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Tools against oblivion: 3D visualization of sunken landscapes and cultural heritages applied to a dam reservoir in the *Gorges de la Loire* (France)

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Abstract

Around the world, thousands of reservoir dams have flooded valleys and become concrete symbols of the Anthropocene. These landscapes, as well as material or immaterial cultural heritages, were flooded and thus became invisible, even though they remain in the memories of local populations. Today, alternative technologies can enable inhabitants to reappropriate these lost heritages and, in a way, make them visible again. 3D digital tools can effectively recreate representations of these landscapes and restore the visibility of these underwater heritage sites. In this study, we propose a 3D geographic information system methodology combined with 3D geovisualization to recreate sunken landscapes, and we demonstrate the results using the valley of the *Gorges de la Loire* in France as an example. We show how developing a historical database can provide a “backup copy” of lost landscapes and cultural heritage sites, enabling populations to safeguard and restore these features in their memory following flooding.

Keywords

3D, geovisualization, Geographic Information System, sunken landscape, cultural heritage, dam reservoirs

Declarations

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Introduction

Dams and associated reservoirs have multiple socioeconomic functions, such as generating renewable energy production, supplying water to people and crops, and facilitating tourism and leisure activities (Marnezy 2008; Loloum 2016). Dams can also have positive health impacts (Lerer and Scudder 1999). However, dams are usually associated with numerous adverse ecological and biophysical effects on the environment, including threats to connectivity for freshwater fish (e.g. Barbarossa et al. 2020), alteration of flows, sediment transfer and transport leading to vegetation encroachment, riverbed incision and narrowing, and in-stream habitat degradation (e.g. Petts and Gurnell 2005).

Since the 1950s, the number of large hydroelectric dams, that is, those with heights of 15 meters or more from lowest foundation to crest or a dams between 5 meters and 15 meters impounding more than 3 million cubic meters (ICOLD 2011), has rapidly increased and can be seen as a symbol of the Anthropocene (Steffen et al. 2015). Because large dams and associated reservoirs cover larger land surface areas, they are more likely to include historical and cultural heritages. Several case studies dealing with reservoir impoundment losses have been reported in the literature. In 1970, Egypt's manmade Lake Nasser, created by the Aswan Dam on the Nile River, flooded archeological sites including the Buhen fort and the cemetery of Fadrus, while several other temples that were physically moved were preserved (Harris et al. 1970). In 2003, China's Three Gorges Dam, on the Yangtze River, sank two large cities, 11 towns, 114 townships, numerous villages and farms (Jackson and Sleight 2000) and over 1280 archaeological and cultural heritage sites (Ponseti and López-Pujol 2006). In 2020, the Turkish Ilisu Dam on the Tigris River will sink the ancient town of Hasankeyf and its 12 000 years of history, as well as 180 other villages (Drazewska 2019). These dams are among the most emblematic examples worldwide.

In France, after the Second World War, the state embarked on a major policy of building large dams for the stated purpose of electricity production (Barjot, 2013). In his book “*La France des villages engloutis*” (The France of sunken villages), G. Guérit (2019) listed 44 valleys with sunken villages due to reservoir impoundment between 1914 and 1992. Dam construction inevitably entails different degrees of trauma. Difficulties experienced by the local population include the expropriation of land, resettlement of the population, cemetery relocation, police interventions, and residence destruction. Regardless of the location, the trauma of these events is constant and often generates social mobilization (Schapper et al. 2020; Flaminio 2020). This phenomenon was observed in, for example, the hydroelectric schemes of Tignes (in 1953) and Serre-Ponçon (in 1960), where a classic opposition between the “best interest of the nation” and “individual interests” was observed (Bodon 2003). In other cases, projects were more easily accepted by the local population and the situation remained calm, as with the Grangent dam in the Gorges de la Loire (1957).

The construction of such dams is often associated with the disappearance of anthropogenic infrastructures (e.g. bridges, houses, and railroads), socioeconomic activities, and cultural and landscape heritages under these flooded valleys. These landscape features remain mostly invisible, except in instances in which the water level decreases significantly. This invisibility has both a temporal and a spatial dimension. The invisibility is temporal because all of these underwater infrastructures and landscapes belong to the past and do not exist in the present, and it is spatial because these areas are flooded in the present. However, these heritages remain alive in the memories of local inhabitants, for example, through visits during reservoir draining periods or during dives. These legacies are now of interest to a growing number of people. Such renewed interest is also sustained by legends regarding sunken cities, where Ys (Brittany), Kitezh (Russia), Atlantis, Lemuria, and the Great Flood of Gun-Yu (China) are among the best known.

