Chapter 17
Digital Heritage

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Abstract Natural and cultural heritage, the common wealth of human beings, are keys to human understanding of the evolution of our planet and social development. The protection and conservation of natural and cultural heritage is the common responsibility of all mankind. Spatial information technology provides a new applied theory and tool for the protection and utilization of natural and cultural heritage. This chapter is divided into four parts. The first part elaborates the connotation of digital heritage, the differences and connections between digital heritage and physical heritage, the technology of digital heritage formation and the research objectives and content of digital heritage. Parts 2 and 3 discuss the contents and methods of digital natural heritage and cultural heritage, respectively, and some practical case studies. In the fourth part, the future development trends of digital heritage research in protection and utilization are described, as well as six research directions that deserve attention.

Keywords Digital heritage · Spatial information technology · Remote sensing · Archaeology · Heritage conservation · Case study

17.1 A Brief Introduction to Digital Heritage

Natural and cultural heritage, with unique value in the realms of science, culture, history and art, are like jewels emerging from a wide variety of ground object types that shine on the surface of the Earth. Heritage is defined as our legacy from the past, what

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we live with today, and what we pass on to future generations. As common wealth of all mankind, its enduring value should be kept for future generations. Accordingly, the recognition and preservation of its outstanding universal value (OUV) has been a great concern for UNESCO, highlighting the emerging role of digital heritage, which is defined by UNESCO as the use of digital media in the service of preserving, protecting, studying and presenting these heritages.

The great value and significance of digital heritage was affirmed by two UNESCO documents released in 2003: the Guidelines for the Preservation of Digital Heritage (National Library of Australia 2003) and the Charter on the Preservation of the Digital Heritage (UNESCO 2009). The Charter describes digital heritage as "resources of human knowledge or expression, whether cultural, educational, scientific and administrative, or embracing technical, legal, medical and other kinds of information, are increasingly created digitally, or converted into digital form from existing analogue resources." When resources are "born digital", there is no other format but the digital original, including text, databases, still and animated images, audio tapes, photos, software, and web pages.

Many of these digital heritage materials will be passed down from generation to generation. Digital heritage may be classified by genres: information resources stored in specific carriers (such as optical disks, disks, and tapes), computer databases, or disseminated via the internet or digital media, and preprint materials or archives held in e-prints.

"Digital heritage", a concept that is distinguished from its physical counterpart, constitutes an integral part of the Digital Earth program. Digitalizing heritage enables the enduring value of physical heritage to be long-term preserved, easily accessible to, widely shared and disseminated to the public. Heritage in the digital form also facilitates in-depth research from various perspectives (Hu et al. 2003). Digital heritage plays an important role in permanently preserving the information derived from physical heritage. The implication of "digital heritage" used in this handbook is compatible with that described in the two UNESCO documents mentioned above. However, unless otherwise specified, the term of "digital heritage" here refers to "digital natural and cultural heritage", which means digital resources or products converted from existing natural and cultural heritage or analogue resources. It includes dynamic or static digital information created during the process of digitalization, which includes creation and documentation, preservation and protection, processing, dissemination and presentation. In this handbook, digital heritage refers to the categories of cultural relics and natural landscapes. Similar to general digital heritage, digital culture and natural heritage exist as information resources that are stored in specific carriers (such as optical disks, magnetic disks and tapes) or computer databases, or presented on display and disseminated via the internet.

The technologies involved in digital heritage cover a variety of aspects including creation, storage, monitoring, dissemination, presentation and protection.

The creation and documentation of digital heritage consist of technological processes such as digital perception, data collection and processing, information extraction and interpretation, and digitally documenting.

Joint efforts should be undertaken to preserve and protect digital heritage and to keep it accessible to the public and maintain its long-term availability to future generations. Efforts include developing technology and tools, designing management frameworks, initiating protection programs, taking management measures, and related law-making issues.

The dissemination and presentation of digital heritage involves several aspects including the technology and tools for digital creation, channels and measures for dissemination, management measures, and the support from regulations and laws. Digital heritage should be presented vividly to ensure that the public can understand, share and make good use of it.

Digital heritage focuses on the digital products derived from its cultural and natural heritage ontologies and related environment. The research covers the process of how digital heritage is created and presented, how to protect it and develop related products, and how to transform these products into new digital products in the form of knowledge. It is also necessary to have a profound understanding of the ontology-environment interaction, and therefore take effective protective measures in advance. Digital heritage research features noncontact and nondestructive ontologies.

Digital heritage shares some common characteristics of cultural heritage. The research is centered on the techniques and knowledge for (1) digitalization of the heritage ontology; (2) preservation of digital heritage; (3) the use of digital heritage (4) demonstration, sharing, and publicity of digital heritage; and (5) laws and regulations on digital heritage protection.

The creation of digital heritage, namely, the digitization of heritage ontologies, involves the use of satellite-based or airborne data as well as data obtained from ground and underground exploration or manual observation. It involves a set of techniques and methods for nondestructive detection, monitoring, and evaluation. In addition, heritage preservation and digitalization also need the support of legislation at the national level, which constitutes the cornerstone for implementing digital heritage programs. The use of digital heritage involves a wide range of technologies and knowledge in terms of digital generation, heritage protection, monitoring, and law-making issues on heritage protection.

The purpose of digital heritage preservation is to ensure that it remains accessible to the public and to prevent it from disappearing. Accordingly, digital representation of heritage ensures that the essential value of its ontology is widespread and enduring. To achieve this, specified approaches are suggested for the use, research and protection of two kinds of heritage, corresponding to its natural or cultural characteristics.

17.2 Digital Natural Heritage

17.2.1 Technology and Research Methods of Digital Natural Heritage

The Convention for the Protection of the World Cultural and Natural Heritage describes "natural heritage" as "natural features consisting of material and biological structures or groups of such structures of outstanding universal value from an aesthetic or scientific point of view; geological and natural geographical structures of outstanding universal value from a scientific or protective point of view, and clearly designated as threatened animal and plant habitats; natural attractions or clearly defined natural areas with outstanding universal value from a scientific, conservation or natural beauty point of view." Comprehensive use of digital technologies and methods for outstanding universal value (OUV) characterization of elements of natural heritage include the observation and its originality, integrity (AI) monitoring and evaluation as effective measures to achieve heritage protection and management.

To ensure the feasibility, effectiveness and long-term nature of digital technology for natural heritage monitoring, practical and simple monitoring and evaluation methods should be adopted, and the collection and management of monitoring data should be standardized. With the rapid development of 3S technology, multisource high-resolution (temporal, spatial, spectral) images form a large amount of remote sensing data. We have carried out different remote sensing spatial scale data fusion techniques. The spatial analysis function of GIS, high-precision satellite navigation and positioning functions, and different evaluation models of natural heritage site protection are used for Sustainable Heritage Protection and development monitoring, taking into account the monitoring objectives and conditions of different types of natural heritage sites. By combining qualitative and quantitative methods, field investigation and remote sensing investigation, the OUV and its original integrity can be effectively monitored and assessed, and natural heritage can be effectively protected and managed.

