of vision as technique to organize and retrieve archaeological artefacts and AH information. To demonstrate this fact, we just remember that the most popular technique to retrieve information of each dimension also in our fields is the Google page rank (BRIN, PAGE 1998), supported by other 1D algorithms, that is an efficient technique to order textual information.

From 1997, instead, we developed a framework grounded on the Zeki and Marr considerations. It is based on five main concepts:

a) The use of 3D models as replica of original artefact with its attributes (color, shape, …) defined analyzing the real object. This allows to know the object with its visual and shape properties.

b) 3D models built as "knowledge representation": structures are described as a series of structured objects using a specific architectural/archaeological lexicon. This allows to know the semantic structure of the object and the technique of its construction and allow to organize information according to. Our semantic structure is mainly described in (APOLLONIO, GAIANI, BENEDETTI 2012). The adopted "shape-grammar" uses a pre-established set of tree-shaped formal rules that indicate a clear purpose and evident structure. This organization can be extended – if necessary – to several hierarchical levels. Therefore, our approach can identify, highlight and discuss not only the scheme but also the constructive rules; it is not limited to architectural objects and can address a wide set of objects ranging from a simple brick or bas-relief to a whole building.

c) A common database for all the uses: where data are simply filtered for the different type of users. This allows common contents between the users.

d) The content retargeting between different type of devices: to efficiently return the contents to a specific device and to the user to move the same information across multiple devices.

e) The geo-localization of the artefacts: to locate the object and to understand the object in its context.

A fundamental choice of this framework is to start each operation from a "Master model", i.e. the replica of original artefact with its attributes. Such approach makes possible to benefit of a digital document with its complete chromatic, graphic and metric attributes. The key step to generate a "Master model" is to define the qualities of a model in relationship to those of the object to represent. Therefore, the standards for object acquisition, modeling and visualization have been referred to the object itself, following the *ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites* (*ICOMOS* 2008). In this way, the intrinsic properties of each artifact determine the 3D data capture technique and instruments and the modeling level of accuracy. A "Master model" – based capture and processing workflow allows – unlike for methodologies and systems technology-based – to resolve the issue of the integrity of the original data providing many advantages in their long-term preservation.

The framework is the results of researches and experiments done on different subject and situations. The developed applications were designed for different types of users, with a largely scalable interface, able to support different output devices and to work at different levels of iconicity. For the IS designed and built, refer to Gaiani, Gamberini, Tonelli (2001), Brevi, Ceccarelli, Gaiani (2004), Gaiani (2008). Here we just recall the experiences of *PALLADIOLibrary* and of Parco Archeologico di Pompei Unified IS.

3. Solutions developed – The *PALLADIOLibrary* (2012)

In the panorama of 16th century architecture, Andrea Palladio is an exceptional and impressive figure, whose opera had an enormous impact and influence in the following centuries all over the world. Since 1958, the Centro Internazionale di Studi di Architettura Andrea Palladio (CISAAP) is the main research institute for the study of Andrea Palladio; its mission regards research, editorial and educational activities aimed at a deeper understanding, dissemination and promoting of Palladio's work. Since the middle 1990s the CISAAP focused on the digital applications for database management in order to facilitate research and public accessibility across a huge number of documents related to Palladio, as well as quantitative and comparative researches, thanks to the encouragement by the President of the Scientific Board, Howard Burns. In 2012 CISAAP launched the *PALLADIOLibrary* Project (Gaiani, Beltramini 2012), a system that, using advanced technologies of that time but available to all (RTR of 3D models, Web 3.0, geospatial systems), aims to unify and display all the key digitized materials as well as a set of multimedia and virtual reconstructions for a clear understanding of Andrea Palladio's work (Fig. 1). It is about his drawings, the largest existing photo library devoted to Palladio (over 5,000 photos), approximately 1,200

Fig. 1 – *Andrea Palladio - 3D geodatabase* (2012): interface with a descriptive card.

survey drawings, Palladio's writings (nearly 8,000 pages) as well as a set of multimedia and virtual reconstructions that allow both specialists and the general public to learn about Andrea Palladio's world: 54 constructions spanning houses, public buildings, palaces, churches, bridges. The *PALLADIOLibrary* arises at the end of a long process of accumulation of the sources and their digital conversions over the years, becoming the new starting point for the study and dissemination of the work of Palladio and his heritage, which is still alive and present in the world.

