Chapter 27
Geoheritage to Support Heritage Authorities: Research Case Studies on Maya Archaeological Sites

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Abstract Since the adoption of the World Heritage Convention (1972), modern technologies have significantly changed the way our society behaves and operates, with an increased demand for energy, fast and reliable communications, etc. Some modern technologies might contribute to negative impacts on heritage sites, e.g. through climate change and/or excessive tourism; however, modern digital technologies can also be extremely beneficial for heritage activities. In this paper, we focus on how modern digital geo-science and geo-technology can support heritage authorities' daily work. We introduce herein the concept of digital Geoheritage, which can help heritage authorities to discover and understand the enormous benefits that geomatics can provide for their daily heritage activities. This research case, implemented through an interdisciplinary scientific approach, originally aimed to support the preservation, restoration and management of a cultural heritage site; however, it was later expanded to also support archaeological research, stability risk assessment, planning, design, education, dissemination and promotion. The use of digital geo-sciences for the benefit of the local Maya communities living around a heritage site is also illustrated. Our objective, within the current book, was to present a paper that is oriented toward heritage authorities, and, therefore, technical language has been avoided.

Keywords Cultural heritage · Modern technologies · Applied geomatics · Citizen science · Geosciences · Community participation

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27.1 Heritage and Modern Technologies: An Introduction

Some modern technologies might be a threat to heritage sites, while other modern digital technologies can be beneficial for heritage activities. Recent advances in digital technologies have enabled a new emergent heritage assistance methodology, herein referred to as digital Geoheritage. The use of Geoheritage can have many advantages for heritage sites; the digitalisation of cultural heritage sites is important for the protection, conservation, restoration, research, dissemination and promotion of tangible and intangible cultural assets. For heritage sites, the possibilities created by advances in digital technologies are impressive and ever-growing, e.g., three-dimensional modelling or virtual/augmented reality that enables the concept of a "virtual heritage site" in such a way that if the heritage authorities cannot go daily to the heritage site, then the heritage site can come to them virtually. These non-invasive digital technologies are providing significant support in all aspects of heritage-related activities. The following research case, implemented through an interdisciplinary scientific approach, originally aimed to support the preservation, restoration and management of a cultural heritage site; however, it was later expanded to also support archaeological research, stability risk assessment, planning, design, education, dissemination and promotion. The paper further illustrates the use of digital geo-sciences for the benefit of the local Maya communities living around a heritage site. As our objective was to present a paper that is oriented toward heritage authorities, technical language has been avoided.

27.1.1 Modern Technologies, a Threat to Heritage Sites

More than half of the world's population now live in urban areas. Modern technologies, e.g., remote-controlled building cranes, are facilitating the growth of urban areas, and this sometimes affects World Heritage sites. The World Heritage Committee (WHC) identified a list of factors that affect World Heritage properties (WHC, 2008) in a report that specifically mentions "Buildings and Development". Urban growth, facilitated by modern technologies, is invading the historical landscape[1] of certain World Heritage sites, e.g., the *Giza Pyramids* (Egypt) (Vaz, 2011) or *Teotihuacan* (Mexico) (WHC, 2007b).

In 2015, the United Nations adopted Resolution 70/1, "Transforming our World: the 2030 Agenda for Sustainable Development" (UN, 2015). The document lays out the 17 Sustainable Development Goals (SDGs), which aim to end poverty and hunger, protect human rights and human dignity, protect the planet from degradation, and foster peace. Within SDG 11, "*Make cities and human settlements inclusive, safe, resilient and sustainable"*, Target 11.4 makes a vague reference to heritage

[1] Historical landscape is used herein as the geographical area around a heritage site, having remains of the human activities of the habitants that used to live in the heritage site.

(UN, 2015, 21–22). Such a reference is not nearly enough to safeguard heritage sites, especially from the uncontrolled urban growth facilitated by modern construction technologies.

