2020 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Trento, Italy, October 22-24, 2020

A digital twin for distant visit of inaccessible contexts

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***Abstract* – This paper describes the example of an interesting distance visit approach carried out during the COVID-19 emergency, applied to an underground oil-mill in the town of Gallipoli (Puglia, Italy). The limitations of access for people with disabilities and the complete closure of Italian museums during the emergency have suggested the development of an immersive platform, in the broader perspective of using the output in according with digital twin perspectives. Then a tool to support an innovative visit method has been realized: a virtual visit assisted by a real remote guide, hereinafter referred to as "Live-Guided Tour" with e-learning functionality. All this has been made possible starting from a three-dimensional model of an underground oil-mill, from which we extracted the stereoscopic scenes. The stereoscopy is very important for the overall success of the project, because this aspect influences the level of interest, the immersion and the ability to generate emotion and wonder. Probably this is the only system available today for a shared virtual visit for an inaccessible context, which implements many features of a VR visit in a multi-user and multi-platform environment.**

I. THE DIGITAL TWINS, NEXT FUTURE

The term digital twins was originally developed to improve manufacturing and industrial processes. Digital twins were subsequently defined as digital replications of physical entities that enable data to be seamlessly transmitted contents from physical to virtual worlds. Digital twins facilitate the means to monitor, understand and optimize the functions of all physical entities and provide people continuous feedback to improve quality of life and well-being (El Saddik A., 2018).

Digital twin is at the vanguard of the Industry 4.0 revolution enabled through advanced data analytics and the Internet of Things (IoT) connectivity. IoT has increased the volume of many heterogeneous usable data from manufacturing, healthcare and smart city applications (Haag S. et alii, 2018). The IoT environment provides an important resource for predictive maintenance and error detection, in particular for the future health of manufacturing processes and smart city developments, while also aiding in fault detection and traffic management in a next smart city. Since a perfect integration between IoT and data analysis will be necessary in the near future, this important need will be possible thanks to the creation of a connection between physical and virtual twins. A Digital Twin environment allows smart cities for quick analysis and, using 5G network, real-time decisions can be made through an accurate analysis.

The first terminology was given by Michael Grieves, Research Professor (Florida Institute of Technology) in a 2003 presentation, and later documented in a white paper where are traced the future developments of Digital Twins. The first articles make a definition of "digital model". These are described as a digital version of a pre-existing or planned physical object. An important distinguishing feature, with the old definition of "digital model", is that there is no form of automatic data exchange between the physical system and the digital model. This means that a change made to the physical object has no impact on the digital model, and vice versa.

When data runs between an existing physical object and a digital object, and they are fully integrated in both directions, this establishes a "digital twin" reference. A change made to the physical object automatically leads to a change to the digital object and vice versa. A digital twin consequently provides an intimate connection with his real counterpart, and in some way determines an influence on it. An environmental monitoring system on the real object will be evaluated on the digital twin and, consequently, interventions on the internal microclimate, for example, will be managed remotely with effects on other environmental parameters. If a digital twin is connected with IoT systems or sensors, it allows a remote intervention that by the digital object affects the real object. In the near future, the use of digital twins will potentially be very common, they will grow in step with the rapid developments in connectivity via IoT within a smart city. As the number of smart cities grows, so will the use of digital twins. Moreover, the more data we collect from the IoT sensors embedded in our main services within a city, the greater the opportunities for economic growth and development of new innovative start-up able to provide those services will be. Digital twins can be used to aid in the planning and development of current smart cities and to help with the ongoing development of new ones in the world of energy saving. This data can facilitate growth by being able to create a living test bed within a virtual twin that can achieve two goals: first, to test the scenarios, and second, to allow Digital Twins to learn from the environment by analysing changes in the collected data. (A. Fuller et alii., 2020).

Therefore digital twin can evolve to become a true digital replica of potential or actual physical resources (physical twin), processes, people, places, infrastructures, systems and devices that can be used for various purposes. We can compare digital twin to other mirror model concept, which aims to model part of the physical world with its cyber representation.

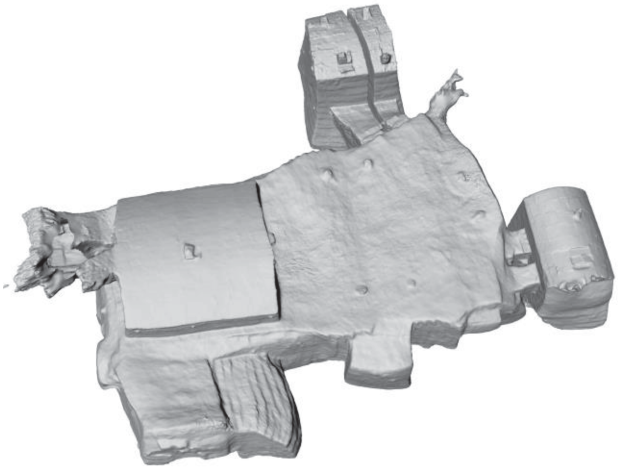

Fig.1: 3D model of oil-mill, phong shading mode.

