



Space technology: A powerful tool for safeguarding world heritage

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WORLD HERITAGE AND SPACE TECHNOLOGY

The Convention Concerning the Protection of the World Cultural and Natural Heritage (WHC), adopted by United Nations Educational, Scientific and Cultural Organization (UNESCO) on November 16, 1972, aims to ensure the identification, protection, conservation, presentation, and transmission to future generations of the world's cultural and natural heritage. The WHC works toward these goals by emphasizing the Outstanding Universal Value (OUV) of heritage sites and the unique contribution such places can make to conservation and human development agendas.¹ As of the end of January 2023, the WHC has been signed by 194 state parties, covering 1,157 sites (including 900 cultural, 218 natural, and 39 mixed properties), 55 of which are considered to be in danger. These sites, totaling an area of more than 370 million hectares are designated as World Heritage (WH) sites (<https://whc.unesco.org/en/list/>). WH sites have played a significant role in the sustainable development of society globally and helped effectively maintain and preserve the cultural diversity and global biodiversity of the Earth.²

However, WH sites around the world are experiencing significant impacts caused, in large part, by increasing anthropogenic threats (such as the rapid spread of urban sprawl, deforestation, resource overexploitation, air pollution, armed conflict, excessive tourism, and poor management).³ There is also a range of overarching, long-term global challenges posed by climate change, extreme and severe weather events and geological hazards.⁴ These threats, anthropogenic or otherwise, have put an unprecedented amount of pressure on the protection of both cultural and natural properties at the heritage sites. There is no conclusive solution to effectively protect heritage sites in the foreseeable future, and the public is becoming increasingly conscious about the negative impacts some anthropogenic activities have brought to heritage sites, exposing them to various risks for irreversible damage and loss.

In light of this predicament, UNESCO, alongside its conservation partners, has been actively calling for the use of non-intrusive space technology (ST) to better evaluate and understand the detrimental factors surrounding WH sites and devise effective plans to mitigate negative impacts on OUV through the accurate identification, documentation, monitoring, and understanding of WH sites and their changes across large spatiotemporal scales. For this commentary, ST refers mainly to remote sensing (RS) based on Earth observation (EO) from space, as well as other geospatial information technologies such as geographic information systems (GIS) and global navigation satellite systems (GNSS).

PROGRESS, CHALLENGES, AND OPPORTUNITIES OF ST FOR WH CONSERVATION

Even though ST was not developed intentionally for WH protection, it provides an advanced set of innovative and flexible tools that integrate scientific research into heritage science, which forms the evidential base to support measures for

the protection of WH sites. ST also opens up paths of methodological innovation to facilitate future conservation of cultural and natural properties with new paradigms. On the basis of a half-century review of the applications of ST in the field of WH, we find that ST has effectively reshaped our means for WH conservation in four major domains of application: mapping, monitoring, modeling, and management of WH sites (Figure 1A).

ST, as an objective and reliable "eye" from above for heritage experts, has enabled detailed mapping of heritages at various scales. This application commonly involves the acquisition and updatable analysis of multimodal datasets, combined with near real-time survey and investigation of WH sites and their contextual environments. ST is also an invaluable tool in identifying and designating potential new WH sites.

The widespread integration of ST has played a crucial role in UNESCO's routine monitoring and emergency monitoring of cultural and natural heritages as a countermeasure to the challenges presented by global change. In particular, ST has made major contributions to fine-grained monitoring at very high resolutions in time and space and in assessing change caused by natural and/or anthropogenic processes.

The combined application of RS, GIS, and augmented reality has facilitated the production of three-dimensional (3D) modeling of WH sites. In addition, photogrammetry and laser scanning can be used in WH surveys for generating 3D documentation of cultural and natural properties. Heritage information models of some popular WH sites have already been actively used in the fields of architecture study and digital ecology.