This interest raises the question of how to keep these lost heritages “afloat” and accessible to all. To meet such an objective, several digital methods are generally used in heritage studies involving the preservation or management of specific sites, including remote sensing and GIS (Summerby-Murray 2001; Agapiou et al. 2015; Domínguez-Ruiz et al. 2020; Elfadaly et al. 2020; Griffiths and Vaughan 2020), 3D GIS (Campanaro et al. 2016; Dell’Unto et al. 2016; Deguy et al. 2019; Ferdani et al. 2020), (H)BIM (Colucci et al. 2020; Raner et al. 2020), 3D modeling and virtual landscaping (Jacquinod 2014; Berti and Landi 2020), and more generally, 3D digital technologies (Koutsoudis et al. 2020; López et al. 2020). These tools and technologies are not mutually exclusive; they can be used on different types of objects and applied to a wide range of spatial scales (e.g., vessels and such buildings as

tombs, temples, castles, cities, and landscapes). Tools should be chosen according to the type of heritage being documented, the scale, and research or management objectives. Each tool involves a relevant methodology. In this paper, we propose a 3D GIS methodology associated with 3D geovisualization to recreate the sunken landscape of the *Gorges de la Loire* (Loire gorges).

Methodology

Study area

The study site under investigation is located in France, near the city of Saint-Etienne, in the *Gorges de la Loire* (Figure 1). Following a construction period from 1955 to 1957, the impoundment of the Grangent reservoir profoundly and abruptly changed the socioecological landscape of the valley between the cities of Aurec-sur-Loire and Saint-Just-Saint-Rambert (Figure 1).