17.2.2 Case Study of Digital Natural Heritage

17.2.2.1 Information Extraction from Mountain Vertical Belt Based on an NDVI-DEM Method Model

Xinjiang Tianshan Mountain is an outstanding representative of the mountain ecosystem in temperate arid regions. It has a typical vertical natural belt spectrum in temperate arid regions. Within a horizontal distance of less than 30 km, Bogda's elevation rises from 1,380 to 5,445 m, and the vertical elevation difference is nearly 4,100 m. Six vertical natural belts from desert steppe to ice and snow belts have developed: temperate desert steppe belt, mountain steppe belt, alpine coniferous forest belt, alpine meadow belt, Alpine cushion vegetation belt and ice and Snow Belt. At the Bogda World Heritage Site, snow-capped mountains, glaciers, rivers, lakes, forests and meadows coexist with each other to present the superlative natural beauty of mountains in a desert area. The vertical natural belt distribution reflects the water and heat variations at different elevations, gradients and slopes. It is an outstanding example for the study of biological community succession in mountain ecosystems in an arid belt undergoing global climate change.

The impacts of climate change are the main driving factor of vertical belt change. According to the seasonal and periodic characteristics of the monitoring objects for the protection of the Bogda Heritage Site, Wang Xinyuan's research group (Ji et al. 2018) selected TM data from June 19, 1989, and OLI data from July 28, 2016 (Fig. 17.1), combined with auxiliary data such as ground object spectrometer information, field GPS acquisition and UAV data, and made use of scatter plot of DEM-NDVI-Land Cover Classification (Fig. 17.2) based on probability and statistics. Based on the study, the demarcation elevation of the vertical natural belts was

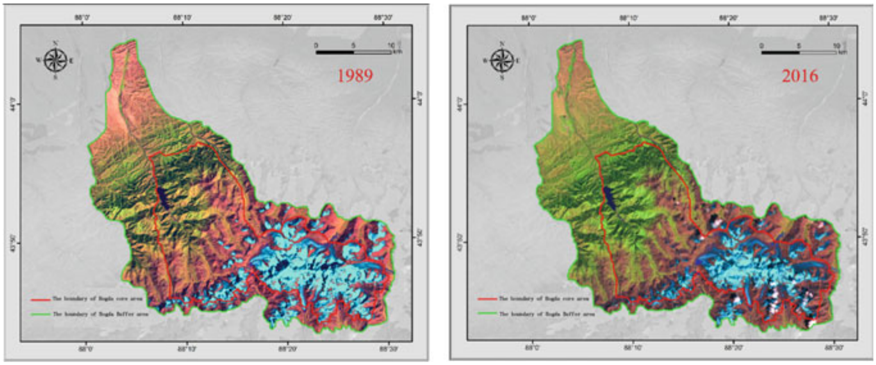

Fig. 17.1 Bogda images for (left) 1989 and 2016 (right)

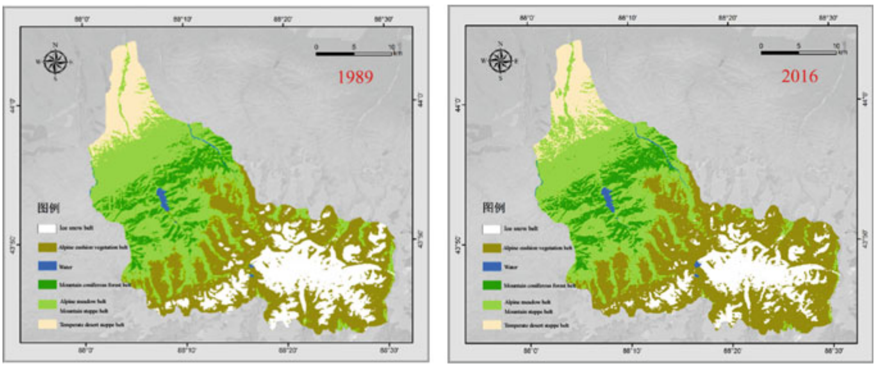

Fig. 17.2 Bogda classification results for 1989 (left) and 2016 (right)

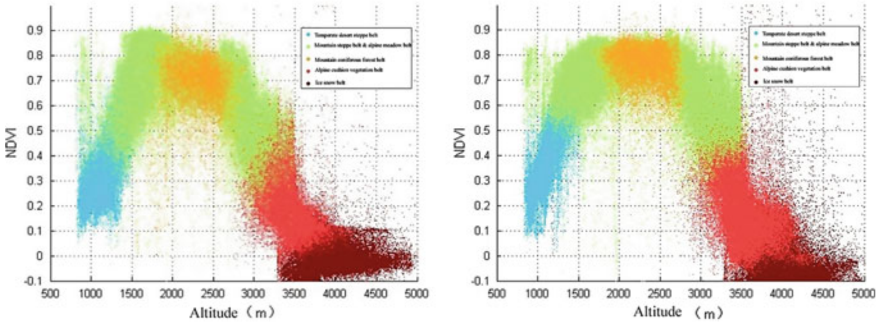

Fig. 17.3 Bogda scatter plot for 1989 (left) and for 2016 (right)

extracted to monitor the changes in the vertical belts in the Bogda Heritage Site in the past 30 years.

Remote sensing images are classified according to the zoning content of vertical zones. The images are classified by comprehensive supervised classification, decision tree hierarchical classification and visual interpretation.

Using the superpositioned DEM data, NDVI (Chang et al. 2015) and classification results of the Bogda Heritage Site, the "DEM-NDVI-classification information scatter plots" for 1989 and 2016 were created, as shown in Fig. 17.3. The two-year trend in the distribution of scatters shows an inverted U-shape of "uniform rise-remain stable-uniform decline".

With the elevation increase in the Bogda area, the heat and water and the environment of vegetation growth change, and the coverage types change regularly, corresponding to the six colors in the scatter plot. There was a clear demarcation between scatters in different vertical belts. The proportions of pixel classification attributes at different elevation ranges in the scatter map of the DEM-NDVI-Land Cover Classification was calculated by sliding statistics, and the vertical zoning results for the Bogda Heritage Site in 1989 and 2016 were obtained by setting thresholds. The extraction results are shown in Table 17.1.

Table 17.1 1989 and 2016 data with elevation results (spline data)

	Temperate desert steppe belt-mountain steppe belt (m)	Mountain steppe belt-alpine coniferous forest belt (m)	Alpine coniferous forest belt-alpine meadow belt (m)	Alpine meadow belt-alpine cushion vegetation belt (m)	Alpine cushion vegetation belt-ice and snow belt (m)
1989	1278	1784	2714	3277	3636
2016	1185	1759	2730	3288	3690
Difference	−93	−25	+16	+11	+54

Note + indicates boundary line elevation, −indicates boundary line elevation drop

The vertical belts of the Bogda Natural Heritage Site in the Tianshan Mountains in 1989 and 2016 were extracted, as shown in Table 17.1. The boundary between the temperate desert steppe belt and mountain steppe belt decreased 93 m, the boundary between the alpine meadow belt and alpine cushion vegetation belt moved up 11 m, and the lower limit of the ice and Snow Belt increased 54 m. This shows that the area of mountain grassland has greatly expanded, and the protection of natural heritage is critical; due to the impacts of global climate change, the glaciers have retreated. Therefore, considering the problem of OUV performance in heritage sites, it is necessary to carry out Sustainable Heritage monitoring using qualitative and quantitative methods, field investigation, social investigation and remote sensing investigation to protect and manage natural heritage.

Using field research and Google Earth high-resolution image data, six points were selected in each area where the land type obviously changed. Thirty-six verification points were selected to verify the mountain vertical band extraction results. As shown in Table 17.2, the elevation of the verification points fluctuated above and below the demarcation elevations, but the overall trend was consistent with the research results.