Digital technologies, e.g., artificial intelligence and robotics, have revolutionized travelling by air, making it affordable and easier. Before the current worldwide pandemic, the airline industry was carrying 3.6 billion passengers yearly. Consequently, heritage sites are receiving a larger number of visitors. Overcrowding at a heritage site leads to degradation of the site and affects the quality of life of the local population.

Modern digital communication technologies have transformed our society and the way we communicate. There are many advantages of these incredible methods of communication; however, there are also disadvantages, for example, social media has created an anxious tendency to take a "selfie"[2] exactly as posted by others on social media. This is causing significant concentrations of social media tourists and damaging overcrowding at specific heritage sites, and it is a form of tourism that is uninterested in the various heritage values of such sites. European social media data shows that Paris, Istanbul and Rome have the largest number of posts for cultural World Heritage cities (between 50 and 110 million posts). The Acropolis in Athens is the most popular archaeological site (Thomas, 2021). Social media will continue showing users' preferred places and travel experiences, contributing to severe congestion and associated damages to certain heritage sites.

27.1.2 Digital Modern Technologies: Non-invasive Tools Supporting Heritage

Digital techniques that support heritage documentation, preservation, protection and presentation cover a wide range of technologies, mainly grouped in three major areas: data capture, virtual reconstruction and visual communication. Contemporary advances in science and technology facilitate the elaboration of accurate 3D models of heritage sites' features. Heritage 3D models can range from using high-resolution satellite images to model entire historical landscapes with a resolution of meters (m) to the modelling of small archaeological features (e.g., small pottery artefacts) with a resolution less than 1 mm.

Today, thanks to powerful laptops and digital cameras, digital Geoheritage can be used at heritage sites to capture data and upload such data to the internet for processing. In fact, during the last decade, digital applications have become part of the archaeological toolbox. Together with archaeological sciences, digital databases

[2] A "selfie" is a self-portrait photograph, typically taken with a digital camera or smartphone and showing the person taking the picture with a well-known element in the background. Selfies are often shared on social media to inform friends that the author has been visiting such a place.

and other computer methods, modern digital technologies are now present in every respectable archaeological investigation (Nicollucci, 2020).

27.2 The Heritage Site and Project Partners

Our research case study focuses on an outstanding Maya archaeological site that represents a masterpiece of human creative genius; it exhibits an important interchange of human values over a span of time within the Maya culture. The archaeological Maya site of Edzná, located in the State of Campeche, Mexico, was the ancient urban area that hosted the *"Itzaes" (*in Maya *Ytzná/Edzná)* (Fig. 27.1). *Edzná has an urban extension of 25 km*^{2}. The main elements of the heritage site buildings correspond to the Maya *Petén* architectural style (Benavidez, 1997, 2014). *Edzná* was abandoned around 1450 A.C., and then the exuberant vegetation of the tropical forest grew between the stones in such a way that *Edzná* became a series of hills covered by vegetation. In modern times*, Edzná* was well known by the local Mayas living in its surroundings. Being very humble people, they never thought about letting others know about this heritage site. The discovery of *Edzná* is then erroneously attributed to an Austrian explorer who published about it in a European journal. In 1943, Mexican heritage authorities began to remove the vegetation and initiated the associated restoration of *Edzná* (Benavidez, 2014). Today, heritage management, archaeological research, restoration, safeguarding and dissemination

Fig. 27.1 Heritage site of Edzná. (*Note*. Source: Photograph, by Hernandez M., 2018)

related to the site is under the authority of the Mexican Institute of Anthropology and History (INAH).

The type of research described herein, originated in 2000, when the European Space Agency (ESA) and UNESCO launched the "Open initiative on the use of space technologies to support World Heritage sites, From Space to Place" (ESA, 2003). This was a call to all geo-space actors to join in supporting heritage sites. Over eighty space partners joined the initiative, and Ghent University (UGent), Belgium, was among these. Financed by the Belgian Science Policy Office (BELSPO), UGent, through its Department of Geography, provided invaluable contributions. UGent, jointly with ESA, produced the very first full and accurate cartography for the five World Heritage sites of the Democratic Republic of Congo and Rwanda. In 2005, UGent significantly assisted with the inscription of *Calakmul*, Mexico, as a mixed site (Belspo, 2003). Since then, UGent and Dr. M. Hernandez have been working jointly with INAH Campeche supporting Maya archaeological heritage sites. For this research, the team is composed of INAH Campeche, UGent and Dr. Mario Hernandez.