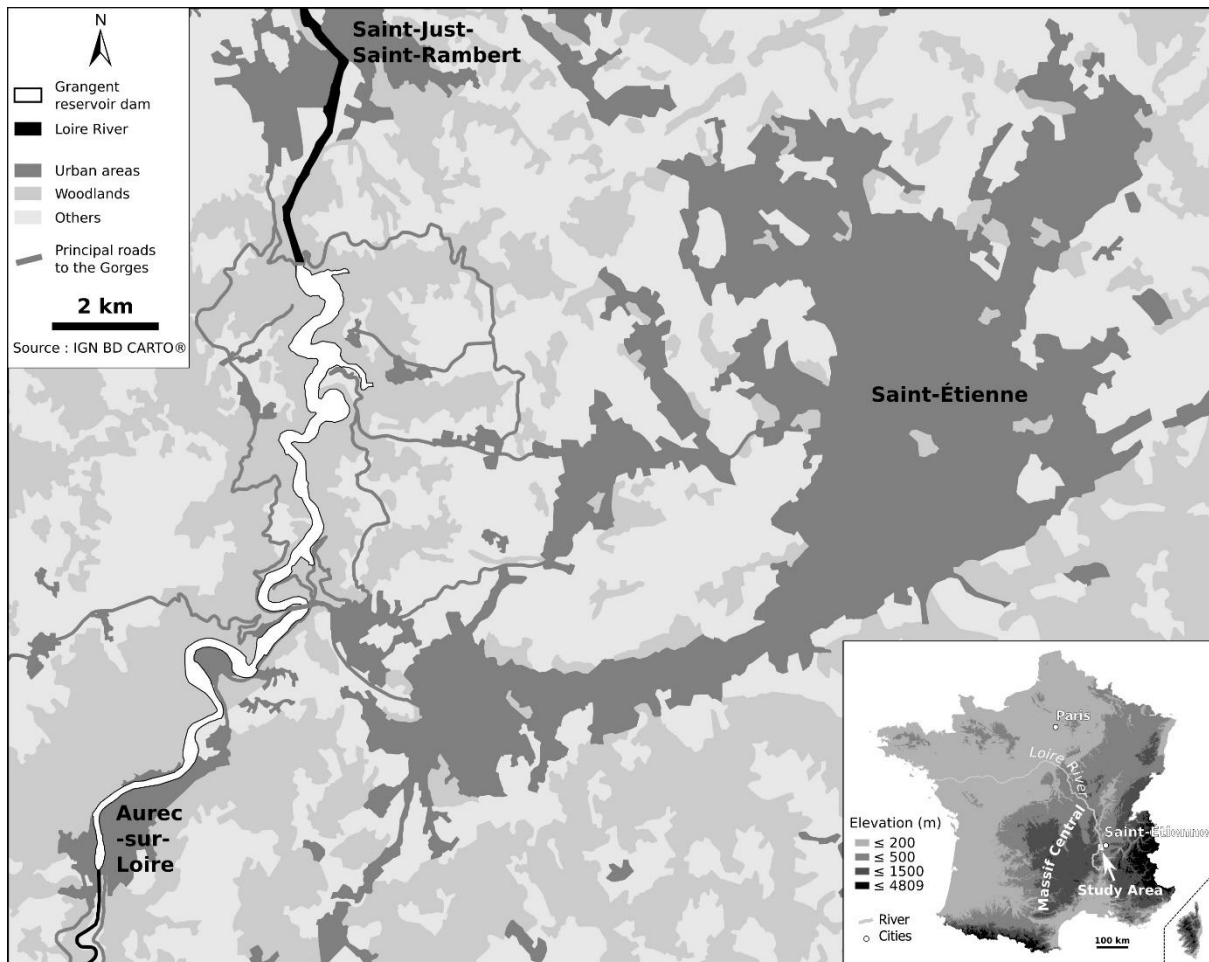


Figure 1. Location of the study area in France

This valley has been used for centuries and remains in the collective memory. Before the establishment of the Grangent dam, there were villages, farms, factories, roads, and a canal, as well as a railroad and related infrastructure, such as bridges and tunnels. All these landscape elements symbolized the history of an industrial region through the 1950s. Furthermore, the river had an important social role for inhabitants of the surrounding towns, including Saint-Etienne. These residents appreciated relaxing on the banks of the Loire, dancing and drinking wine in the open-air dance halls, swimming, or attending water jousting events (Peyraud 2006). During the postwar economic boom and in the context of reconstruction and economic growth, the construction of a hydroelectric dam began a radical transformation of this area. The landscape underwent a radical change as a 365 ha and 21 km long lake with a total reservoir capacity of 57 million cubic meters, which submerged the Loire Valley. The change symbolized modern life in the second half of the 20th century abruptly replacing the former

landscape of industrialization. This new landscape is dedicated to electricity production but also to leisure activities and tourism with a marina, a nautical base and a beach. However, during partial decennial emptying for maintenance purposes, the level of the reservoir drops from approximately 420 m asl to 405 m asl, and indicators of the past temporarily reappear as ruins and other remains resurface. During these events, the people of the Saint-Étienne region visit the remnants of the past, use bridges, and enter former tunnels. Such an infatuation reflects their interest in this area and the need to reappropriate these historically significant locations. The methodology proposed in this study constitutes an alternative method of providing access to sunken heritages to inhabitants and local authorities.

Data collection

The first step of our work is based on relevant archival research on valley memory, including socioeconomic activities, villages, hamlets, water mills, isolated houses, ownership information, bridges, and railways (Peyrot, 2006). Other archival records have been collated to complete this dataset (Niogret 2019), including land registers, historical iconography, maps, newspaper articles, and interviews with associations and inhabitants.

Georeferencing

We created a spatial database with a 3D component and then constructed a 3D geovisualization using the projected coordinate system for France: RGF93/Lambert 93 - EPSG: 2154. To this end, we used ArcGIS Pro (ESRI), mainly because it provides an all-in-one solution.

We used different sources of referential spatial data. Georeferenced and orthorectified aerial photographs of France from 1950 to 1965, provided by the French National Institute of Geographic and Forest Information (IGN), provide national coverage that is heterogeneous in terms of available dates and photograph quality. In our area of interest, the pre-dam orthophotographs date from 1953 but are unfortunately too blurred to be used for geovisualization. The IGN also provides several non-georeferenced aerial photograph series from different periods (<https://remonterletemps.ign.fr/>). We selected a total of 68 images dating from 1955 to cover the study area which encompasses approximately 120 km². These images were georeferenced from 1953 images. We chose approximately fifty ground control points per image (scale: 1/28978) evenly distributed over the scene within the area of interest and used the “adjust” transformation. The RMS error is near 0. We obtain 68 warped images that need to be cropped to obtain a mosaic of 75 regular raster images. We created a color-balanced mosaic dataset and ensured that transitions from one image to the adjoining image appear seamless (Figure 2).