17.2.2.2 Recognition of Coral Reef Health Status Based on RS and GIS

Corals require harsh growth conditions, and subtle changes in sea temperature, salinity, sediment content and other environmental factors can lead to widespread bleaching or death of corals. Coral reefs are the most responsive ecosystem to climate change on a global scale. Therefore, it is very important to grasp the health status of coral reefs in time to study the effects of climate change and the utilization and protection of marine ecological resources (Holden and Ledrew 1998). Australia's Great Barrier Reef (GBR) is 2011 km long and 161 km at its widest point. The scenery is charming and the flow of water is complex. It is a sensitive area of global change, with more than 400 different types of coral reefs. The GBR, extending 2000 km along Queensland's coast, is a globally outstanding example of an ecosystem that has evolved over millennia. The area has been exposed and flooded by at least four glacial and interglacial cycles, and reefs have grown on the continental shelf over the past 15,000 years.

Kutser et al. (2003) used hyperspectral sensors to measure the reflectivity spectra of six different colors of coral communities in the Great Barrier Reef (approximately 5–6 m deep), and analyzed live corals, dead corals, and algae. The reflectivity of ground objects obviously differs between 550 and 680 nm; the spectral reflectivity of sand is the highest, the reflectivity curve is gentle, and the reflectivity curve is the easiest to distinguish from those of other materials. Coral and seaweed have low reflectivity. The waveform is determined by the light absorption characteristics of pigments in the body, which comprises wavelengths from 500 to 625 nm for the big difference in reflectivity waveforms between coral and seaweed.

Table 17.2 Vertical natural belt extraction verification results

	Temperate desert steppe belt-mountain steppe belt		Mountain steppe belt-alpine coniferous forest belt		Alpine coniferous forest belt-alpine meadow belt		Alpine meadow belt-alpine cushion vegetation belt		Alpine cushion vegetation belt-ice and snow belt	
	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)
1	1174	+11	1774	−15	2713	+17	3309	−12	3681	+9
2	1186	−1	1761	−2	2745*	−15	3272	+21	3672	+18
3	1192	−7	1742*	+17	2726	+4	3232	+39	3697	−7
4	1105	+80	1740*	+19	2736	−6	3297	−4	3666	+24
5	1147	+38	1741	+18	2743	−13	3307	−19	3705	−15
6	1194	−9	1779	−20	2737	−7	3317	−29	3687	+3
R	1185 m		1759 m		2730 m		3293 m		3690 m	

Note E-elevation, D-difference value, R-extraction results, *represents in situ data
+ indicates the verification point elevation was greater than the extraction result
– indicates the verification point elevation was lower than the extraction result

In addition, Clark et al. (2000) found that recently dead corals can be distinguished from corals whose death time is longer than 6 months by derivative spectrum. In addition to spectral measurement and analysis of coral reefs, Landsat and SPOT series satellite data can be used to identify coral reefs with coarse accuracy (Benfield et al. 2007). Collin and Hench (2012) identified the healthy and unhealthy status of coral reefs from Worldview-2 high-resolution imagery using a support vector machine (SVM).

17.2.2.3 Habitat Suitability Assessment of Animal Habitat Based on Spatial Information Technology

A great deal of observed evidence shows that the combination of climate change and other pressure sources has led to the migration of species distribution, wildlife phenology, reproductive behavior, population composition and ecosystem function changes.

The giant panda is a rare wild animal unique to China. It is also the flagship species of biodiversity conservation in the world. The giant pandas are now confined to six mountain systems, from north to south: Qinling Mountain, Minshan Mountain, Qionglai Mountain, Big Facies Mountain, Small Facies Mountain and Liangshan Mountain. Based on spatial information technology, the Wang Xinyuan Research Group (Song et al. 2014; Zhen et al. 2018) carried out a habitat suitability assessment of giant panda habitat.

Based on remote sensing, geographic information system (GIS) and other spatial techniques, using the latest data from the fourth Giant Panda Survey and the maximum entropy model (MaxEnt), the assessment of the impacts of climate change on the habitat of giant panda (Ya'an) was carried out at this stage and is planned in 2050. In the course of carrying out the detailed assessment, the latest data on panda occurrences and human disturbance factors were based on the fourth Giant Panda Survey (2011–2014), with elevation, slope and aspect as physical environmental variables. The distribution map of the staple food bamboo and distance from water source were biological factors. Human disturbance factors included the interference factors, with a high encounter rate in five study areas of roads, mines, hydropower stations transmission lines and scenic spots. The bioclimatic data were derived from climate variables on the WorldClim website, 12 land cover thematic data from 2001 to 2015 that were uniformly processed by NDVI, and high-resolution remote sensing data such as GF-1, as shown in Fig. 17.4.

The research analyzed the suitable conditions of giant panda habitat and its changing trends and related rules under the background of the current stage of and future climate change in Ya'an, Sichuan Province in China. Through on-site visits to nature reserve management agencies and local residents' research, the evaluation results were verified through field studies. The evaluation results, such as those shown in Fig. 17.5, provide a deep understanding of the trends and extent of habitat change in

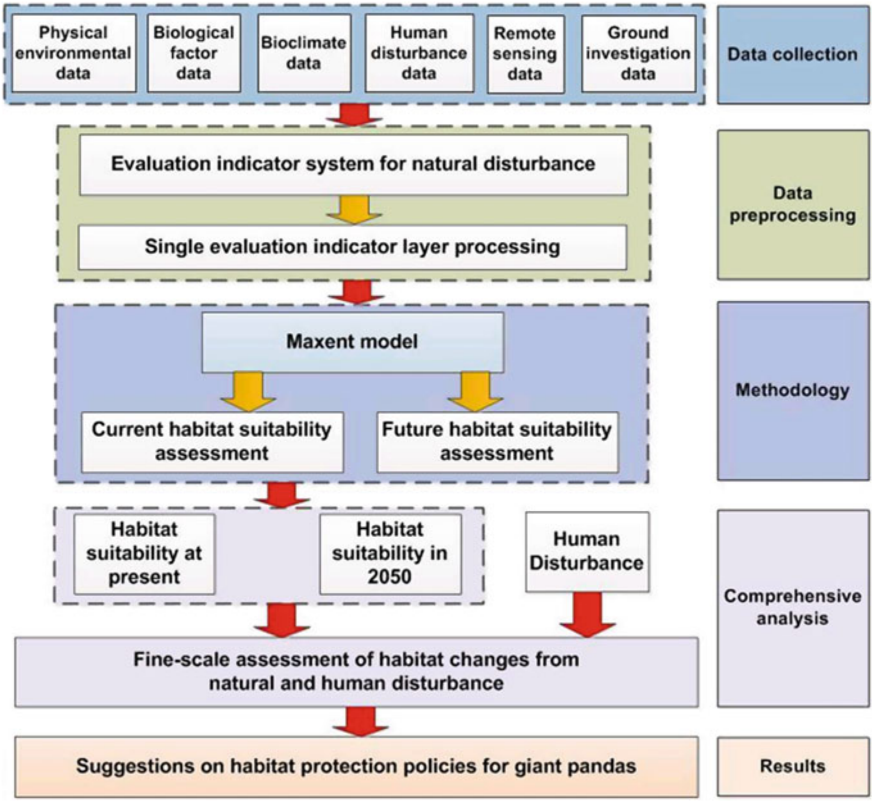

Fig. 17.4 Flow chart of fine-scale climate change evaluation and countermeasures

the context of climate change. They are of great significance for the effective protection of current and future giant panda habitat, ecological protection and coordinated development of the local economy.

