Digital Preservation of Cultural Heritage

Subjects: Others
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The intensifying effects of climate change are becoming one of the main threats to cultural heritage, posing risks of degradation or destruction. Climate change is bringing complexity and uncertainty to ensuring the resilience of cultural heritage, and among risk mitigation measures digitalisation is regarded as a promising tool. However, the infrastructure required for the digitalisation process exerts significant pressures on the environment contributing to climate deterioration.

Keywords: cultural heritage preservation ; digital preservation ; sustainability ; ICT

1. Introduction

Heritage means something inherited, and often refers to material or immaterial items which have historical, cultural, symbolic, social and/or aesthetic values [1][2]. A distinction is often made between tangible heritage, which are material elements such as historic cities, collections, archives, natural landscapes, and technological achievements, as opposed to intangible heritage which includes immaterial aspects like knowledge, skills, traditions, craftsmanship, beliefs, social practices, and values [3]. Cultural heritage implies a sense of belonging and can be interpreted as a shared bond within a community. Therefore, it is often an important component of a community's identity but also a driver of the economy [4][5].

Through the transformative socio-economic developments that occurred in the late 20th and early 21st century, a need for protecting cultural heritage emerged and led to the creation of the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List, which now counts more than a thousand sites judged important to be preserved for their "*outstanding universal value*" [6]. Due to its vulnerability to multiple threats, including natural and climate-related disasters, cultural heritage was also integrated into international disaster risk reduction frameworks such as the Hyogo Framework for Action and the Sendai Framework for Disaster Risk Reduction 2015–2030. In particular, climate change impacts on natural and cultural heritage were emphasised during the 29th Session of the World Heritage Committee in Durban in 2005 [7].

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as "*any change in climate over time either due to natural variability or as a result of human activity*" [8]. According to the Framework Convention on Climate Change (FCCC) and IPCC, human activity is a key driver of climate change as it directly or indirectly modified natural climate vulnerability mostly through the emissions of greenhouse gases [9]. Among the observed effects and impacts of climate change are the increase in frequency and intensity of climate extreme events such as storms, floods, and droughts but also longer-term effects such as sea-level rise and increased temperatures [10][11]. As a consequence, climate change has become in recent years one of the main threats to cultural and natural heritage, as it can cause the degradation or loss of tangible heritage as well as intangible heritage (e.g., due to people's displacement or modified cultural practices or traditions due to climate stressors) [10][12][13]. For instance, even if the global mean temperature remains stable for the next two millennia, 6% of the UNESCO sites would be affected by sea-level rise [14]. Not only sites but also buildings and objects would be affected by climate change-related risks, which are creating new stressors as well as emphasising or accelerating already existing natural (climate-related risks, geohazards, etc.) and human-induced risks (mass tourism, air pollution, urbanisation) [15][16][17][18].

2. Risk Management of Cultural Heritage

With the current threats affecting cultural heritage sites as well as the ones exacerbated and/or created by climate change, studying risks is important for finding measures that can reduce their likelihood or consequences. Risk is commonly defined as the likelihood of a hazard multiplied by its consequences [19][20]. Potential risks affecting cultural heritage have been taken into consideration notably through practical guides or policy documents established by international organisations such as the International Centre of the Preservation and Restoration of Cultural Property (ICCROM) and UNESCO [21][22].

Even though risks are often context-specific, some main trends and deterioration processes can be highlighted and described. First, cultural heritage sites are exposed to natural conditions such as humidity, temperature, wind pressure and soil characteristics leading to natural deterioration processes which include natural decay of materials as well as erosion processes related to weather events, insects, and vegetation. Natural deterioration processes lead to chemical, physical and biological degradations of the materials that compose buildings as well as their components (including objects and artefacts) that are considered cultural heritage assets [21]. These degradations may be emphasised or accelerated by different types of risks which can sometimes be complex to comprehend. Indeed, risks vary from sudden to slow-unset events (e.g., hurricane versus erosion) and can affect directly or indirectly heritage sites (certain events can lead to secondary risks e.g., a fire can directly destroy some parts of a cultural heritage asset while the fluctuation of humidity caused by this fire can also cause damages to the cultural heritage asset). Furthermore, cultural heritage assets can be affected by large-scale risks (e.g., an earthquake) as well as microscale risks (e.g., biological degradation caused by pests) [20][21].

The potential effects and impacts of climate change on tangible heritage are multiple, and include for instance: corrosion of materials such as limestone due to unusual weather patterns and intensification of rainfall; structural damage and collapse of heritage buildings due to the increase of extreme weather events such as heavy wind; destruction of cultural sites situated on a seaside environment due to coastal erosion; deterioration of building facades due to thermal stress such as thaw and frost, or due to atmospheric pollution; deterioration of surfaces (e.g., paintings, frescos) due to exposure to wetting and drying that results in the crystallisation and dissolution of salts; and for some materials, such as wood, climate change and rise in temperature are likely to lead to a more frequent proliferation and to the migration of new parasites [7][23][24].

Even though disaster risk management has been incorporated into preservation and conservation techniques and principles, climate change is bringing a new dimension of complexity and uncertainty to ensure the resilience of cultural heritage [25]. In this context, existing strategies for the whole disaster risk management cycle (preparedness and mitigation, response, recovery) should be reinforced in addition to the implementation of climate integrated cultural heritage management strategy and targeted actions [13][18]. Managerial and structural adaptation measures include dedicated funding and insurance schemes, regulations, and governance procedures, and fostering knowledge and learning opportunities (e.g., awareness and communication campaigns, education through training and drills) to bridge climate change science and cultural heritage communities to increase collaboration [18][24][26]. Among preservation measures, digitalisation is regarded as a promising tool that can "*enhance access to cultural heritage and the benefits which derive from it*" according to the Faro Convention [26][27][28]. Indeed, more and more advanced Information and Communication Technology (ICT) and image processing tools allow both a form of digital preservation of heritage and the possibility to remotely discover or explore an artefact or a site through the development of virtually generated versions of it, usually in three-dimensional and interactive visualisations [27].