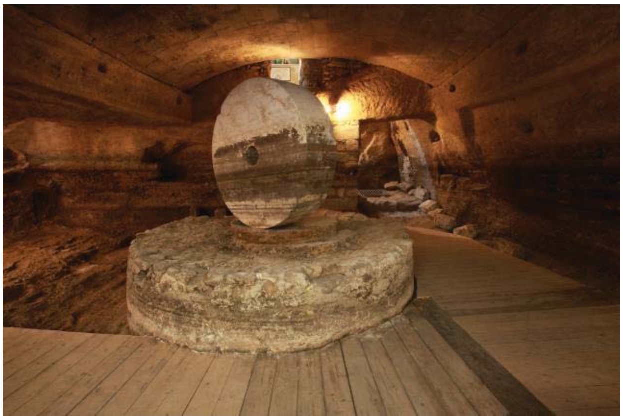

Fig.2: Real photo of the interior. The 3D survey held in high regard the "genius loci" of the real space.

II. DIGITAL TWINS FOR CULTURAL HERITAGE ENJOYMENT: A FUTURE PERSPECTIVE?

From this analysis, however, a criticality emerges. There is still a real difficulty in fully assuming a cultural heritage as digital twin, because, as Grieves himself pointed out, a Mirrored Spaces Model always refers to an extremely dynamic representation (Grieves M., 2019). The real dimension and the virtual dimension, in the primitive definition, remained connected during the entire life cycle of the system, going through all the phases of creation, production and operation. The definition of digital twin is still closely related to industrial production and its processes (Tao F. et alii, 2019). A necessary condition for the realization of a digital twin is the existence of physical products in real space, of virtual products in virtual space, and systems for connecting the flow of data that unite physical and virtual space.

Over the past 30 years, product and process engineering teams have used 3D rendering and process simulation to validate the feasibility of an asset within a production process. A 3D model allows the entire system to be merged into a virtual space, so that conflicts and critical issues are discovered more economically and quickly. With these premises, a product is only released when all the problems have been solved. Thanks to digital twin it is possible to test and understand how systems and products will behave in a wide variety of environments, using virtual space and simulation as a predictive moment. All this is possible by combining different technologies related to a single database that will contain all plant or product design data, simulation software, real-time data from the production environment and much more. The advantages are many, starting from the possibility of easily accessing data from many different sources, aggregating and visualizing them through a single synchronized and shared portal, and being able to add contextual information.

Many of the requirements among those listed will certainly not be met, due to the very nature of cultural heritage, which is not linked to the production industry. However, we can certainly imagine a future populated by digital twins of cultural heritage that systematically respond to a series of needs, ranging from conservation to knowledge of places, to fruition and enhancement.

In a new perspective of growth and use of the IoT, digital twins can become real "models of knowledge", integrated into a wider domain of elements. We can create a cyberspace with digital models that can allow facilities in a city with obstacles and limitations of use. Indeed, with other assumptions, this path has been opened for many years. In fact, the term digital heritage refers to the cultural heritage, which exists in relation to a digital model, a copy or replica of the physical (real) model, but often it is intended as "digital media in the service of preserving cultural or natural heritage". Therefore, if the digital heritage is within a broader system (for example of a smart city), where each digital resource communicates or it is connected in different ways to the others, then this could mean an evolution of the digital heritage in the direction of digital twins.

Next to an environment monitored by sensors and intelligent systems, it is possible to achieve an effective way of using digital models to ensure an ideal interaction with real spaces. This has always been done in the past: virtual archaeology pursues precisely these objectives, but if these models are connected to each other in a smart city, then they will also be part of an ecosystem. Considering that, it is possible to convert old digital scenarios with smart visits of cultural heritage in immersive and participatory virtual environments, within enabling platforms. The starting point is to make the virtual visit more collective, more interactive and more participative, with the possibility of receiving a valuation of the understanding level of the communicated contents. The ultimate goal is to integrate these virtual scenarios into an IoT system, where each of them can be connected with others 3D models which can be used in a digital twins perspective. These 3D scenarios can give information on their physical counterpart, information relating to environmental monitoring, energy consumption, state of conservation. At the same time we can use these models to cross the gap related to visitors with disabilities, or use them effectively as a distant visit tool. The important condition to make the digital twin effective with regard to communicative issues, is to obtain an ultra-realistic virtual restitution, in order to be able to offer emotion to the visitor, an emotion similar to the one achieved during a real visit. (Grieves M., 2012). The second condition is to have an accurate 3D model. Physical measurements can be effective, obviously, only in a reliable 3D space. When these two requirements are both satisfied, it is possible to deal with all the developments according to the world of digital twins.