27.3 Heritage-Related Issues and Objectives

We identified various challenges with respect to *Edzná*. As with many other heritage sites, common issues related to insufficient funding, lack of staff, inappropriate or non-sufficient tools for the cleaning of vegetation, etc., were mentioned by INAH heritage authorities. We decided to focus on the following challenges where Geoheritage could be of assistance: 3D digital models to enable office research, avoiding frequent field visits to the heritage site, as well as facilitating the measurement of different archaeological components and significantly reducing the complexity of on-site research; temporal digital 3D models (and 4D, where time is the fourth component) to monitor the vegetation cleaning and restoration work; accurate digital architectural plans to speed up the process of vegetation cleaning; assessment of eventual ground subsidence causing structural damage to the main archaeological buildings; use of 3D models for education, dissemination and promotion.

It is also important to understand that the main goal of our research work was for the results to support the *Edzná* heritage authorities in the following: developing a methodology that can be used locally in the long term, eventually with the support of a local university (know-how and technological transfer); selecting equipment for data capture that is affordable for the heritage authorities; implementing all digital processing methods in such a way that they become open access and accessible as web services. On the other hand, our research also aimed to identify high-level research topics that enable the involvement of Masters or PhD degree students at UGent.

27.4 Geoheritage Assisting Site Managers

Human eyes work together to gauge distance (called depth perception); each eye sees a 2D image, which is similar to photographs. These two images are then processed internally by our brain to extrapolate depth (stereoscopic vision). Conversely, photogrammetry uses a sensor (e.g., photographic camera) to capture a surface. The line between the camera and the centre of the object is called the “line of sight” (sometimes called “ray” or “beam”). However, if we capture a second photograph of the same object from a different location, being careful to cover almost the same surface as the first photograph (overlap), we can then obtain a different 2D photograph. The different “lines of sight” of each photograph can then be mathematically intersected to produce the 3D coordinates of the various points located on the common surface covered by the two 2D photographs.

Modern digital technologies are facilitating the acquisition of 2D digital photographs. Using the Global Positioning System (GPS), extremely accurate digital measurements are obtained for the position of the camera and the distances between the archaeological object and the camera. In our research, to obtain high-cartographic accuracy, we used ground control points (GCP) in a geographic network. Thanks to digital cameras that can autofocus and hold thousands of photos on their internal memory card, an enormous number of digital images of an archaeological object can be captured. Big Data methodologies (Pence, 2014) and artificial intelligence can then be used to process all digital images, including the GPS points in the process. The results are extremely accurate 2D architectural plans of the archaeological monument or, even better, highly accurate 3D models.

Digital technologies have also enabled the development of digital devices that can capture the 3D coordinates of points located on archaeological monuments, e.g., hand-held laser scanners make it possible to obtain 3D models with higher than 1 mm precision. An airborne LiDAR scanner (LiDAR stands for Light Detection and Ranging) can also be used to model a historical heritage landscape. LiDAR on an aeroplane can map terrain at 30 cm resolution.

Appropriate sensors (to capture digital images and/or digital points) can be chosen depending on the needs of the site manager. A series of new data capture sensors as well as tools have been developed in the last 15 years, including high-resolution satellite images, laser scanning, rapid prototyping, red-green-blue-depth (RGB-D) sensors, high dynamic range imaging, spherical and infrared imaging, mobile mapping systems, unmanned aircraft systems (UAS), based imaging, augmented and virtual reality, etc. In summary, Geoheritage comprises a wide range of digital scientific and technological methodologies (Fig. 27.2).