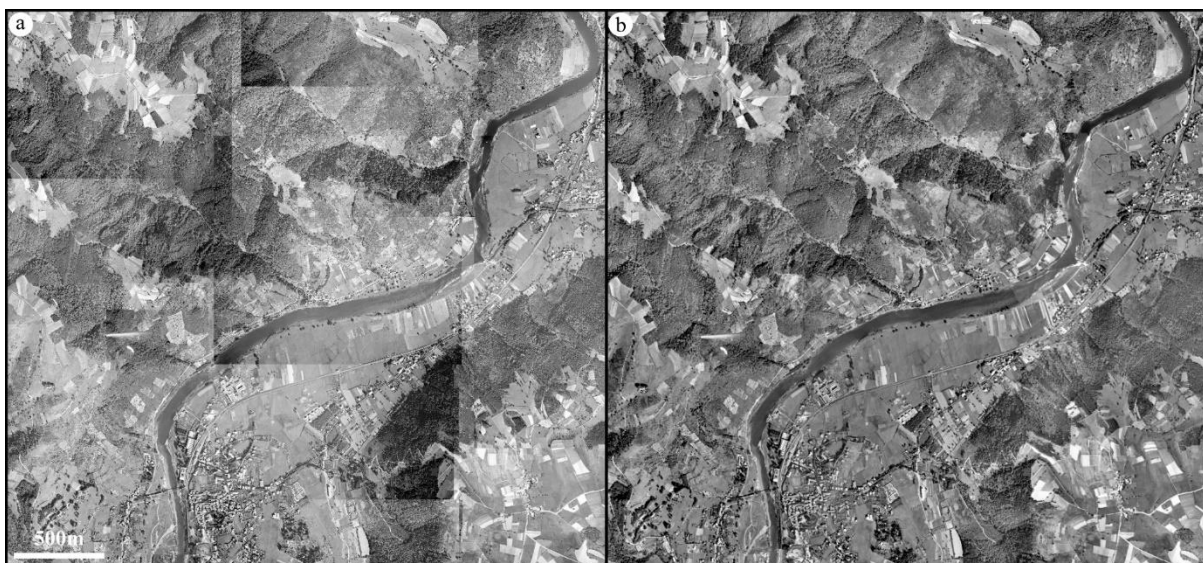


Figure 2. Georeferenced images from 1955 (a) before and (b) after balancing the mosaicked image

Automatic colorization of grayscale aerial images

As we needed to obtain the best possible visual reproduction of the pre-dammed landscape, we chose to colorize these grayscale images. This step is the only one performed without ArcGIS Pro. We adapted the method developed by Ratajczak et al. (2019) to automatically colorize historical aerial images (Figure 3). This method is based on a relatively small cyclic generative adversarial neural network, inspired by Zhu et al. (2018), that the authors designed to handle relatively large images (1024x1024 image pixels), considering hardware constraints. The strength of this method is in its ability to learn colorization in an unsupervised way, eliminating the need for panchromatic-color image pairs that could be difficult to obtain for historical data. In our experiments, we reused the model trained by the authors after 60 epochs, whose colorization results were evaluated through a Mean Opinion Score study. However, while Ratajczak et al. (2019) proposed working patchwise to keep the images at full resolution, we noticed that the color bands usually have a lower resolution than the panchromatic band. Inspired by classical pansharpening methods, and in order to make the colorization process faster while avoiding undesired mosaicking effects, we experimented with applying the colorization method on downscaled panchromatic images (from original size to 1024x1024 image pixels) instead of applying it patchwise. Generated downscaled color bands were further upscaled before being merged with the original panchromatic image. Next, we created another mosaic dataset from colorized photographs and added it to the geodatabase.



Figure 3. Comparison between grayscale (top) and colorized (bottom) aerial photographs of 1955

Digitization

We digitized different elements of the past landscape into several thematic vector layers and edited attribute tables from the archive work for roads, streets, paths, ferries, railways, houses, factories, mills, castles, canals, bridges, and tunnels. We chose to digitize only elements within a 300-m buffer zone along the centerline of the river, which already represents a significant amount of work. Buildings have required special attention. Two approaches were implemented depending on whether the buildings were (1) in the buffer zone or (2) outside the buffer zone.

1. The buildings in the buffer zone, which are now submerged, destroyed or still lakeside, have cultural, historical and heritage significance. The attribute data linked to these features are as exhaustive as possible, and include construction date, demolition date, current condition, type of building (*e.g.* farm, factory, and house), owner, cadastral parcel number, and height (sometimes estimated from period photographs).

- For buildings outside of the buffer zone, we chose to downgrade a pre-existing layer provided by the IGN (BD TOPO®). This approach implies correction of the height, removal of buildings constructed since 1955 and addition of those that have been demolished.