III. THE CASE STUDY

An example of this approach has been carried out during the COVID-19 lockdown, applied to an underground oil-mill in the town of Gallipoli (Puglia, Italy). The main and most profitable activity, which has ruled the fate of Terra d'Otranto for many centuries, has been the oil industry, carried out in over 2500 hypogeous and semi-hypogeoum trappeti. In these sites only lampante oil was produced i.e. for industrial use, exported mainly to France and England, where it was used as a lubricant in wool industries and soap factories. (Monte A., 1995). The oil mill described here is entirely dug out of the rock and is actually preserved in its original form, with a very "organic" appearance, without regular or squared surfaces. The three-dimensional survey must be carried out taking care to faithfully renstitute its natural morphology, but above all the color of the walls and the dark aspect. The limitations of access for people with disabilities and the complete closure of Italian museums during the emergency have suggested the development of an immersive platform, in the broader perspective of a use of output as Digital Twin. Then a tool to support an innovative visit method has been realized: a virtual visit assisted by a real remote guide, hereinafter referred to as

Fig. 3: 3D model based on digital photogrammetry. Here two sets of images were used, the first to obtain the 3D model and the second to ensure optimal texturing.

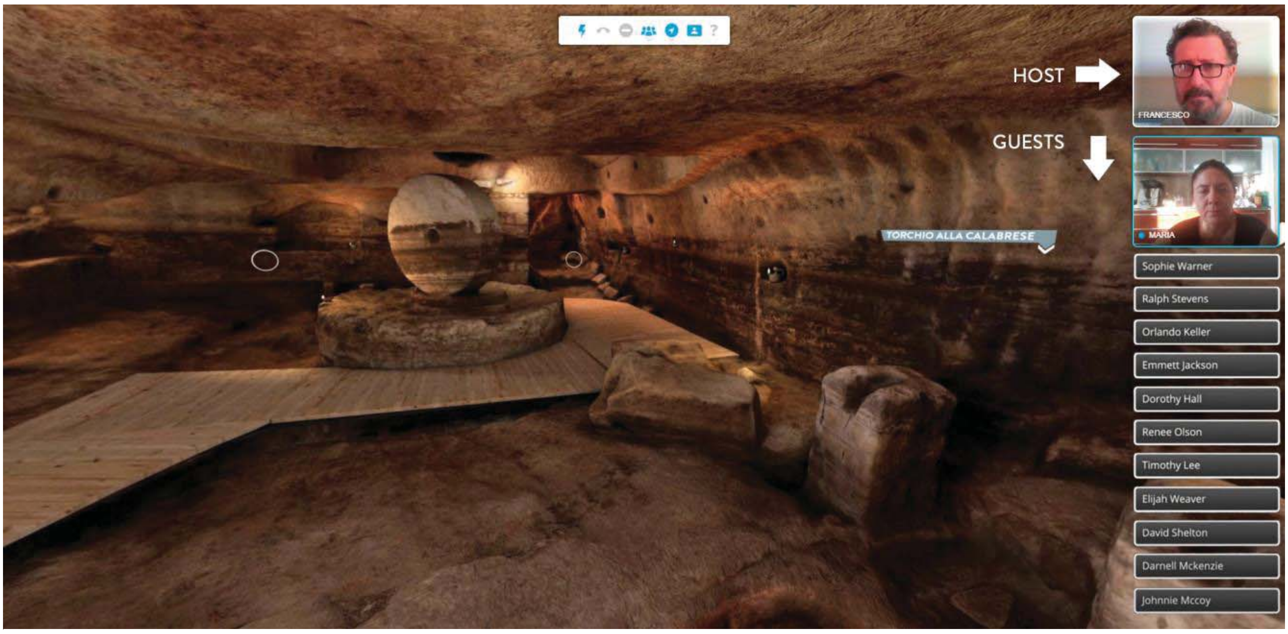

Fig. 4: Screen-shot of live-guided tour within the WebApp. The best way to obtain great sense of presence is to use VR headset (Like Oculus Go or Oculus Quest).