17.3 Digital Cultural Heritage

Digital cultural heritage is the application of the theory, methodology and technology related to Digital Earth in the field of cultural heritage. Applying digital technology focused on spatial information technology to tangible cultural heritage is of great significance for the protection, inheritance and exploitation of cultural heritage.

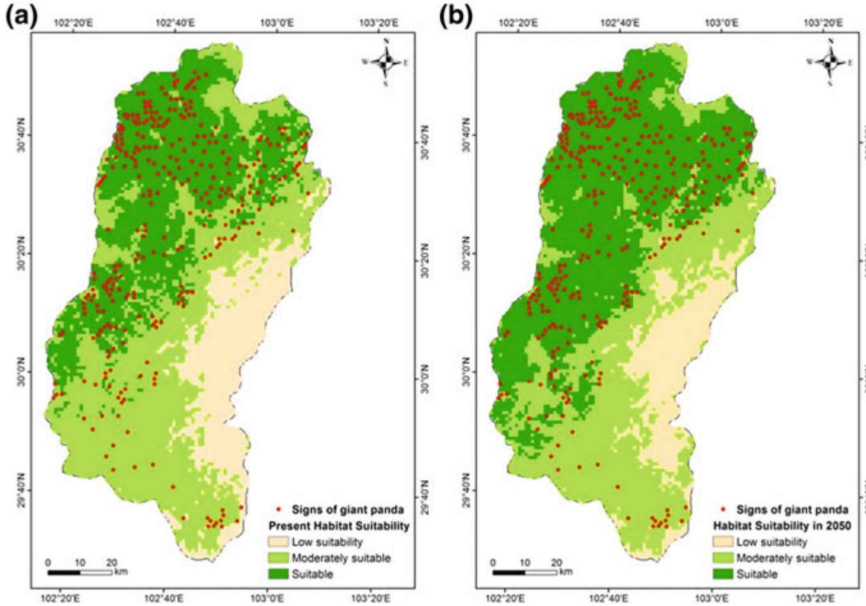

Fig. 17.5 Giant panda habitat suitability (**a**) at present; and (**b**) in A.D. 2050

17.3.1 Digital Cultural Heritage Research and Technical Methods

As the core technology supporting the deep development and wide application of Digital Earth, spatial technology provides new means as well as new tasks and connotations for digital cultural heritage research. Through digital technologies such as photogrammetry and remote sensing, digital cultural heritage can realize nondestructive archaeological detection, digital archiving, dynamic monitoring and evaluation of heritage, and support the preservation and sustainability of the heritage ontology and the environment on which it relies. The main technical methods for digital cultural heritage research include:

17.3.1.1 Space Archaeological Technology

Space archaeological technology integrates worldwide earth observation technology from space, air to ground and underground exploration technology to detect and discover archaeological objects (Luo et al. 2019). In the positioning and discovery of heritage, technical features of spatial earth observation technology including the high-resolution, multi-spectral and multi-resolution nature, objectivity and non-intrusiveness can be fully utilized to provide technical support for archaeological heritage investigation, exploration and research. The remains of ancient human activities (surface or subsurface) can lead to variances in the spatial structure between the remains and their surroundings. These are represented in the digital records of remotely sensed imagery as interpretation marks such as micro geomorphology, soil moisture, and vegetation growth distribution, which have become the theoretical basis of remote sensing archaeology. Space archaeology is the inheritance and development of remote sensing archaeology. It extends the working spectrum of remote sensing archaeology and has the advantages of multi-scale observation of a satellite with aerial and ground integration. The introduction of geophysical exploration and other technologies has enabled the development of spatial archaeological observations of the subsurface or even lower, providing a new approach for nondestructive detection of buried remains.

17.3.1.2 Digital Recording and Preservation of Cultural Heritage

Accurate digital recording is the premise of heritage protection and monitoring. Based on principles of photogrammetry and remote sensing, it collects and digitizes ground control points by acquiring satellite and aerial high-resolution remote sensing images, and uses photogrammetry software to produce high-precision maps of the heritage ontology. Through the three-dimensional (3D) data acquisition equipment of aerial, low-altitude aerial, car-based or ground platforms, 3D modeling software is used to construct 3D models and record the shapes and spatial attributes of the heritage ontology and the environment. A large heritage database system that can be queried and updated is then formed using geographic information system (GIS) and database technology to digitally manage various types of heritage information.

17.3.1.3 Heritage Ontological and Environmental Dynamic Monitoring

By obtaining data on the same heritage object at different times, through comparative analysis, changing information identification and model calculation, the status and potential risks of the heritage object can be evaluated. Earth observation technology based on Digital Earth has great potential for monitoring large cultural heritage remotely and dynamically and even in 3D form. The analysis and evaluation of the situation and risk of the heritage object are conducted by applying artificial or intelligent remote sensing recognition technology and monitoring and identification algorithms on remote sensing data at a certain interval (appropriate spatial resolution, spectral resolution and temporal resolution, etc.) or 3D digital models.

17.3.1.4 Heritage Demonstration on Virtual Reality Technology

Virtual reality (VR) is a new and integral technology in the sphere of computer science, which developed from the integration of disciplines involving computer graphics technology, multimedia technology, sensor technology, human-computer interaction technology, network technology, stereo display technology and simulation technology. With advantage of lifelike, immersive reconstructions, it can be applied in cultural heritage research, restoration and digital virtual tourism. The seamless integration of digitalization and virtual reality technology can be an effective means for digital protection.

17.3.2 Digital Cultural Heritage Application Cases

17.3.2.1 Space Archaeology

As a successor of remote sensing archaeology, Space archaeology is a new paradigm of space information technology employed in archaeology (Wang and Guo 2015). Through multiple technology integration and comprehensive analysis, it provides the essential information linked to the acquisition, interpretation and reconstruction of archaeological remains. Space archaeology research is in the emerging stages. At present, the work is mainly concentrated in deserts, Mayan jungles and the Nile Delta using remote sensing-based methods of archaeological faint information extraction, and has achieved a series of important scientific achievements and archaeological discoveries. American archaeologists discovered the notable ancient Egyptian city of Alexandria, which had slept in the sea for thousands of years; Greek archaeologists employed infrared photographs to discover the ancient city of Hekike, which was destroyed by an earthquake in 373 B.C. in Corinth. Guo (1997) used space shuttle imaging radar data to discover the great walls of the Sui and Ming Dynasties buried in the dry sand at the junction of Shanxi and Ningxia. Ninfo et al. (2009) visually interpreted and digitally reconstructed the urban structure and paleoenvironmental background of the ancient port of Altinum using high-resolution visible and near-infrared aerial photographs and digital elevation models. Evans et al. (2007) used GIS tools to map the most detailed archaeological information of the Angkor Wat site based on multisource remote sensing data such as optical and SAR information. Parcak et al. (2016) conducted a spatial archaeological study of the Nile Delta. They investigated thousands of ancient sites in the area and identified ancient city street ruins and unfinished pyramids based on high-resolution remote sensing data to reconstruct the ancient Egyptian empire.