The ability of ST to contribute to the conservation, planning, and management of WH sites has already been commonly used in the following domains: the definition of authenticity and integrity (AI), the mapping of OUV attributes of cultural and natural assets, the development and maintenance of heritage databases, 3D modeling and digital reconstruction, and informing WH management for sustainable development.

FURTHER PROMOTION OF THE CONVENTION AND WH USING ST

The UNESCO WHC refers to its "strategic objectives" as the "5 C's": credibility, conservation, capacity building, communication, and communities.¹ Here, we propose five key contributions ("5 D's") of ST for conservation work involving WH sites (see Figure 1B): data, driver, discovery, digital transformation, and decision support. ST and the 5 D's, together with the WHC, constitute the "turbine model" for safeguarding WH that is proposed in this commentary and will assist in achieving the 5 C's over the next 50 years.

By providing massive multi-source data, ST plays a crucial role in the WH governance chain. Archived data together with ongoing data acquisition record changes at WH sites and provide evidence for their conservation. The data collected through ST will, in turn, serve as an invaluable store of not only raw

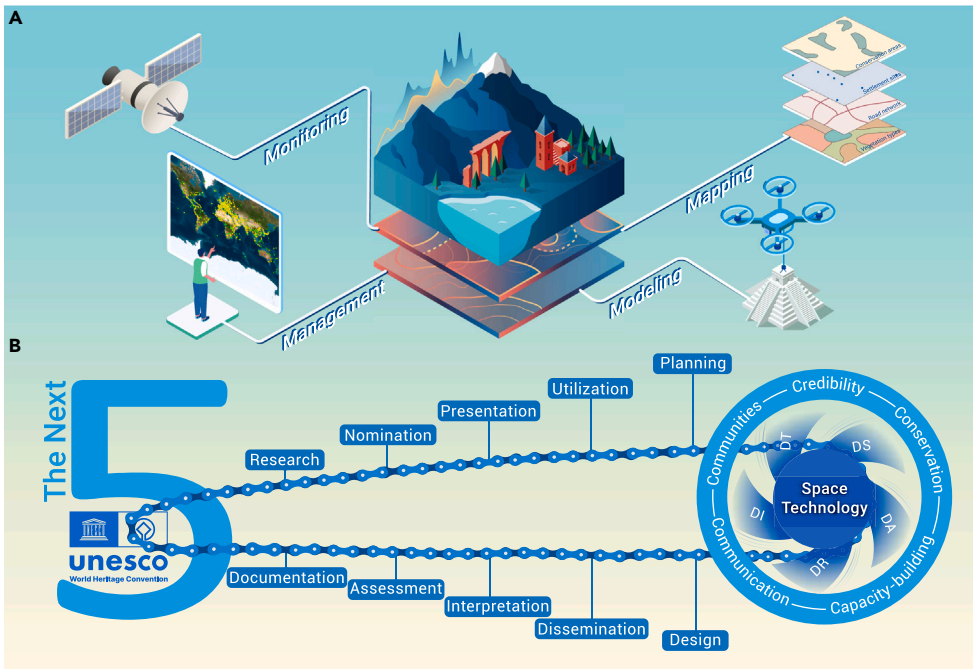


Figure 1. Safeguarding WH using ST (A) Schematic diagram showing the scope of ST application for WH mapping, monitoring, modeling, and management. Mapping produces geospatial maps for WH protection, monitoring grasps the changes occurred in WH sites, modeling provides an important means for digital protection, and ST-powered management improves the capacity of WH governance globally. (B) The “turbine model” of the proposed five key contributions (the 5 D’s: data [DA], driver [DR], discovery [DI], digital transformation [DT], and decision support [DS]) that ST can make toward promoting the five strategic objectives (the 5 C’s: credibility, conservation, capacity building, communication and communities) of the WHC in the WH governance chain. ST is the engine, and its five key contributions are the turbine blades.

observations but also derivative products that can be extracted from imagery.⁵ As a result of this data mechanism, ST will be able to mitigate the problem of lacunae in WH data by offering global coverage and consistency.