Structure from motion (SfM) photogrammetry is a method of deriving a three-dimensional structure by using two-dimensional images. For our research case study, we used the structure from motion (SfM) photogrammetry methodology, which can derive hyper-scale three-dimensional (3D) landform models. This methodology is based on the use of overlapping geo-referenced images acquired from different perspectives. As stated, our objective was to use techniques that would be

Fig. 27.2 Scientific disciplines under the “umbrella” of Geoheritage. (*Note*. Source: diagram created by Hernandez M. 2021 ©M.Hernandez)

affordable within the framework of the heritage authorities of *Edzná*. SfM is widely used in geo-sciences applications as it is a low-cost topographic survey technique that can produce dense 3D point clouds, digital elevation models and topographic maps (Carrivick et al., 2016). As it is a well-structured repetitive methodology, one advantage is that AI can be applied to optimize and speed up the processing of digital images.

A point cloud dataset is a large collection of points that are placed on a three-dimensional coordinate system. Point cloud files greatly speed the design process by providing real-world context where you can re-create the referenced objects or insert additional models. When deriving a point cloud dataset, it is important to eliminate erroneous points that are due to artefacts in the original images and/or erroneous recording of geo-referenced parameters. The automatic detection and elimination of noise in point cloud datasets is an important area of research (Cheng & Lau, 2017).

Digital data sensors and the associated processing software are well known for geomatics experts, but they are not typically within the knowledge of the heritage site managers. Therefore, the main challenge for us has been determining how the produced accurate archaeological 3D models can be provided to heritage site managers who do not have the complex software or educational background to process 3D geomatics data. We have, therefore, developed 3D services based on geographical information systems (GIS) on the web (WebGIS). Such services can then be easily accessed by heritage site managers to search and query, in real-time, segments of the 3D model at different resolutions.

For heritage sites and their associated historical landscape, digital geometric documentation has many advantages. The principal advantage of this new science and technology is, according to our heritage expert partners, that they enable a non-invasive methodology to interact with the different heritage objects.

27.5 Results

Thanks to the accurate digital models that were obtained, the work of the heritage authorities related to archaeological research and associated restoration (cleaning from encroached vegetation) was significantly speeded up. Due to the current pandemic and the lockdown in Campeche, Mexico, the heritage staff were unable to undertake any fieldwork on the site but could continue their archaeological restoration measurements using the digital 3D model from the office and home (tele-archaeology-restoration preparation).

The analysis between the 3D models at different times indicated terrain subsidence of some mm occurring mainly at the end of the rainy season. This was confirmed in 2020 when heavy rain caused a collapse onto part of the main building. The use of infrared cameras on drones has been extremely useful to identify archaeological vestiges. The water channels were identified and mapped, and the wall surrounding the site in *Uxmal* was clearly detected and mapped. A larger replica of our 3D model is being printed with a 3D plotter. Such a model will be shown at the Museum in the city of Campeche and used for education, promotion and dissemination of the importance of this heritage site.

In summary, as the *Edzná* site manager stated, "the digital 3D model, seen from various angles and with different angles of illumination brings per se a completely new set of ideas for further research as well as questions to be addressed".

The more we work jointly with the heritage authorities, the more they identify additional applications. Therefore, we continue with data acquisition and processing to further implement solutions to support the heritage authorities in their daily tasks. The most attractive results can be visualized in 3D on the associated website for this research project (UGent, 2013) (Figs. 27.3 and 27.4).

Fig. 27.3 Digital 3D model of the "Edificio de cinco pisos". Multitemporal 3D models were used to assist the cleaning of vegetation. (*Note*. Source: Screenshot from http://cartogis.ugent.be/edzna/ 2021 ©UGent)