The Silk Road is precious cultural heritage owned and shared by all mankind. To enhance the ability to rescue archaeological discoveries, space archaeology provides new technical methods for the detection, discovery and reconstruction of sites along the Silk Road at different scales. With the benefit of spatial information technology, a spatial forecast model of heritages based on GIS spatial analysis was built by Wang and Guo (2015) by considering the similarity of environmental and geomorphological landscapes of the ancient Silk Road between NW China (Luo et al. 2014a, b) and southern Tunisia using satellite imagery, historical documents, archaeological survey data and other multivariate data. Three ancient city sites related to old stages in Dunhuang, northwest China, were discovered on the high-resolution satellite remote sensing imagery. The field archaeological survey supported by GPS technologies and historical research material confirmed the specific locations of the ancient stages. Based on the Digital Earth platform and existing spatial archaeological results, the postal system between Guazhou and Shazhou (two prefectures) in the period of the post-Wuhou Tianshou second year (A.D. 691) was digitally reconstructed (Fig. 17.6). It laid a scientific database foundation to study the route of the ancient Silk Road and the changes in the ancient oasis in medieval China. The new

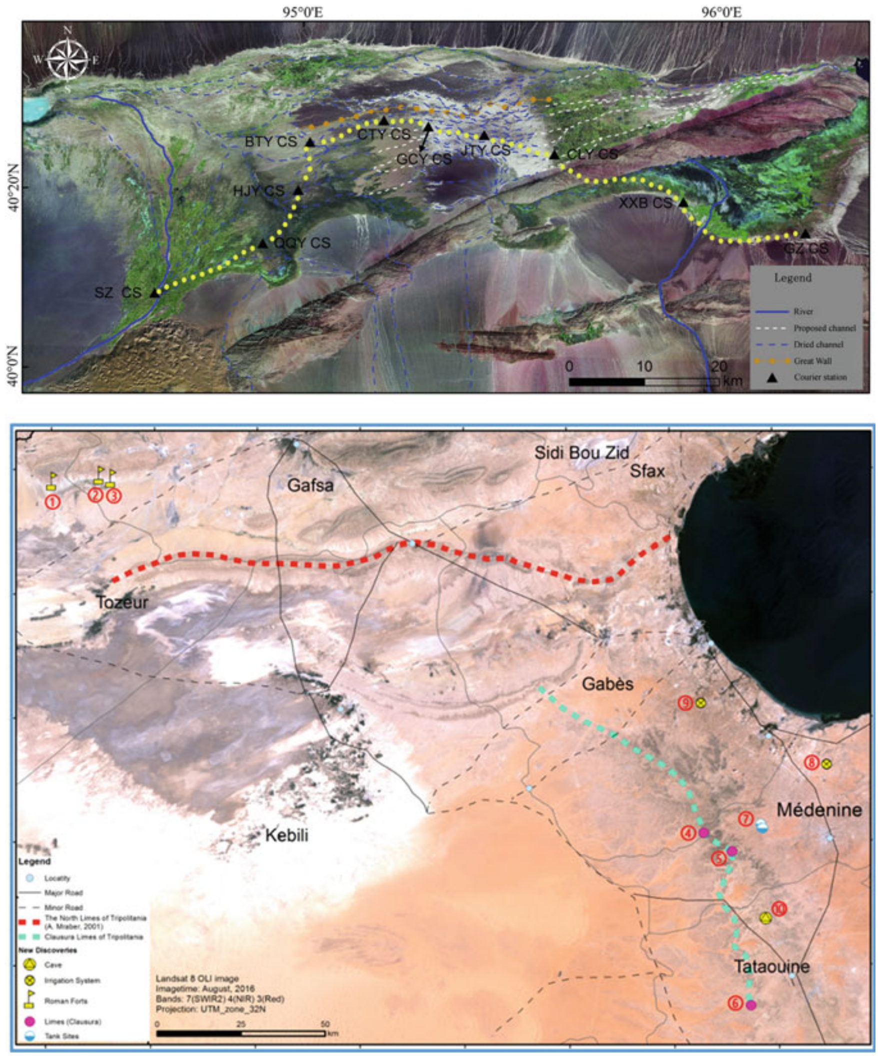

Fig. 17.6 Space archaeology of the silk road in China (upper) and Southern Tunisia (lower)

paradigm of spatial archaeology has been promoted and applied to Tunisia, where 10 ancient Roman remains have been discovered; the legacy evidence chain reflected the military defense system of the southern frontiers of the Roman Empire (Fig. 17.6).

The comparative space archaeological study of the defense system along the Silk Road between the Han Great Wall and the Roman Lima system provides detailed knowledge of the defense system, border defense strategy, human-land relationship and environmental changes in areas along the Silk Road as scientific references.

17.3.2.2 Cultural Heritage Monitoring and Protection

In the face of frequent natural disasters, global changes and increased human activities (such as urbanization, tourism development and local wars), the sustainable protection of cultural heritage has encountered challenges. As a common nonrenewable wealth of all mankind, safeguarding and protecting the world's heritage is the focus of the UN 2030 Sustainable Development Goal 'Sustainable Cities and Communities'. Considering the wide coverage, diverse types and different landscapes of cultural heritage, it is urgent to take advantage of near real-time, wide coverage and high precision of remote sensing big data under the digital earth framework for dynamic monitoring and intelligent protection of cultural heritage.

First, due to the rapid development of sensor technology and the Internet of Things in recent years, heritage protectors can now automatically monitor elements of micro environmental change information in near real-time, from the monument to the landscape (e.g., humidity, temperature, air pollution, power, precipitation, structure vibration and deformation), providing quantitative data for the identification of trigger mechanisms for heritage sites affected by diseases and for the consequent conservation measures.

Second, high-resolution remote sensing platforms with multiple bands and high revisit frequency and satellite-airborne (low-altitude) information processing technology make it possible to monitor the whole-day and all-weather dynamics of a heritage scene; the extraction and storage of topographic factors such as slope and water catchment can aid in detailed mapping for heritage protection; natural disasters such as landslides and human activities such as urbanization can be identified by remote sensing images, and the GIS platform space-time analysis function can be used to support early warning and assessment of heritage risks.

Third, the key advantage of Digital Earth platforms such as Google Earth, World-Wind and ArcGIS Explorer is the wide use of Keyhole Markup Language (KML) to ease the integration of multisource datasets from different providers and to simultaneously visualize and identify relationships for use in subsequent quantitative investigations. Cultural heritage applications require the integration of heterogeneous georeferenced 1D/2D/3D/4D data from local computers or data obtained 'on the fly' from distributed sources due to the demands of comprehensive archaeological understanding and knowledge discovery. In Google Earth, these data are usually in KML format. A case study was conducted on part of the Great Wall (Fig. 17.7a) in NW China (Luo et al. 2018) in the early 20th century by famous archaeologists and