"Live-Guided Tour" with e-learning functionality. This tour mode allows to organize virtual tours for groups of visitors who can simultaneously connect to the web and participate in a tour in which a real guide, which is also connected remotely, organizes and sets the visit, providing information to visitors. A WebApp allows to accompany customers, students or colleagues in a shared virtual walk (Gabellone F., Chiffi M., 2015). The virtual tour is similar to a video conference in which the interactive content viewed on PC or portable device can be controlled by any participant. The guests of the tour may be accompanied by a real guide in a virtual tour where the guide (Host) has the ability to control the scene displayed by visitors, or to let them freely choose where to turn its gaze. Guests can then "break away" at any time by driving control and freely explore every scene, without losing the interactivity that characterizes the virtual tour. With a mouse click they can relate to the host location; in the same way, the host can force any visitor to reconnect to his point of view. Since the Tour mode is comparable to a video conference, during the visit each participant can take part in the discussion. The host (whether he is an agent, a teacher, a colleague, a tour guide) can call attention to areas of interest in real-time and discuss what is seen at 360° by all. The guest (customer, student, visitor to a museum, etc.) can follow the guide trip or ask permission to check out the tour for everybody. In this case he himself leads the tour: an ideal solution for asking questions about elements and details scene displayed. This type of visit is a significant improvement compared to video conferences with split screen: in this case we have a built-in communication tool in a virtual tour. Each participant will have a name and a small screen that identifies all.

The WebApp is available on any device, whether desktop or mobile, so every visitor can also connect their mobile phone. The information elements are available in different types: text, audio, images, virtual reconstructions and videos, all specifically developed to enable you to get the best knowledge of the places. The application has been developed with the features of a WebApp, which allows greater flexibility and compatibility with most media and operating systems.

In addition to these features, the WebApp integrates a learning management system (LMS), an application platform that allows the development of courses in e-learning mode in order to contribute to the realization of an educational or didactic project, but also to obtain objective results in terms of "evaluation of the communicative effectiveness" of a lesson or a guided tour. In other words, an LMS platform determines a score that gives the user a level of competence or knowledge. The use of these VR-based tools has shown greater effectiveness in learning than traditional teaching methods (Baruwal Chhetri M., et alii. 2004). The solution permits you to query visitors at any time of the tour. They can also be conditioned by a previous action (such as the discovery of a hidden element in the scene, after which a question that asks the user about it will subsequently appear). In addition to the questions and answers (simple or multiple choice questions), queries can contain all kinds of media, including photos, videos, 360º views or 3D models. At the end of a visit session, users will be able to see a score screen that depends on the settings chosen by the author of the tour. The user can download their performance sheet as file.cvs or send it immediately to the LMS. This feature allows the organizers of the visit to collect analytical data of the tour and verify the level of satisfaction reached by the participants.

All this has been made possible starting from a three-dimensional model of an underground oil-mill, from which we extracted the stereoscopic scenes. The stereoscopy is very important for the overall success of the project, because this aspect influences the level of interest, the immersion and the ability to generate emotion and wonder. Regarding the management of digital resource in the river of the possibilities outlined by the digital twins, it is crucial to have a very realistic three-dimensional model. Consequently a complete three-dimensional model with digital photogrammetry techniques has been created, now extremely widespread and known to all. The three-dimensional restitution has given many problems of coverage in the hidden areas and location management due to the lack of indoor lighting, but also due to the precise intention to obtain a digital twin that gives the same "*genius loci*" of the real space. Then about 3,000 high-resolution photos (21 megapixels each) have been taken, which have resulted in a mesh resolution of about 0.4 cm, acceptable for the purposes of the project and for the extension of the oil-mill (250 square meters). The measurements have been georeferenced with the sticking of coded target, and the total station coordinates have been recorded. From the morphological point of view, the digital model of the oil-mill is therefore a reliable replica of his physical one. As regards the extraction machines no longer preserved, presses with one or two screws were included in the visit, taken from other similar contexts with the same 3D techniques. Since the photogrammetry ensures excellent accuracy even of the visible colours of surfaces, the 3D model is ready for all subsequent implementations that affect the state of preservation, the measurement of the volumes, the static verification in relation to the loads and road surfaces, the calculation of the needs, energy, etc. At this time our Digital Twin allows remote visit for user groups in immersive way, with the possibility of expanding the tour trip to other contexts that can follow the same philosophy. Probably this is the only system available today for a shared virtual visit in an inaccessible context, which implements many features of a VR visit in a multi-user and multi-platform environment.

Fig. 5: The complexity of interiors and the realism guaranteed by digital photogrammetry (more of 3000 images were used).

The long-term goal is the creation of an advanced management model for cultural heritage. The association between physical reality and virtual reality makes it possible to activate a data analysis and monitoring of the systems in such a way that it is possible to operate in predictive mode, facing problems even before they occur. In addition to preventing anomalies, downtime and inefficiencies, using appropriate simulations it is possible to develop new opportunities, planning future business. By creating a digital twin, it is possible to better understand how to optimize operations, increase efficiency or discover a problem before it happens. For what we are interested in, the creation of digital twins related to cultural heritage allows the making of models representative of reality, to be used for conservation purposes, for knowledge and for overcoming physical and cognitive barriers.

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