The core application of *PALLADIOLibrary* is a complete 3D web geo-database where 3D models support a complex IS, named *Andrea Palladio – 3D geodatabase* (AP3D) (Apollonio *et al.* 2010), which includes:

1) 3D digital models that represent as-built and serve as a metaphor of the observed objects, allowing a direct and semantic knowledge of the data;

2) 2D textual and iconographic materials provided by the CISAAP Scientific Board;

3) Development of a new web-based architecture that allows multi-user customized access on different platforms, using standard guidelines.

The application was conceived as the preferred interface for accessing the Palladian database, to give easy, user-friendly access to individual buildings and whole information systems. It allows a powerful representation of the architecture, whose complexity can hardly be approached and understood through textual or iconographic documentation.

The added value of AP3D – thanks to the visualization in real-time at high-quality rendering inside the geovisualization system of GoogleEarth – is given by the inclusion of the buildings in the territory, allowing to discover unknown relationships between the villas and the environment, to evaluate their architectural occupancy and to quickly access a complex system of information collected by several extensive researches along the years.

Designed as an IS capable to fill the requirement of heterogeneous data integration, it allowed to create a progressive digital consciousness in users who are not very receptive, thus creating user-friendly interfaces; to have an IS organized to be familiar and useful to AH scholars; the creation of specific tools that can promote research and study advancements.

AP3D is easily generalizable to the entire field of AH knowledge and is organized starting from the architect's protagonist documentation and works. The Palladian case of study is, in fact, a superset of the other possible cases, for the standing of the architect, for the amount and variety of the work accomplished (villas, palaces, churches, bridges), for the broad availability of graphic and textual sources, for the presence of a large number of studies on the subject and, finally, for the collaboration with our work of the most important researchers in the field.

Users of developed ISs include, first, important architectural historians from around the world and secondly also the public attending many temporary or permanent exhibitions made by the CISAAP, such as that in Villa Poiana in Poiana Maggiore, one of the best-preserved Palladio's villas, or that in the Palladio Museum, located within one of the finest Palladian architectures, Palazzo Barbarano in Vicenza.

4. Solutions developed – The Parco Archeologico di Pompei Unified IS (2010)

The study for the Unified Information System (SIU) of the Parco Archeologico di Pompei, carried out with the Pompeii Project financed by ARCUS S.p.a., developed by the Scuola Normale Superiore of Pisa (SNS) together with the University of Bologna, the at that time Soprintendenza Speciale per i Beni Archeologici di Napoli e Pompei (SSBANP) and implemented by Liberologico S.r.l. (Benedetti, Gaiani, Guzzo 2008), dates back to 2008-2010. The aim of the work was to produce a consistent 3D component in an archaeological IS able to reduce the level of complexity of the system and to improve the granularity of the information, facilitating the interpretation, the exploration and the analysis of large volumes of data strongly characterized in the geo-spatial, temporal and semantic sense. The project was ultimately intended

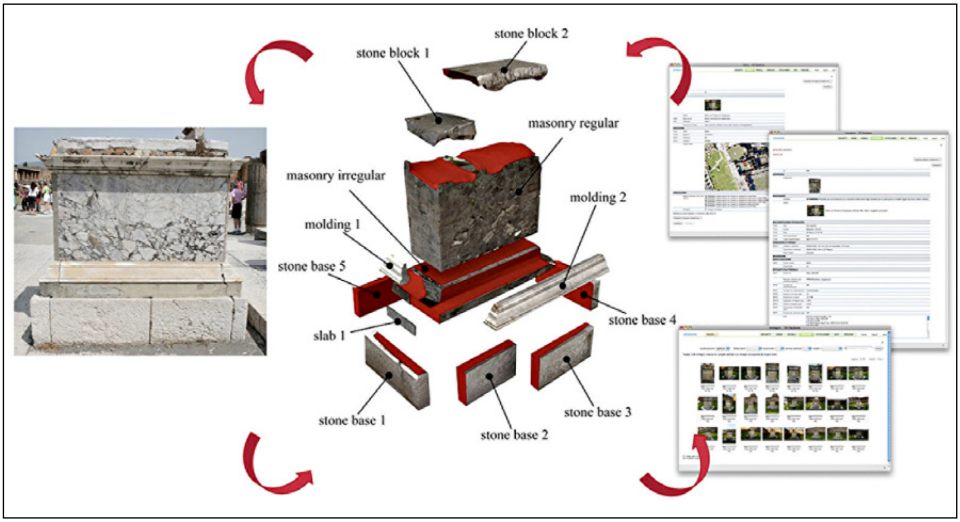

Fig. 2 – The Parco Archeologico di Pompei Unified IS (2010): the outputs developed to drive 3D model construction for the IS.