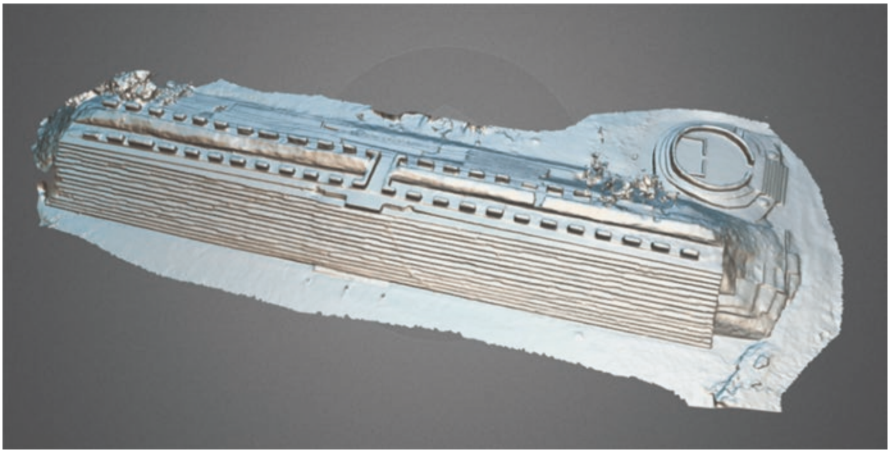

Fig. 27.4 Digital “mesh” for the building Hochna of Edzná. This result was used to restore the main stairs. (*Note*. Source: Screenshot from http://cartogis.ugent.be/edzna/ 2021 ©UGent)

27.6 Geoheritage Science and Technology, Supporting Communities of the Surroundings of a World Heritage Site

While undertaking field research studies in *Edzná,* we met Archaeologist José Huchim, the site manager of the World Heritage *Uxmal* (WHC, 1996). Mr. Huchim was having a series of meetings with the Maya communities of all villages surrounding *Uxmal*, one of the main concerns being that the heritage site was not perceived by the locals as a benefit but rather as a nuisance to their daily lives. According to the 2015 census, over 70% of people in all the municipalities surrounding *Uxmal* live in poverty.

The WHC has been encouraging the participation of the local communities in heritage-related activities. At the 31st WHC session, a fifth “C” was adopted, with the five “Cs” being the following: strengthening Credibility, ensuring effective Conservation, promoting effective Capacity-building measures, increasing Communication and enhancing the role of Communities in the implementation of the WH Convention (WHC, 2007a). In the case of *Uxmal,* the Maya communities are not asking to be involved in the implementation of the Convention but rather to benefit from the large number of visitors who come to *Uxmal*. Such an expectation is extremely valid, and if the heritage site can help improve the poverty situation of the Mayas, then the local communities will appreciate the site and become interested in its associated safeguarding. However, if the heritage site only causes inconvenience for the local community, it is understandable that they would not want to participate in any related activity.

The *Uxmal* local communities have identified offering eco-tourism services as potential activities that might encourage visitors to *Uxmal* to stay longer in the area and enjoy the richness of the habitat of the Maya communities and unique intangible heritage, including traditional food, handicrafts, etc. The area has significant potential for the proper development of tourism services. Modern Mayas live within an outstanding richness of natural heritage and tangible and intangible cultural heritage. Mexico is among the world's largest megadiverse countries, with the Yucatán area being home to the country's largest remaining swath of tropical forests (Varns et al., 2018). The three peninsular states (Yucatán, Campeche, and Quintana Roo) have long recognized that they share one ecosystem in the great Mayan Forest, as well as a common cultural heritage.

Therefore, the Maya communities aim to locally design, implement, manage and operate tourism services. Such locally designed tourism services would then bring necessary financial income to alleviate the poverty of the Maya population. These activities will contribute towards a successful implementation of the UN Sustainable Development Goals: SDG 1 no poverty; SDG 2 no hunger; SDG 3 good health and wellbeing; SDG 5 gender equality; SDG 6 clean water and sanitation; SDG 8 decent work and economic growth; SDG 10 reduce inequalities; SDG 15 life on land (by promoting the protection of nature).