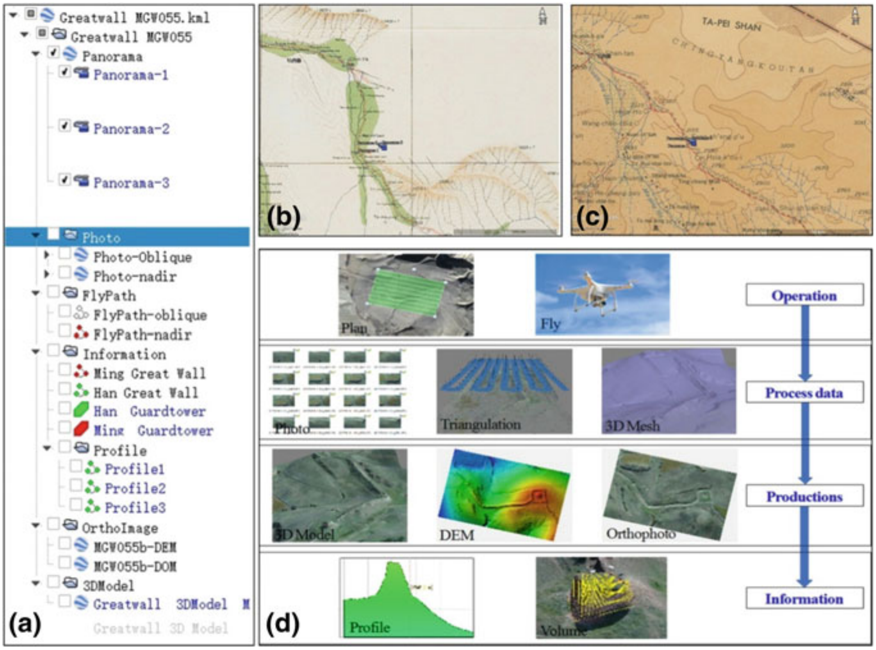

Fig. 17.7 The integration of geospatial data of the Great Wall in northwestern China. **a** The overall tree structure of the KML layers in GE; **b** the archaeological maps made by Stein; **c** the archaeological maps made by Hedin; **d** the operation flowchart for our UAV investigation. We deleted the photo layer in the supplementary file because the volume was too large

geographers, who made many great discoveries and uncovered its mysteries. The work of these expeditions served different roles and provided clues to researchers seeking to find unknown sites. The most famous explorers were Stein and Hedin, and their precious investigation reports and archaeological maps (Fig. 17.7b, c) play important roles in understanding the changes that have occurred in the Middle East and Central Asia in the past century, especially in terms of land use and land cover (LULC).

An unmanned aerial vehicle (UAV) investigation of the Great Wall was carried out (Fig. 17.7d). All of the original and processed data (courses, photos, triangulation and mesh), final products (orthophotos, DEM and 3D model) and derivative information (profiles and volumes) were saved in KML format. Members of the public and scientific peers can download and reproduce the data for integration with archaeological maps and their own data. For example, based on these high-resolution UAV-generated DEM and 3D model analyses, a Great Wall Integrity Index was defined and applied in quantitative evaluation of Ming earthen Great Wall erosion status. Stein and Hedin's archaeological maps were also used in this case; these can be downloaded from the Japanese National Institute of Informatics (http://dsr.nii.ac.jp). By browsing in GoogleEarth, it was evident that Hedin's archaeological map of our proposed pilot area was more detailed than Stein's (Fig. 17.7b). We were unable to find any marks showing the linear traces of the Great Wall in Stein's map but they are present in Hedin's map (Fig. 17.7c). In future research based on data visualization and integration in GE and the LULC specific situations established by GE VHR imagery, it will be possible to use UAV data and archaeological maps to deduce historical LULC changes in the past century along the Great Wall.

However, compared with spatial archaeological detection (which can be traced back to remote sensing archaeology), there is still a lack of research in the methodology and applied strategy of spatial technology employed for heritage monitoring and protection. The existing work on the monitoring of the heritage ontology and environment is often isolated and the monitoring elements and means are relatively simple, which affects the comprehensive understanding and systematic response to the sustainable protection of cultural heritage. Recently, Xiao et al. (2018), from the perspective of UN Sustainable Development Goals 11 and 8, proposed that geospatial information technology such as photogrammetry, remote sensing and spatial information would play an important role in defending and protecting cultural heritage and sustainable tourism. Chen et al. (2017) developed a two-scale radar interferometry method and model for deformation monitoring and health diagnosis of heritage sites affected by disease (Fig. 17.8) that considered the dynamic changes in heritage

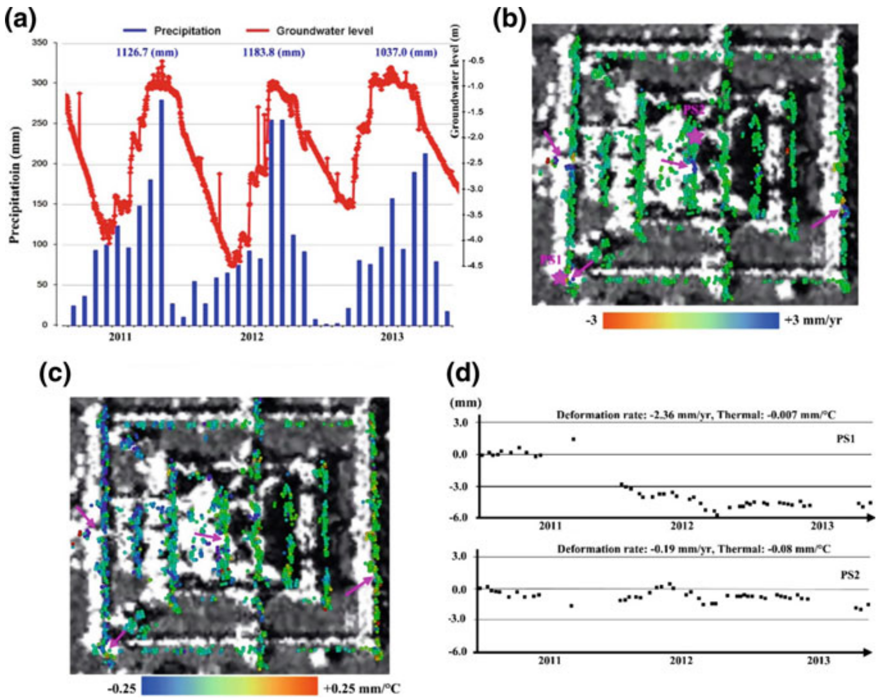

Fig. 17.8 Angkor's environmental remote sensing revealed the collapse of ancient temples and contributed to the sustainable protection of heritage sites. (following Chen et al. (2017))

ecosystems, monitored environmental factors (including urbanization, forest degradation, land use, groundwater level) to resolve the current controversy surrounding the potential structural collapse of monuments in Angkor. They constructed the dynamic model of the disease evolution of the Angkor temple complex and unveiled the mystery of the decline of the heritage site, bringing a new insight for the site sustainable conservation.

17.3.2.3 Virtual Reconstruction of Cultural Heritage

The protection and sustainable development of cultural heritage can be understood from a narrow point of view as the documentation, restoration and maintenance of the heritage site. From a broad perspective, it should be extended to the cognition, understanding and inheritance of the human civilization based on the protection of the heritage entity. Due to the rapid development of information technology in the internet and big data era, the visual demonstration of heritage information from multiple sources can be realized through virtual reconstruction scientifically, intuitively and vividly, which greatly promotes the dissemination and inheritance of ancient civilization.