to document and reconstruct the historical evolution of the documentation system through a series of digital archives of textual and visual documents, and, above all, of geo-referenced systems and 3D models providing massive support for available information (Fig. 2).

In the SIU study, we added to the general work hypothesis a new one. We noted that in a vast archaeological site like Pompeii, to have constantly an updated actual state of the site, instead to charge of the survey one group, is much more realistic to think that anyone working in Pompeii (to study a single piece or portion of the site with scientific or administrative purposes) can contribute to the overall reconstruction following the well-specified guidelines. To meet this requirement, we defined not only specific techniques but also tools, methodologies and basic operating techniques for each type of artefact to be acquired and visualized. This resulted in the development of reference standards and the pipeline for the future 3D reality-based model construction of the Pompeii archaeological area, starting from the specific experience of capturing and constructing of 49 models from 13 artefacts

Following the "Master model" concept, metric standards were referred to the real artefact features instead of being related to the instrument or technology performance. The intrinsic properties of each artefact allowed then to determine the correct instruments to use, the 3D data capture, the modeling procedures and the level of detail (LOD), to fully render each item or part of item. To ensure consistency the work started, then, from an accurate analysis and a typological mapping of artefacts found in the archaeological area of Pompeii; by identifying case studies representative of most archaeological sites. To evaluate the correct methodology and the most effective tools for each specific type, the findings were then analyzed and classified by a typological point of view (geometric, surface and textural properties, semantics). In detail, we considered: shape and material characteristics of each finding; recurrence of the identified shape and material characteristics; tools and methods available and suitable for acquisition and construction of 3D models of archaeological artefacts; relationship between the environment in which the artefacts were found and the acquisition conditions.

The results of this study, aiming at the definition of a standard able to ensure the consistency of the process were of three types:

a) Documentation meant to define not only specifications, but also tools, methodologies and basic working rules for each type of digitized material/artefact, as well as standards related to the type of objects. These data have been transcribed into a manual, which has been used as working basis by the operators and now published in Benedetti, Gaiani, Remondino 2010.

b) A set of prototypes that explains scientific and technical challenges characterizing each type of object as well as how to work for specific classes of size and material properties. To this end, we identified and modeled a series of case-type artefacts, representative of the greater number of existing working environments. The output consisted in a series of high resolution 3D models (master models and derivatives at different Level of Detail) that could be included as geo-objects in a 3D web GIS, supporting metadata and specific analyses; and viewable in a semi-immersive VR environment, or inside a web system.

c) A geo-referenced database for data-entry of digital 3D models; allowing to drive the user to uniquely identify each model in face of pre-defined standards, and check its compliance with the required standards. The application aims to uniquely identify the artefacts 3D models in the Pompeii archaeological area and related documents (scans, photographs, …) in order to ensure their quality level and understand quickly the limits (Baldissini, Manferdini, Masci 2009).

5. A new IoT-based vision to preserve, manage, and communicate archaeological artefacts and architectural heritage

If we review today problems emerged after 20 years of experimentation with 3D-based IS we could immediately observe that results are very marginal, and also the methodological model is rarely used in its true formulation. The typical solution consists, in fact, in a series of isolated IS based on manual data entry (i.e. digitization). So, the knowledge is inclined to be recreated at each level, in contrast to what should be done in the knowledge society, where contents must be common and reused filtered according to the user and purpose. Accessibility to the entire corpus of information that should be shared by the specialist total lack and, as said in the introduction, the process is broken into discontinuous isolated parts. Integration remains a blue-sky project due to lack of coordination between different institutions and stakeholders.