After a full overall assessment, we identified that we could use a series of geo-packages to provide the local Maya population with a simple end-user interface (geo-tools) to collect main points of interest (POI) for the automated elaboration of attractive and accurate eco-tourism cartography. We define POIs as being geo-referenced points related to, e.g., Maya hut where local food can be eaten; viewpoint for biodiversity; points on a path for bike tours inside the tropical forest; *cenote* for swimming etc. This participatory activity of collecting ground data can then be used to automatically elaborate tourist maps. The resulting eco-tourism maps would be a first step in initiating the promotion of associated eco-tourism services. Based on UGent's long tradition of developing geo-educational packages (Zwartjes, 2016), we made use of complex GIS services that can combine with an easy-to-use front-end smartphone application (app software) and facilitate the Maya communities collecting of geo-referenced POIs. The Mayas can further enrich this information by adding pictures and descriptive text. The collected POIs can also be uploaded to the world wide web through the app, using the internet facilities at the *Uxmal* heritage authority office. The POIs are then automatically downloaded into a complex web Geographical Information System (WebGIS) developed by UGent. Once in UGent's server, the cartography is built through WebGIS tools and artificial intelligence. Such cartography is enriched with the automatic addition of satellite imagery as backgrounds, as well as GIS administrative boundaries from the Mexican Institute for Geography and Statistics (INEGI). The resulting cartography is sent, through the web, back to *Uxmal* headquarters in the form of a printable file (Fig. 27.5).

At this stage, it is important to understand that our research has developed the app for the collection of POIs, but the current pandemic has prevented us from returning to *Uxmal* to work jointly with the local communities.

Our solution of automatically elaborating tourist cartography resolves one major challenge of eco-tourism services. However, the Mayas are now facing the

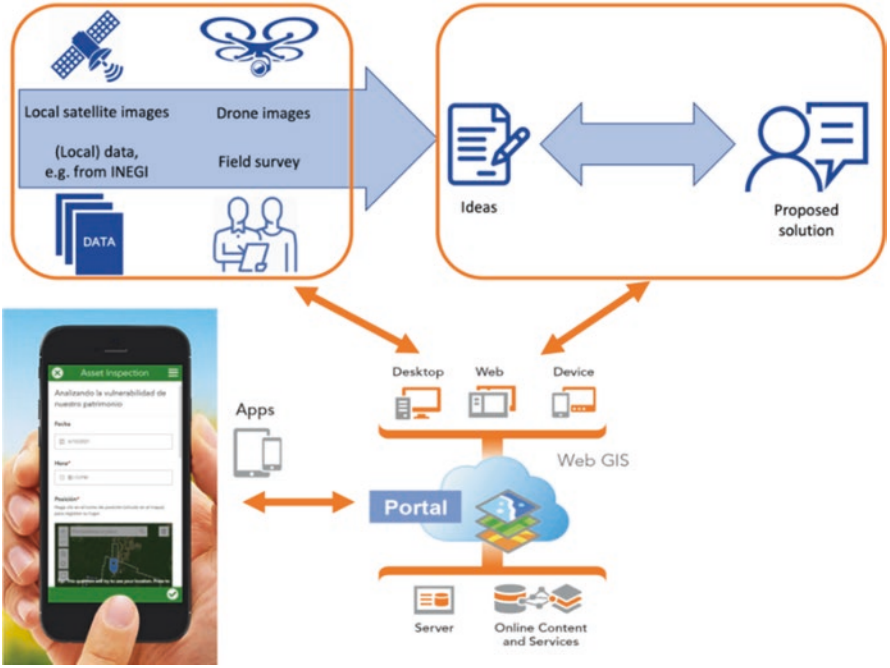

Fig. 27.5 The local Maya population can use the app to capture POIs. (*Note*. Source: Diagram created by Zwartjes L. 2021 ©UGent)

challenge of not being able to promote their eco-tourism services because there is a strong and well-established tourism monopoly, where everything is predefined in advance, including the time that tourists spend in *Uxmal*, souvenir shops where the bus will stop, places where they will have lunch, etc. This makes it impossible for the Mayas to offer their eco-tourist services due to the strong dominance of existing tourism operators. This issue illustrates the complexities of providing support for sustainable development using science and technology. This situation clearly reflects that the involvement of the local population in heritage-associated benefits and activities is not as simple as it is stated in the decisions of the WHC.

27.7 Conclusions

We have described an applied research study with the main objective of assisting and supporting heritage authorities in their daily work and how a second opportunity emerged to assist the local Maya communities using Geoheritage.