DEM creation

The digital elevation model (DEM) is a crucial element of our work. The IGN currently provides a 5-m resolution DEM (RGE ALTI®, version 2.0). However, the IGN represents the surface of the lake and not the sunken relief. To complete these data, we used a 1-m-resolution bathymetric DEM derived from multibeam echosounder measurements performed in the lake in 2010 by Électricité de France (EDF), the company managing the dam. The EDF DEM, representing the permanently submerged lands, was resampled to match the 5-m resolution of the IGN DEM. Next, using a raster calculator, we replaced IGN DEM values with bathymetric ones to create a new DEM representative of the relief in 1955. At this stage, some artifacts remained, primarily due to the bridge ruins (Figure 4). An analytical hillshading calculation applied on the new DEM, combined with the bridge vector layer created, enabled us to easily locate such artifacts. Then, we removed artifacts from the DEM and applied a nearest neighbor interpolation using the *Nibble* function of ArcGIS Pro to replace cells. It was then possible to transform 2D vector layers to 3D vector layers from this final DEM.

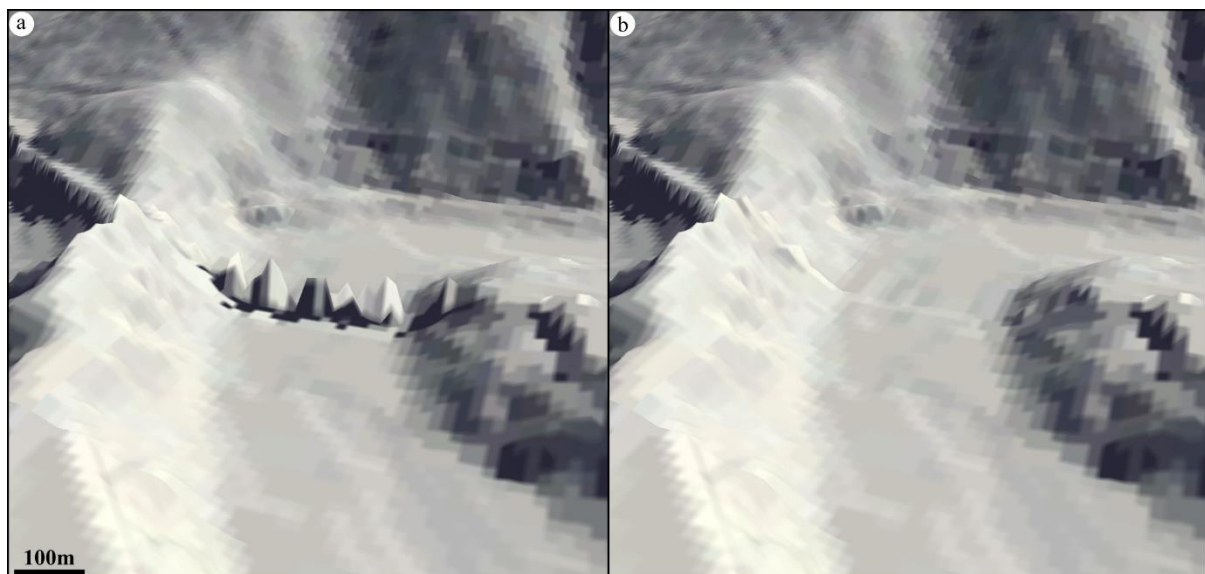


Figure 4. Bathymetric artifact removal from the DEM: (a) bridge ruins remain and (b) the final DEM

3D Modeling

This step involved integrating the colorized aerial photographs draped over the DEM representation of the 1955 relief and the 3D vector layers into a 3D scene. To obtain a visual appearance that was as authentic as possible, we added three principal types of 3D objects: multipatch features, 3D objects from non-GIS software and extruded polygons. The Esri multipatch data format is a geometry used as a boundary representation for 3D objects. This format provides levels of detail ranging from a simple cube to complex 3D models. We used multipatch features to model complex details of buildings, such as roofs, chimneys, windows and doors. We also added wall textures derived from colorized period postcards or photographs when available (Figure 5). Other 3D objects were created and imported from Sketchup software, such as bridges or important buildings, such as the “castle of Essalois” (Figure 6), and even a steam train. For other buildings, we opted for a simple representation with extruded polygons (Figure 6). For comparison purposes, we also created a basic 3D scene for 2016 based on available IGN databases (Figure 9) (buildings from the BD TOPO®, DEM from the BD ALTI® and aerial photographs from the BD ORTHO®).