The main reason of this deficit lies not only in the large amount of heterogeneous data (3D models, images, photos, drawings, written documents, etc.) required by the process, which prevents the immediate usability and an easy transfer of information, but also in the complexity and partiality of the systems developed to provide an answer to these problems. In addition, isolated 3D digital representations do not provide the same level of information like their peers from the real world, since these are not aware of the represented object, of its relationships, or of its history and provenance. Physical objects often play a significant role in this important cultural activity. It has been put forward that the memories of Cultural Objects provoke thoughts and emotions, constitute part of its identity, and mediate our relationship with the today configuration and the actual state, acting as intermediaries between future and past. Tools to share memories and their representations are today marginal in number and quality.

Furthermore, 3D web-based ISs enriched by heterogeneous data, are a complex solution to use for archaeologists and in general for CH and AH operators, high-costly. Also, 3D digitization is a largely manual complex task and photogrammetric and laser scanner based 3D model constructions are expensive and need experts to be used. Therefore, built 3D models need to be processed, analyzed and semantically enriched, in order to achieve a minimal professional level of cohesion. Also enrichment is a very complex task. Users need to have the ability to work with 3D software systems (e.g. modelling tools such as Autodesk Maya or 3ds Max), a requirement completely above the skills of the typical CH operator.

We could state that the simply digitization or 3D-based IS today are not an effective solution. In addition, we could observe – after 20 years of experimentations – that the today best tools developed and ICT-based technological innovation has not yet made substantial advantages in this context, although have desirable, as regards the management and use of assets.

It is still weak, for example, the adoption of the IoT and Machine-to-Machine Communication (M2M) paradigms, even if in the last years some solutions have been developed, mainly related to protection and access and interpretation of CH.

However, IoT related technologies could play a main role in archaeological and AH field as well depicted by Kim Veltman: «The earliest Internet focused on bits and on born digital words and images on computer screens.

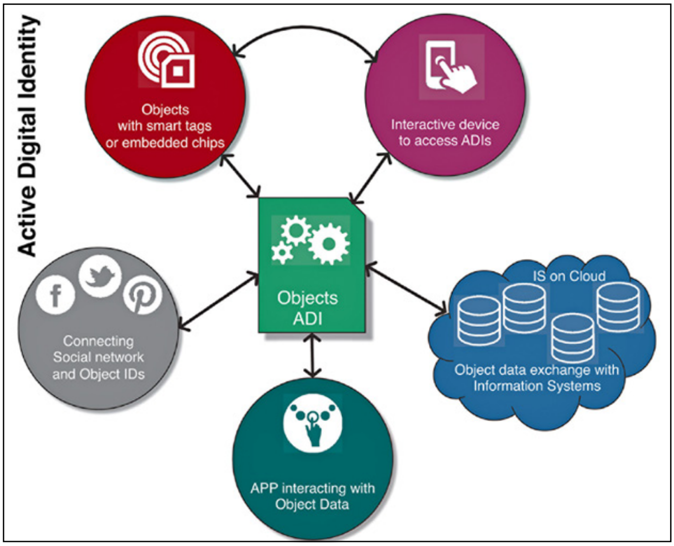

Fig. 3 – From Cultural Objects to Smart Cultural Objects: the Active Digital Identity.

The Internet of things is linking the electronic world of computers with objects in the physical world. Present day links are indiscriminate. Future links need to be tagged as relating to persons (who), things, ideas (what), spatial (where), temporal (when), procedural (how) and causal (why)» (Veltman 2012). An information framework enabled by IoT provides a means for consolidating these tasks and sharing of data between various service stakeholders and Institutions. Of course, this is not a simple technological progress: this is a key feature in our field, where the data are highly heterogeneous.

A fully integrated system containing sensing, storage, analytics and interpretation is required and possible. Their introduction and usage allow the use of the IT as infrastructure of cognitive systems to create a dense network of interconnected global knowledge and to create a close link between this infrastructure of knowledge and the end user accustomed to using only analog processes. The new network of Smart Cultural Object generates and broadcasts knowledge actively and dynamically (Fig. 3). Thus, the implicit knowledge in Cultural Objects is not accessible only in institutional sites related to their preservation and use; it is "distributed" through the city, directly and dynamically enacted by the same objects as associated with their own perceived reality. In fact, a SCO, thanks to network connection, is an object capable of taking an active role: to be immediately recognizable, to communicate information about itself and to connect to other objects. Therefore, the system of Cultural

Objects becomes a system capable of generating knowledge and accessing the collective knowledge generated through itself.