We are thankful to INAH Campeche for their enormous support. The main success of our research study is that we were able to put together a multidisciplinary team of scientists with a wide range of expertise, covering satellite remote sensing, cartography, geography, geographical information systems, photogrammetry, education, computer sciences, archaeology, heritage restoration, etc. Clearly, heritage-related issues require assistance from various disciplines, with the main challenge being to establish a common language and, as a consequence, a common understanding within the scientific team. The science and technology we have used can be transferred to a local team of experts supported by a local university. Although we have colleagues that are archaeologists who have acquired an outstanding knowledge of Geoheritage, we recommend that heritage experts, already overloaded by their daily work, remain focused on their domain of expertise and that other sciences should be used to assist them.

There are many advantages of using Geoheritage for heritage sites; for example, the digitalization of cultural heritage sites offers unique opportunities to share heritage information among heritage experts, heritage authorities, and many other scientific disciplines. All this contributes significantly to supporting heritage-related activities.

Working in *Edzná*, questions concerning the inscription methodology of the WH List emerged, as *Edzná* could easily fulfil all the requirements. However, without the WH label, *Edzná* is perceived as being a third-class heritage site. Tourists prefer to visit already overcrowded sites, causing severe damage. A better distribution of tourism crowds would be more beneficial for all the heritage sites. A serial nomination of Maya Heritage sites from El Mundo Maya should be considered.

Advances in digital technologies are continuously improving what we have referred to as Geoheritage science and technology. This is creating new opportunities for the cultural heritage sector, offering innovative non-invasive methodologies for heritage research, presentation, dissemination, education and enjoyment. Digital Geoheritage also makes it easier for other scientific disciplines to participate in heritage research activities, constituting a unique and powerful multidisciplinary scientific platform for supporting heritage.

There are also new challenges that heritage experts alone may not be able to solve, including the tremendous amount of digital data, the complexity of algorithms and computer processes involved, as well as the expertise required to produce accurate 3D heritage models. Therefore, the main challenge is providing heritage experts with easy-to-use end results that do not need to be installed or require particular expertise for dealing with sophisticated software packages. All complex data processing can be completed in "the cloud"[3] using artificial intelligence. With the support of WebGIS services, we have been able to make the final results available to heritage experts. Heritage experts can then visualize the 3D model on the web, observing virtual tours, and, when necessary, selecting different sections at different scales of 3D models. This enables them to have accurate digital replicas of their selected sections in the office. The number of emerging applications is infinite: heritage authorities can virtually undertake a digital

[3] "The cloud" refers to computer servers, software and databases that are accessed over the Internet. By using cloud computing, users do not have to manage physical servers themselves or run software applications on their own machines.

restoration to see the results and decide then if such a methodology should be applied or not to the real heritage site. Heritage authorities can upload their results on private websites to exchange these results with other cultural experts working on similar issues elsewhere, providing a fast and unique exchange of results and expertise. The main success of our research case study is how much the heritage site managers and heritage authorities appreciated the support provided by Geoheritage.

With respect to the WH Convention, UNESCO's Science Sector could have a significant role to play in supporting heritage (Cultural Sector). Unfortunately, UNESCO carries out its programmes through individual sectors, with each sector remaining a "closed silo", struggling to obtain visibility for survival. As an example, *Calakmul* has dual labelling as a UNESCO Biosphere Reserve and a mixed World Heritage site. Issues related to sustainability have to be addressed within the Sciences Sector, while issues related to the Outstanding Universal Value have to be addressed within the Cultural Sector. However, both of these issues cannot be separated in the field.

The Educational Sector also has significant potential to contribute to heritage. If the different sectors were focused on supporting heritage, it would give UNESCO a unique role within the UN system, in contrast to its current widely dispersed roles. Outside UNESCO, in pursuit of the UN SDGs, scientists are setting up multidisciplinary scientific teams as the best and only option to address the complexity of sustainable development (Hernandez, 2017), and the time has come for UNESCO to consider this approach.

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