ST is driving a revolution to become a new paradigm of WH protection. It provides advanced tools, such as RS data processing and GIS spatial analysis powered by machine learning, which can be used for dynamic monitoring and spatiotemporal analysis of changes that are occurring at WH sites. From this enhanced monitoring method, WH specialists and managers are empowered with the tools to monitor change over time and to assess whether conservation efforts to mitigate the impacts of natural and anthropogenic processes are contributing to positive outcomes toward sustainability.

ST plays a key role in aiding frontier research across multiple disciplines related to heritage science. Scientific discoveries based on the use of new geospatial technologies and big EO data can be applied to the quantitative assessment of the state of WH protection. They can also be used to support deepened multidimensional interpretations of the OUV of WH sites, to guide the sustainable use of WH, and to improve accessibility so that all stakeholders may obtain unbiased and open information, thus increasing the credibility of WH as a global brand.

ST provides a means of digital transformation that can be used for identifying, understanding, visualizing, presenting, and interpreting WH sites and their OUV in the digital space. In the future, ST will promote the transformation of WH protection through studies such as tangible heritage, digitalized heritage, or both. GIS-aided digital transformation will greatly improve the quality and efficiency of global communication and the dissemination of information related to WH sites, promoting public awareness of protection concepts and smoothing the implementation of actions.

ST is becoming an invaluable tool to provide decision-making support along the entire chain of WH governance, from mapping to monitoring, modeling, and management. ST-based solutions could offer spatial intelligence to inform strategic decision making for multiple stakeholders, including local communities, WH sectors, institutions, and organizations. It offers an innovative path for capacity building and capacity enhancement in relation to the global governance of WH. These solutions are delivered in numerous ways, including databases, technologies, protocols, visualization platforms, and analytical systems.

TOWARD WH PROTECTION IN A TIME OF GLOBAL CHANGE

WH is under the influence of a wide array of anthropogenic and natural processes, giving the heritage bodies and national and international organizations promoting the preservation of WH sites an unprecedented opportunity to use sci-

ence, technology, and innovation, including ST, to experiment innovative solutions and promote the role of WH in achieving sustainable development. Given that natural and anthropogenic challenges can present similar issues in various regions across the globe, it is evident that sharing knowledge and expertise, as well as developing collective strategies to leverage ST, while tailoring our methods to local circumstances, will be fundamental in developing a global approach for WH that is successful in the long run.

The past 50 years of applications have resulted in continuous innovation in the development of ST to become powerful, cutting-edge tools for use in heritage documentation, monitoring, assessment and protection, and sustainable development. Although the progress is promising, we must underscore that relying solely on ST is insufficient; the greatest benefits are achieved by integrating ST with a variety of disciplines, such as management, economics, sustainability, sociology, education, ethics, politics, law, art, and aesthetics. Through closer and sustained engagement with a broader cross-section of society and local communities, ST can contribute to opening new horizons for WH protection over the course of the twenty-first century.

REFERENCES

1. UNESCO, United Nations Educational, Scientific and Cultural Organization. *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris, France: UNESCO, 2021.
2. Luo, L., Wang, X., and Guo, H. (2022). Contribution of UNESCO designated sites to the achievement of sustainable development goals. *Innovation* **3**, 100227.
3. Allan, J.R., Venter, O., Maxwell, S., et al. (2017). Recent increases in human pressure and forest loss threaten many Natural World Heritage Sites. *Biol. Conserv.* **206**, 47–55.
4. Voudoukas, M.I., Clarke, J., Ranasinghe, R., et al. (2022). African heritage sites threatened as sea-level rise accelerates. *Nat. Clim. Chang.* **12**, 256–262.
5. Levin, N., Ali, S., Crandall, D., et al. (2019). World Heritage in danger: big data and remote sensing can help protect sites in conflict zones. *Global Environ. Change* **55**, 97–104.

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DECLARATION OF INTERESTS

The authors declare no competing interests.