3. Digitalisation and the Environmental Impacts of Information and Communication Technologies (ICT)

The digitalisation of cultural heritage offers indeed a unique opportunity for the preservation of a virtual copy of the material object in standard quality over time that would enable the continued use and appreciation of its cultural value for future generations. However, the digitalisation process is relying upon extensive material (hardware) and immaterial (software) ICT infrastructure which directly and indirectly contributes to environmental pressures and the intensification of climate change [29].

ICT equipment is enabling both the preservation and the dissemination of digital content, so it is indispensable for all essential processes that fulfil digital preservation purposes, from securing safe storage of the digitised or born-digital content to sharing and providing access to the end-user. In this respect, ICT equipment comprises the whole communication network, meaning the data services or core network for the electronic distribution of data (e.g., data centres' computational power and hardware) as well as the extended end-user's network (e.g., laptops and servers) to connect to it [30]. However, the actual ICT system required for digital preservation is hard to define precisely, especially the extent of the enabling infrastructure and the resources and energy consumption needed, as well as its environmental impacts. This is why the adoption of a life-cycle perspective is required to address both resources (e.g., scarce minerals) and energy use throughout the production, use and disposal phases of ICT equipment [31][32].

In the production stage, the direct impacts of ICT equipment mainly derive from energy-intensive processes linked to resources' mining and refining [33]. The extraction of raw materials, including scarce metals (gold, indium, palladium, silver, etc.) as well as rare earth elements (tantalum, magnesium, etc.) leads to resource depletion [34]. Moreover, the extraction process of these materials requires excessive use of chemicals, and the mining industry is highly dependent on fossil fuels, contributing tremendously to carbon dioxide emissions [29]. Major impacts occurring during the mining and refining processes include biodiversity loss, contamination of soil and water in the surrounding areas, and emissions in the atmosphere [35][36]. Consequently, the ‘embodied energy’—the upstream energy demand of the material composition of the product—is largely contributing to the overall environmental impacts of ICT equipment.

In the use phase, direct effects can be found in the ICT infrastructure and cloud-computing, due to the energy demand of the computing and networking equipment as well as the cooling needs of data centres [35][37].

Ultimately, ICT equipment is forced to replacement due to either technological or software obsolescence, which in the context of digital preservation is dictated by the digital assets’ safety and preservation standards [37]. Therefore, ICT equipment exerts further pressures on the environment at its end of life, especially considering that only 17.4% of the total electronic waste produced was reported as officially collected for treatment in 2020 [38]. The rest was disposed of in landfills, burnt, or illegally traded mainly for extracting the precious metals from ICT components, leading to the production of highly toxic substances, and usually treated under hazardous conditions [39][40].

The mitigation focus of ICT impacts has mainly been on the energy consumption and the extended energy demand implications from the optimisation, virtualisation, or substitution processes in other sectors, e.g., in transportation [31][35]. Thus, the preferred path for mitigating the resource and environmental impacts of ICT is to increase technological efficiency as it will lead to energy and material resources savings, and thus reduced environmental impacts [31][41]. It is argued, however, that perpetual technological fixes by increasing constantly the energy and resource efficiency of ICT, cannot reach sustainability in the long run [42].

Increasing the efficiency of ICT implies having more service/work produced per unit of ICT equipment. For example, for the same computational outcome, only half of the energy would be needed if the processing efficiency doubles [43]. However, the ICT sector (products and services) keeps growing on a global scale and this translates directly to an increase in the total resources consumption. Therefore, it remains uncertain whether efficiency improvement alone could outpace the sector’s growing impacts [41].

Energy consumption of ICT has been continuously increasing over the past years, from 3.9% of the global electricity demand in 2007 [44] to 4.6% in 2012 [45]. Recent estimates point out that the sector could reach 13% of the global energy consumption by 2030 [46]. Moreover, the IEA [47] predicts exponential growth in data usage, with global internet traffic expected to double by 2022 to 4.2 zettabytes per year (4.2 trillion gigabytes). This suggests that despite technological efficiency improvements in the ICT sector, energy and resource consumption will keep increasing. The reasons for this can be better understood with insights from the ‘rebound effect’ and ‘resource decoupling’.

The rebound effect means that the technological efficiency improvement of a process or product is not followed by a decrease in its demand. On the contrary, demand bounces back, counteracting much of the efficiency gains [48]. Consequently, reducing energy consumption through efficiency increases cannot be guaranteed because of potential rebound effects [41][49][50].

On the other hand, understanding the decoupling of resources and negative environmental impacts per function of ICT is deeply attached to the broader economic system [31][41]. For instance, there is a discrepancy between the current technical value of ICT growth and its economic measuring—an example of this could be the prices of smartphones which have remained steady over the past ten years despite significant computational efficiency increases [51]. Moreover, the value of digital services is underestimated since they are not charged per data unit but rather at flat rates [41]. Such actions may counteract the resource-saving effects of efficiency increases by driving an increase in total consumption [31].

Consequently, a complementary approach is needed beyond the widely applied technological fixes of ICT efficiency, and emerging one is suggesting the introduction of a sufficiency perspective [31][41].

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