Figure 5. Multipatch feature with texture from colorized period postcard (*Hôtel des Bains*, Destroyed and sunk in 1957)



Figure 6. Sketchup 3D object (castle of Essalois) and simple extrude polygons

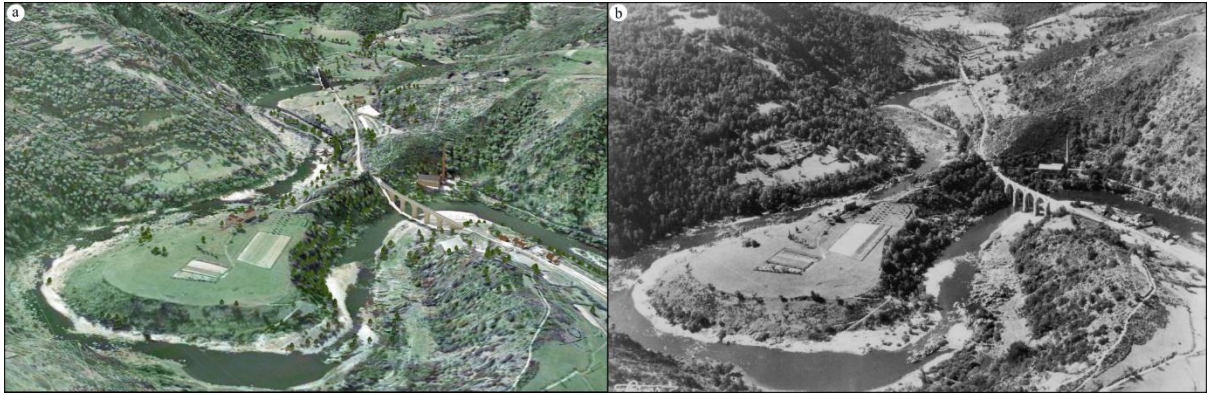


Figure 7. Comparison between (a) the modeled pre-damming landscape and (b) a period postcard