As a result, the cultural system, i.e. the system of institutions that produce (or should produce) cultural effects through the relationship established between the subject and object of knowledge, completely changes its appearance: from network of institutions that hold cultural objects to a network of SCO that "bring with them", as perceived together with the knowledge associated with them, the possibility of acquisition, transmission and creation of knowledge (Gaiani, Martini, Apollonio 2017). For example, IoT allow you to invert the classic mechanism of knowledge acquisition by making it possible to acquire not only general knowledge but also specific (documents) and personal (interpretive) knowledge, constituting the two most significant impacts.

A primary feature of these systems is the ability to conceive cultural objects as objects to be interpreted rather than as objects to be simply preserved and protected. This is, e.g., the purpose of the project *Tales of Things* (Barthel *et al.* 2013), a tagging service that makes use of QR Codes and RFID tags to allow ordinary users to attach object stories and memories.

A second feature of IoT systems is related to the spontaneous geo-location and creation of geo-localized data. This process is described by the concept of "citizens as sensors", where citizens are considered a dynamic source of information to feed spatial data infrastructures (Goodchild 2007).

In this new vision, the new knowledge system is distributed because it is directly associated to the things allowing to move from the today Level 1.0 where a network of institutions collect and distribute static knowledge related to the Cultural Objects, to a Level 2.0 where a network of SCO collect, distribute and generate knowledge and themselves IS.

As technical driver in another paper we suggested technologies derived from the Smart Card Secure microcontroller, used in contact or contact-less applications for high security environments (Gaiani *et al.* 2016). These technologies help to support, or even incorporate, a processing ability inside the artwork, and manage different domains: public (for visitors) and private (for managers). So, e.g., a security element embedding technologies typical of the smart card connected to an artwork may not only serve to identify it uniquely but, managing secure electronic transactions, will allow secure update of information related to interventions made on the artwork itself. The integration with inertial and magnetic silicon sensors, such as accelerometers, gyroscopes and magnetometers, can enable additional monitoring.

Finally coupling with radio frequency proprietary solutions can enable the use of applications developed for different areas such as Smart Metering, Telemetry, Fleet & Asset Management, Security and Surveillance. The coupling with NFC (Near Field Communication), allows transfer of information related to Cultural Objects via contactless devices.

Proposed solutions are characterized by small size, energy efficiency, low cost, and easy integration into the existing systems, allowing deploying the devices on a large scale, limiting the visual impact, the invasiveness of the solutions and with adequate sustainability in terms of cost.

Finally our hardware/software solution helps to support, or even incorporate, a processing ability inside the artefact, and manage different domains:

– public (for visitors);
– private (for managers).

This is a fundamental revolution in the way we conceive not only the CH system but also how to generate, acquire and transfer the knowledge related to it, and in the management, conservation and communication process.

6. Conclusions

After 20 years of development of 3D based IS to support archaeological and AH artefact knowledge, management and communication we verified that new paradigms are needed to overcome today issues. We introduced a model of global knowledge shared and made available at any time, in any place, to any user: researchers, professional operators, students, and city-users.

Based on this model we discussed a framework to support active management and communication of Cultural Objects using IoT-related technologies. We introduced, mainly, the concept of SCO, sources and recipients of advanced information. Finally, we demonstrated that their use could provide a valuable contribution to emphasize the knowledge processes through augmentation of past memories with information interfaces and bins, allowing a complete management of the artefact from conservation to communication.

Marco Gaiani
Alma Mater Studiorum – Università di Bologna
Dipartimento di Architettura
marco.gaiani@unibo.it

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ABSTRACT

In this paper, we reviewed 20 years of development of 3D based IS to support archaeological and AH artefact knowledge, management and communication and their theoretical work basis. In detail, we illustrated our experiences showing the advantages and limits we had observed after extensive use. In conclusion, we have illustrated a new paradigm based on IoT-related technologies, potentially able to overcome existing problems, and the theoretical foundation of the new framework that has been designed, the concept of the Smart Cultural Object, sources and recipients of advanced information and related technological underpinning.