The virtual reconstruction of digital heritage includes three main aspects. The first is to combine multisource data to model historical sites and the paleoenvironment and establish virtual ancient scenes; the second is to design lively and representative key historical and cultural events and scene elements (such as costumes or hairstyles that reflect the cultural elements of the time, street arrangements, etc.) considering the cultural background and geographical environment of specific historical periods; the last is to realize the digital display of virtual ancient scenes integrating virtual reality, holographic projection, augmented reality, digital animation and other technologies. By providing visual, auditory, tactile and other sensory simulations, it allows for users to immerse themselves in the cultural relic environment and its historical context (Mortara et al. 2014).

Some relevant experts and scholars have achieved fruitful results in this field, such as the virtual reconstruction of the cultural site of Pompeii by the University of Geneva and the digital restoration of Yuanmingyuanby Tsinghua University, but there are still some major challenges in the virtual reconstruction process for cultural heritage.

First, cultural heritage often contains various elements and complicated space characteristics. It is difficult for a single platform or sensor to meet the requirements of all types of data acquisition due to multi-platform, multisource, heterogeneous sensors. The need for collaborative stereoscopic observations is increasingly evident (Lin et al. 2014). The cultural heritage HuaixiuShanzhuang (HXSZ) in Suzhou, China, has a complex structure, which is a challenge for modeling. To acquire high-accuracy 3D models, Liang et al. (2018) collected point clouds via terrestrial laser scanning(TLS) and modeled texture via terrestrial digital photogrammetry(TDP) (Luo et al. 2014a, b). They fused the TLS and unmanned aerial vehicle digital photogrammetry (UAVDP) point clouds and integrated the TDP point clouds with the already-merged point clouds for 3D modeling and digital documentation. The multiple surveying methods, multisource and multi-scale data collection, procession and presentation and documentation overcome the limitations of a single technology and data source, providing a solution for high-accuracy preservation of cultural heritage sites that contain complex space characteristics.

Second, multi-sensor observations are prone to many structural problems such as data structure differences, uneven acquisition granularity, and weak spatial and temporal coupling. The development of collaborative observation, joint registration, and multisource data fusion modeling techniques can provide digital protection for cultural heritage. In addition, the integration of multi-source/multi-scale data and models requires efficient management platform. Hua et al. (2018) developed an internet-based 3D geographic information service system for Hakka culture preservation with data storage on the cloud and service functions such as scene loading and browsing, thematic cultural map display, online virtual experiences for tours, and tourist route navigation for users. The data sources were based on surveyed and collected materials and knowledge of Hakka culture through field work and the 3D model of Tulou reconstructed with TLS, UAV and digital camera data. It provides a virtual experience for a cultural tour in a 3D interactive way and a novel platform for Hakka culture presentation, cognition and heritage.

Third, to enhance the vivid experience and the comprehension of the public, Barsanti et al. built a virtual museum with 3D interactive scenarios of Egyptian funeral objects that was exhibited at the Archaeological Museum in Milan (Barsanti et al. 2015) (Fig. 17.9). In this scenario, users could grab, wave and rotate 3D models to observe them from different points of view with the movement of their virtual hands, which was implemented by wearable virtual reality devices named HMD. In addition, Eva et al. realized gesture-based natural interaction in a virtual reproduction of the Regolini-Galassi tomb, one of the richest and most famous tombs of the Orientalizing period (Pietroni et al. 2013). By exploiting the recognition of the skeleton and the grammar of common gestures, this application leaves users completely free to walk through the 3D scenes of the ancient cultural heritage site and dynamically choose 3D objects they are interested in with a gesture of their arms.

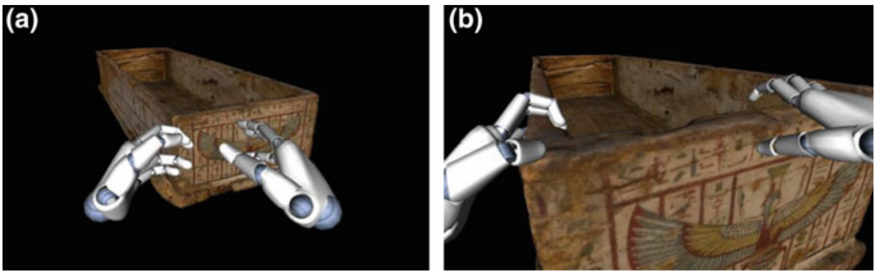

Fig. 17.9 Pictures of the implemented VR scenario: **a**, **b** grabbing and rotating of an object with the option to enlargeit (following Barsanti et al. (2015))

Furthermore, in most outdoor cases, users are inclined to compare the current site with the immemorial one that shared the same location with it, so that they can infer the changes that occurred over time. To address this issue and allow for the capability of combining the natural world and artificial world, augmented reality technology appears to be a suitable choice. Quattrini et al. (2016) reconstructed a Roman theatre in Italy using TLS point cloud data and validated the 3D models using a geometrical survey of evidence. Moreover, they showed how it is possible to realize on-site visualization of cultural heritage that no longer exists based on a mobile augmented reality (MAR) platform (Quattrini et al. 2016) (Fig. 17.10).

Notably, the whole life cycle of cultural heritage is a complex historical process that includes site selection, construction, completion, maintenance, and the current physical restoration, which comprises both natural processes and human activities. For example, the EU's Seventh R&D Framework Program officially launched research on the impacts of natural processes (climate change) on historical and cultural heritage (http://www.climateforculture.eu/index.php?inhalt=project.overview). To effectively recognize the temporal and spatial characteristics of cultural heritage, it is particularly important to develop and construct a dynamic knowledge environment. The dynamic knowledge environment requires integrated sensors for real-time observation, geographic process simulation and prediction, and agent behavior analysis methods and techniques to provide comprehensive analysis capabilities that can trace the past and more effectively predict the socialization process of cultural heritage.

Fig. 17.10 The development of MAR visualization for the reconstructed Roman Theatre in Fano, Italy, using Layar. (following Quattrini et al. (2016))

The effective solution of the above challenges rely on the development of related technologies such as the acquisition and digitization of cultural heritage related information, seamless integration of multisource/multi-scale data and models, non-rigid physical modeling and its free interaction and real-time response, space-time evolution modeling of ancient sites and ancient civilization activities, and behavioral model building. Narrowing the gap between high-tech virtual reality and cultural heritage remains a challenge. Academician Huadong Guo of the Chinese Academy of Sciences advocated constructing and developing spatial archaeology, an interdisciplinary field combining the strengths of spatial technology, cultural heritage, big data science, and computer technology, which practically applies new and sophisticated technology to heritage protection and sustainable development. At present, the pilot project "the Earth Big Data Science Project" of the Chinese Academy of Sciences, which oversees Academician Guo Huadong, has been set up to support related research on heritage protection along the Belt and Road. It will reproduce the past glory of the ancient civilization of the Belt and Road through the virtual reproduction of digital heritage.

17.4 The Development Trend of Digital Heritage

Cultural and natural heritage are the precious wealth of mankind, and the primary condition of heritage protection is to ensure the authenticity and integrity of heritage. Although digital technology applied to cultural and natural heritage, their preservation, protection, research and utilization provides an important support, digital heritage itself also faces issues such as data security, distribution, interoperability, cost, simplification and speed problems for application. It is also a challenge to open access and increase the ease of understanding. The preservation and protection of digital heritage involve technology and methods for preservation and protection, management systems, protection schemes, and management measures and laws regarding the protection of digital heritage. The future development of digital heritage preservation, protection, research and utilization has the following trends.