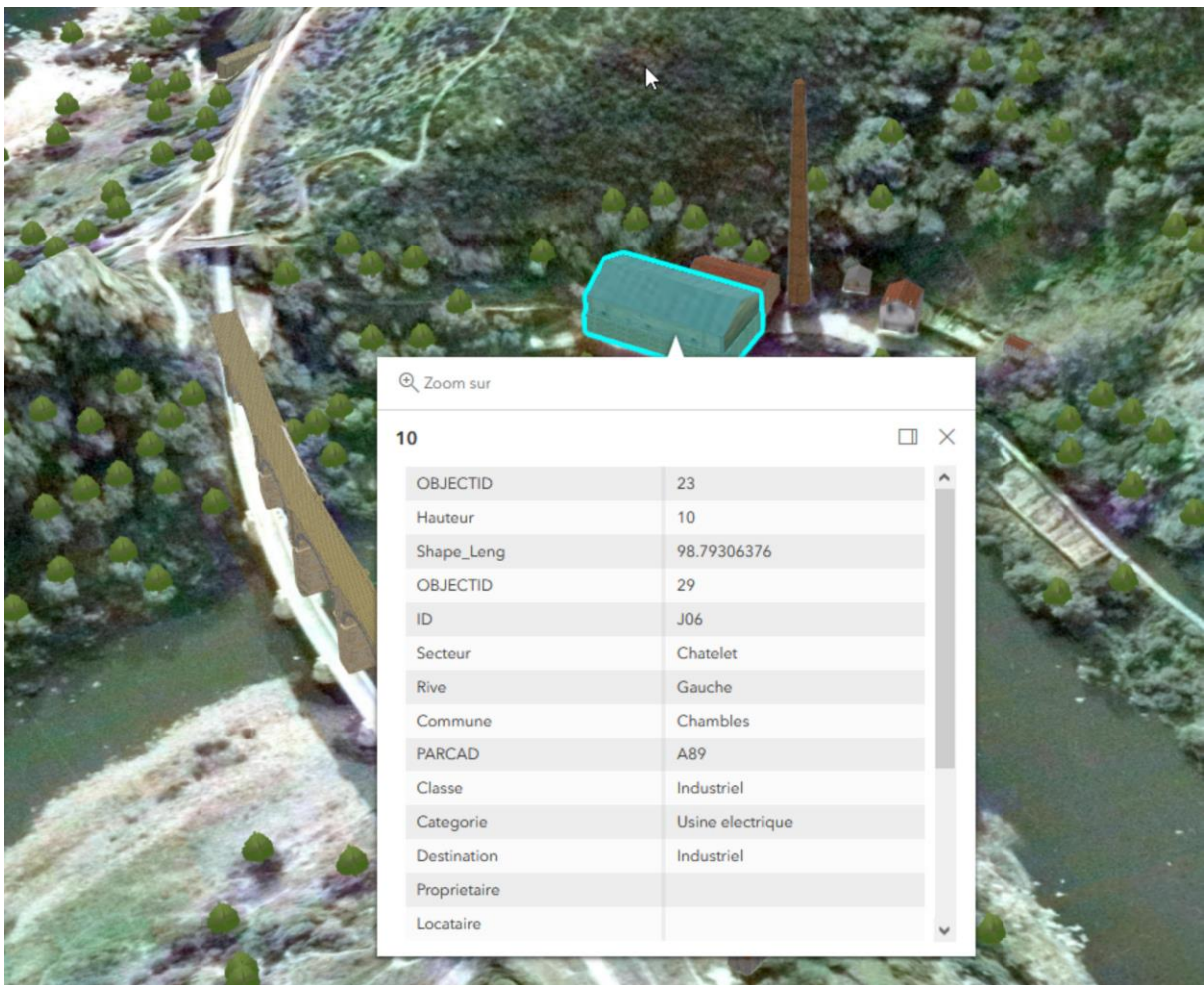


Figure 8. Interactive interrogation of the dataset in ArcGIS Online

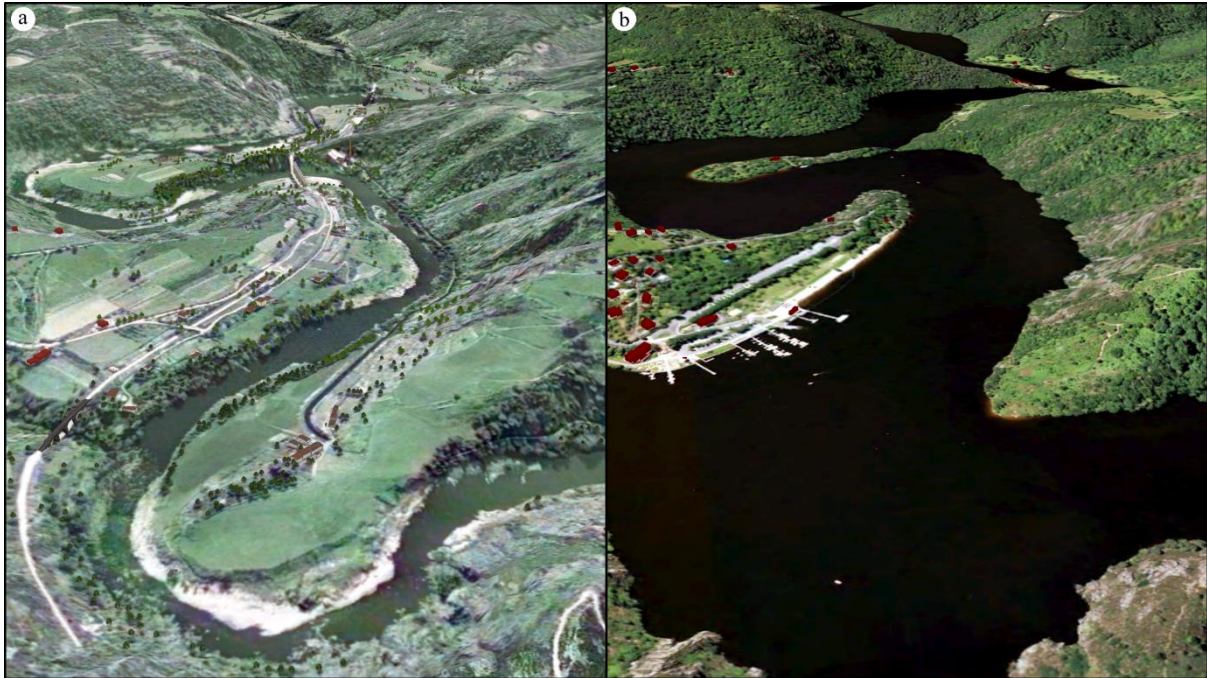


Figure 9. Comparison between modeled landscapes for (a) the pre-damming period (1955) and (b) the current one (2016)

Results and Discussion

Interactive 3D geovisualization

Our methodology provides a realistic 3D geovisualization of the past *Gorges de la Loire* landscape (Figure 7). The 3D scene (<https://arcg.is/0LOeTH>) and the 2D map (<https://arcg.is/1jqam4>) are available on the web. This visualization is dynamic and interactive. Indeed, users can navigate easily into this 3D scene, interact with all objects by clicking on them (information included in attribute tables is displayed in a pop-up window, Figure 8), or choose what layers they want to activate and see in the 3D scene or the 2D map. Using an ArcGIS online account, it is possible to share 3D scenes and 2D maps and to provide access to anyone through a web browser. The last way to share the modeling results is video exports (<https://mediacenter3.univ-st-etienne.fr/videos/?video=MEDIA200930111345487>) or screenshot.

