Digital cathedrals: bringing Notre-Dame de Paris back to life

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The devastating fire at Notre-Dame de Paris sparked intense emotion around the world, demonstrating the cathedral's important place in history and culture as well as its enormous symbolic power. As France

and other countries around the world continue to mourn the tragedy, the French government, experts, journalists and others are already mobilising to launch an ambitious restoration – funding, planning, skills, materials and technologies.

The debate has already started between traditionalists and modernists. Should the cathedral be restored as exactly as it was, including the wooden roof structure? Should metal or other fire-resistant materials be used? Whatever the choices made, digital heritage tools will be critical, both in restoring and preserving the iconic monument and in developing virtual access to past and present treasures during the restoration process and after its completion.

Cathedrals as sites for digital experimentation

The adoption of information and communication technologies (ICT) by heritage organisations serves both of their two missions, curatorship and access. Because of their size and intricate structures, cathedrals have always been the proving ground for technological innovation, from flying buttresses to immense domes, and this remains true today with digital technologies. Projects such as Digital Cathedral, e-Cathedral, and Mapping Gothic France bear witness to the interest of the scientific community, public authorities and private firms, which see digital technology as a powerful tool to enhance the comprehension, preservation, restoration and transmission of heritage.

For example, the Computer Science Department of Columbia University, New York, has launched a major project to digitally preserve Saint-Pierre Cathedral in Beauvais, France, which has the highest vault in Europe at 48 meters. This monumental structure suffered partial collapses several times during its construction during the Middle Ages, and long after work stopped in 1604, it suffered bomb and fire damage during World War II. Due to its daring design and advanced age, as well

as the unstable ground, past shocks, and poorly managed alterations, the structure is highly fragile. To document and model the it in 3-D, the researchers made 220 interior and exterior scans at multiple locations to better enable the cathedral to be preserved and passed on to future generations.

Digital archaeological technologies have been used to reconstruct and visualise lost or inaccessible sites such as Pompeii, the Lascaux Caves and Palmyra. They have a memorial function for inaccessible monuments, as well as those that have been partially or completely destroyed. These technologies can reproduce them so faithfully that it is possible to feel a measure of sacredness in their virtual doubles.

For example, the St. Donato Cathedral in Arezzo, Italy, demolished during the 16th century, has received a full digital reconstruction. A research group within the Computer Science Department of the University of St. Andrews, Scotland, has digitally reconstructed St. Andrews Cathedral, which was ransacked during the Protestant reformation in 1559 and subsequently fell into ruin.

The Vista-AR European project aims to use digital technologies to "discover the past and invisible history of a site", including the Concergerie in Paris, where Marie Antoinette was imprisoned before her execution in 1793. Located in southwest England, Exeter Cathedral was transformed, damaged and rebuilt numerous times across its long history, including after it was bombed during World War II. Now, through the use of augmented-reality systems, visitors will be able to witness scenes of past life, meet characters from long ago, and virtually access missing or inaccessible artefacts.

Digital technologies are also widely used to create audio guides, applications, sound and light shows, and video games. Some digital events are also based on a combination of technologies, including the

summertime multimedia spectacles on the facades of the cathedrals in Amiens ("Chroma"), Reims ("Regalia") and Montreal "Aura". Prior to the April 2019 fire, Notre-Dame de Paris naturally had its own, "Dame de Cœur".

Digital technologies for restoration

Given the serious damage to Notre-Dame de Paris, digital technology would have a wide range of potential applications:

- Preserve the building digitally forever using ultra-high definition, panoramic, stereoscopic images, as well as digital libraries and archives.
- Explore a number of mysteries associated with the construction of religious buildings and symbols they contain using spectral, infra-red and ultra-violet imagery, and 3-D tomography.
- Reconstruct the cathedral using digital scanning and modelling.
- During the years-long reconstruction process, allow the public to virtually visit the cathedral using applications, head-mounted diplays and other virtual-reality devices.

Notre-Dame de Paris is not only the most visited tourist site in Europe, it has also been extensively studied, documented, filmed and analysed. Prior to his death in 2018, the pioneering art historian Andrew Tallon scanned and documented Notre Dame and many other cathedrals. The invaluable data collected, which contains more than 1 billion data points, has been made available in open access.

The firms Art Graphique & Patrimoine (AGP) and Géomètres-Experts (GEA), which specialise in 3-D digitisation, have also worked on Paris Notre-Dame Cathedral. They produced a 3-D model of the roof and beams for the renovation in progress that could well have triggered the fire. This model will now be crucial for the restoration of the building.

Digital technologies for access

Digital technologies can provide onsite and online audiences with experiential access to heritage knowledge, artefacts and places. In the case of Notre Dame, digital technology can be used to disseminate knowledge about how the monument evolved through the ages, the restoration project, the historical techniques that will be involved and behind the scenes at the construction site.

A similar effort is underway in Basque Country, Spain, where the 800-year-old Cathedral Santa Maria de Vitoria-Gasteiz is being restored but is "open for construction". The foundation directing the project offers two-hour guided tours, from the foundations to the bell tower. The tour concludes with a sound and light show, "El portico de la Luz", revealing how the entrance was originally painted. So far, more than 1.5 million people from all around the world have taken part.

For Notre-Dame de Paris, the first step in the process will be the construction of a temporary wooden cathedral in front, to maintain a living link with the cathedral. Within the temporary cathedral and via an online portal, visitors will be able to follow reports on the restoration's progress, take part in the virtual community of Notre Dame, and learn about related events.

Indeed, to overcome the potential fall in cultural tourism, "phygital" (physical and digital) heritage technologies could be combined next to the cathedral, to create a new fascinating environment with interactive screens, digital tables, virtual reality lounges and arcades incorporating simulations and games providing strong sensations and emotions. For example, visitors could experience the video game *Assassin's Creed Unity*, which features an intricate simulation of the cathedral in all its beauty.

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