17.4.1 The Depiction of Heritage Objects via Remote Sensing Technology Is Becoming Increasingly Precise

Multi-platforms of satellite, airborne and ground remote sensing have increasingly higher spatial resolution. The development of multi-spectrum and hyper-spectrum technology has made object characterization more and more precise. Coupled with the progress of data processing technology and cognitive methods, the recognition of the geometry and attributes of natural and cultural heritage is closer to the actual items.

Especially in recent years, rapid development of laser radar technology as a new means of three-dimensional space data acquisition that can perform complex surface measurement quickly and accurately and obtain a record of the sites of cultural relics that is high-density, high-precision and three-dimensional, representing the information of cultural heritage sites truly, accurately and completely. In addition, hyper-spectrum data will become increasingly important in the fine classification of natural and cultural heritage. There will be great potential in the future for natural and cultural heritage information acquisition based on the fusion of hyperspectral information and LiDAR elevation information.

17.4.2 The Demand for Durable Digital Heritage Preservation Media Will Continue to Drive Innovation

How can advanced technology be used to monitor and protect valuable cultural and natural heritage, and what is the best medium for preserving such data? As early as the 1970s, people began to use photography, video and other technologies to record information about natural processes and cultural relics. However, these data are difficult to preserve for a long time due to the aging of videotapes, disk demagnetization, and image reproduction that produces distortion. In the late 20th century, with the emergence of virtual reality technology and the rapid development of networks, the heritage protection industry has a new opportunity—high-precision and high-fidelity digital heritage preservation technology. Modern high-quality digital image technology and advanced graphic image processing methods have brought the protection of natural and cultural heritage into a new era. Image-based rendering (IBR) and image-based modeling (IBM), three-dimensional scanning-based reconstruction and roaming, retrieval/restoration/color technology, multiple projection immersive virtual environment and other technologies have made digital natural and cultural heritage become a reality and have great potential in future applications of digital natural and cultural heritage.

17.4.3 Data Integration, Development, Publication and Dissemination for Heritage Protection Platform Software Urgently Need to Be Developed

To make full use of different sensors (obtained from aviation, space, and the ground), 3D models, airborne data, and ground laser scanning data, using a GIS environment and software to manage and integrate the available information (digital and the digital format) and synthesize, refine, comprehensively develop, and release multisource data (excavation reports, geophysical surveys, mapping, aviation and satellite photography) can provide effective solutions.

GIS environments or web-based GIS environment tools provide new and more efficient ways to conduct archaeological research, store and process data, and share multisource geospatial data collaboratively. To develop infrastructure, new methods and concepts are needed to handle the increasing big data and data integration requirements, the requirement of efficient archive processing and the simplification of GIS-based technology applications. These problems can be solved via building open source components based on the WebGIS platform. With the rapid development of archaeological WebGIS today, the combination and usage increase of related archaeological applications is occurring. Many platforms with various interfaces and functions have been created for professional and nonprofessional users.

WebGIS architecture provides flexible tools for multiple requirements, applications, and usage phases. The open source tools of WebGIS have played an important role for different application purposes in recent years, for example, a the release of mining results; b the design of archaeological clues to the land; and c the incorporation of archaeological data into the broader national geological portal for landscape conservation purposes.

A system platform and database for monitoring, evaluation, decision-making and exhibition of natural and cultural heritage are an expectation of researchers, users and the public around the world. The Digital Belt and Road (DBAR) Working Group (DBAR-Heritage) is developing such a platform.

17.4.4 Increasingly Convenient Digital Technologies Are Adapted to Non-professional and Wide Public Participation in Heritage Conservation

The growing availability of free data and open access software tools has strengthened the link between field surveys and computer analysis, providing new opportunities for the conservation, development and utilization of natural and cultural heritage sites. The key point is to create accessible tools for different people, including the domain expert groups (archaeologists, remote sensing experts, regulators, museums) and non-professional users, for tourism and education purposes concerning regional natural and cultural heritage of the people. In addition, the effective interoperability between different computer platforms, executing a program or data transmission between various functional units should allow for the user to have little or no need to understand the characteristics of these units. Related operations can also be hosted in the cloud by sending images to a remote powerful server and, after a short period of post-processing, the design model can be previewed. This makes digital archaeology work less exclusive than in the past, which makes it easier for government decision makers, schoolteachers and the public to use data and offers the possibility of wider participation.

17.4.5 Quantitative Research Based on the Value Assessment of Natural and Cultural Heritage via Digital Technology

Although the important role and significance of natural heritage in the ecological balance, scientific research, scientific popularization, natural aesthetics and tourism and leisure are difficult to estimate, some fields can be evaluated. In terms of ecological value, especially large natural heritage plays an extremely important role in the conservation of species and the ecological value of regional and global significance. The earth is an organic whole, and local destruction can affect the local or wider ecological environments. Although we may not see any examples of such local destruction causing an obvious overall imbalance, the changes in Antarctic glaciers and even mountain glaciers caused by current climate changes has been a "wake-up call" (e.g. Kaser et al. (2004)).

For both tangible cultural heritage and intangible cultural heritage, the value is diversified. The intangible cultural heritage of language, handicrafts, performance art and other forms of cultural expression make successive human knowledge to be realized from generation to generation. The result of the accumulation of knowledge greatly promoted human progress. Tangible and cultural heritage is the tangible evidence for humans to know themselves. The archaeological analysis and reconstruction of the physical remains (including artifacts, buildings, etc.) and their related living environments and cultural landscapes have led to the rediscovery of some lost ancient civilizations. The great value of cultural heritage must also be explored further.

Examples of the multiple values of nature and cultural heritage are numerous. Due to the large spaces, time spans and complex situations, quantitative research has not been well conducted. For quantitative research on the value of cultural heritage and natural heritage based on digital technology, the formation of a system and a standard are a possible and urgent innovation issue.

17.4.6 The Study of Effective Protection of Digital Heritage and Legal Protection Is Becoming Increasingly Urgent

At present, the main problems in the protection of digital heritage come from two aspects. One is the problem that researchers' understanding of the value of digital heritage is insufficient. The value of the digital information of heritage may not be recognized before it disappears or changes and it is too late to provide effective protection. Digital data may be well preserved, but the identification and description may be so poor that potential users cannot find them. As the independence of data and data processing applications cannot be confirmed, the use of data is reduced. The second aspect is the problem of incomplete preservation of digital heritage due to insufficient funds and responsibilities. No one is responsible for the information, or the person responsible may lack the knowledge, systems or policy frameworks needed to perform their duties. Information is vulnerable to disasters such as fires, equipment failures, floods, viruses or direct attacks that disable storage equipment or operating systems; measures such as password protection, encryption, and security devices will cause data to be unavailable when they are not applied.

Cyber space generated by the internet is a kind of living form that has not been experienced by humans. It will have an inestimable impact on contemporary and future human beings. Due to the openness and sharing of resource information in the network environment, anyone can obtain the desired information in any place by some means. Digital heritage is faced with the problem of destructiveness caused by openness and sharing. In addition, the problem of infringement occurs relatively easily. As a kind of digital heritage with the characteristics of cultural heritage, the owner of its property rights should be protected by the corresponding laws. Infringement in the network is different from general infringement. Due to the disguised characteristics of network information transmission channels, the copyright and communication rights of digital heritage easily lead to infringement caused by the transmission of digital heritage without the permission of property owners. Therefore, it is necessary to systematically form international legal documents and universal legal protection of digital heritage.

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