Memories

This interactive 3D geovisualization can be considered a snapshot, at a time when what can be referred to as a *bifurcation* (sensu Grossetti et al., 2010) occurs, *i.e.* a radical transformation. In fact, in our case, we observe a quadruple *bifurcation*. The first marked the turning point in the French energy policy after the Second World War. The second induced a drastic upheaval in the trajectory of a territory whose socioeconomic activity is overturned. The third transfigured a landscape considered relatively stable over time. Finally, the fourth bifurcation is those of memories.

We identified two types of memories in the present study. These types of memories are an individual and collective memory of material and immaterial heritages that must be preserved, even when it has already disappeared, and memory as data storage. Regarding this latter type of memory, the creation of a spatial database can be considered a “backup copy” tool for heritages. It seems important to implement such an approach to create a comprehensive territorial 3D GIS knowledge database before the bifurcation event through, for example, the geolocalization of each component of the landscapes or taking photographs. After the bifurcation, the 3D GIS allows safeguarding of the original landscapes and cultural heritages in memory (Figure 9). Without anticipation, the only way to proceed is to conduct archive work as performed in this study, which does not seem to be the best way. Indeed, when the work is done *a posteriori*, information retrieval can be more difficult, often partial, and sometimes impossible. These two types of memories previously mentioned are linked. The sunken memory (*i.e.* material and immaterial heritages) could “resurfaced” through the “backup memory”.

Different purposes of use

This type of 3D geovisualization turns out to be a relevant backup tool for landscape and cultural heritage, not only in the context of dams and their reservoirs, but more generally in anticipation of natural hazards, such as earthquakes or armed conflicts. It could be an interesting tool for the management of these heritage sites, to publicize them and to promote the reappropriation of these lost places. In this regard, our modeling has been requested by two local authorities to be presented to the visitors in two heritage interpretation centers: that of the *Gorges de la Loire* and that of the Saint-Étienne metropolis. Finally, such tools could be of great interest to social scientists, as historians or sociologists, for example, who are not always accustomed to using digital technologies. These approaches allow further analysis of the lost components of a territory, enabling a new point of view that does not always come out through simple analysis of archival records. Indeed, our methodology requires significant research in archival records and allows the creation of important knowledge databases. This analysis makes such knowledge visible, as it was previously hidden in documents or in inhabitants' memories. Second, modeling is a way to gain a better understanding of past territories' organization and to detect certain relations that were not visible simply by reading archival records. We can also present the past landscape to the inhabitants, regardless of whether they are familiar with it. For example, providing the public with a comparison of the pre-dam (1955) and the post-dam (2016) 3D modeling could serve as baseline data to address their perception and values of the pre-damming landscape among other potential perception studies.

Limitations and improvement opportunities

The 3D geovisualization presented in this study is the first step in a longer-term process. The primary limitations of this work have been identified. First, a large part of the proposed workflow is based on a proprietary solution whose cost could be an obstacle to reproducibility and generalization. To date, we have made ArcGIS Pro our first choice, given the relative simplicity of implementation and the quality of results obtained with regard to our original needs, objectives and constraints. Open-source GIS software, such as QGIS, will clearly become a good alternative solution in the coming years. Currently, none of them is able to obtain similar rendering (*e.g.* in terms of color balanced mosaic datasets or 3D modeling and rendering) or to facilitate sharing of 3D scenes on the web. Another important aspect that should not be overlooked is the amount of time needed to create complete 3D modeling on such a large scale.

There are many ways to improve the work performed. In the more global context of our project, 3D geovisualization is a first step towards more elaborate technologies, such as augmented reality or virtual reality, which we will test soon. Indeed, virtual reality interaction with this landscape would be a way to give it back its humanity. The integration of sounds (*e.g.* active factories, bathing areas, and birds) may better reflect this lost landscape and enhance the user experience, as experimented in the Bretez project (Pardoen 2019), whose objective is patrimonial valorization through 3D digital restoration and spatial sound restoration.

Conclusions

In this study, we proposed an innovative and interdisciplinary application of 3D mapping. More specifically, we developed an original approach for the 3D reconstruction of a landscape engulfed by a dam reservoir, as well as reconstructing its cultural heritage in the context of memory preservation. To this end, we notably employed an original automatic colorization method of old grayscale aerial photographs, which considerably improves the visual rendering of the modeled scene. The combination of archive work and geomatic tools enabled us to make visible again a territory that became doubly invisible as a result of time and human action. Our approach can also be viewed as a means of making visible a bifurcation of history in a small territory. This approach is a relevant solution that gives back to the population what it no longer has, but it still feels like a phantom limb and cannot be given back any other way. Crossing disciplinary perspectives makes it possible to take a different look at the same objects and to enhance the user experience.

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