3D Laser Scanning Contributions Toward Understanding and Preserving Medieval Tunnels of the French Massif Central

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Abstract: The estimated number of medieval tunnels is in ten of thousand in France, and almost 500 have been recorded in the Auvergne region. Principal uses include secure storage spaces for crops and keeping goods and possessions from thieves and parasites. Their length is variable, rarely exceeding 100m. Various additions and modifications include: storage (alcoves, silo), ventilation (holes linking the galleries to the surface), security (doors, bottlenecks, S bends, return bends), removal of the infiltrated water (drains, channels), lighting (small alcoves to house lamps), and of course access (stairs, trap doors, etc. ….) were added to the structures. Traditionally the surveys were carried out following methods similar to the ones used in potholing, using measuring tapes, topofils (topography laser), compasses, and clinometers. Using modern topographical instruments such as theodolites or GPS, is impossible due to the minimal space in the tunnels and lack of satellite access. Therefore we tried a new measuring instrument, a 3D laser scanner. Its capacity to render high precision surveys, by associating stations and combining inside and outside measures, allows for connecting structures with their external environments. Its small size renders it effective in confined spaces. It is a pioneer experiment. Two tunnels of the south Cantal (Mourjou and Montvert) were our experimental sites. By crossing internal and external views, the tunnel can be positioned in reference to the surface, offering useful data aiding in the preservation and understanding of these widely known but poorly researched structures.

Keywords: Middle Ages, Tunnels, Laser-Scanner, Archaeometry

1. The Medieval Tunnels

The estimated number of tunnels throughout France is in the tens of thousands; many remain to be discovered, although a large number are destroyed. The documentation on almost 500 of these structures ranks the Auvergne as one of the richest French regions just behind the Aquitaine, the Poitou-Charentes, and the Centre regions (figure 1).

Their construction can be dated to the medieval period, though their use beyond this period is a possibility. Principal uses include secure storage spaces for crops and keeping goods and possessions from thieves and parasites (the latter is directly linked to residences lacking defensive constructions such as fortified castles and strongholds). Therefore, tunnels were typically dug below or in near proximity to farms [1, 2, 3]. In some cases the tunnels had other uses such as escape routes [4] and temporary shelters.

The tunnels are quite distinct in shape compared to other underground works: mines, aqueducts, cripts, quarries, troglodyte (medieval) shelters, ice storage holes.

In the Auvergne their length is variable, rarely exceeding 100m. Various additions and modifications include: storage (alcoves, silo; figure 2), ventilation (holes linking the galleries to the surface), security (doors, bottlenecks, S bends, return bends), removal of the infiltrated water (drains, channels), lighting (small alcoves to house lamps), and of course access (stairs, trap doors, etc. ….; figure 3) were added to these structures. The builders often created a technical access to the tunnel designed to remove rubble, which would later be filled in and hidden from sight. The nature of the modifications varied according to the importance and use of each tunnel. The tunnels are rarely situated deeper than 5m below ground.
Figure 1. Map of the medieval tunnels in the Auvergne. Doc. Y. Rialland, DRAC.
The use of these tunnels as storage spaces for perishable foodstuffs diminishes the chance of unearthing preserved remains, unless they later served as dumping spaces. Surveys revealed the existence of charcoal allowing dating of various stages of tunnel use.

Studying the medieval tunnels geographical distribution shows a direct link with the nature of the subsoils. An absence of tunnels is noted in areas where the ground is too hard (lava flows…) or too soft (clays, limestone, marl).

2. Survey Problematics

From the start, individuals studying these tunnels have drawn out plans in order to define them and situate their existence on the surface while also trying to avoid accidents. Most tunnels discovered to date were actually results of mishaps (the weight of passing heavy equipment causing the tunnel to collapse, e.g.),
or they collapsed due to structural damage. Traditionally the surveys were carried out following methods similar to the ones used in potholing, using measuring tapes, topofils (topography laser), compasses, and clinometers (figure 4).

Figure 4. Original plan of Mourjou's tunnel (1988). Doc. J.-Ph. Usse.

Generally the resulting surveys were of poor quality due to errors and uncertainty of angle calculations causing discrepancies in the maps. Plotting vestiges on the ground proves to be even more haphazard, particularly concerning depths. Using modern topographical instruments such as theodolites or GPS, is impossible due to the minimal space in the tunnels and lack of satellite access.

Therefore we tried a new measuring instrument, a 3D laser scanner. Its capacity to render high precision surveys, by associating stations and combining inside and outside measures, allows for connecting structures with their external environments. Its small size renders it effective in confined spaces. It is a pioneer experiment, all previous experiments were only based on inside measures [5, 6].

3. Methodology

We use the 3D TX5 TRIMBLE laser scanner, capable of precision scans of 2mm to 120m. This small instrument can be positioned in confined spaces. Besides regular laser measurements, the device also takes photographic images; these can be associated by photogrammetry and combined with laser dots. The laser is stationed by spheric targets, designed to combine the different shots, then shifted, while assuring that the previously acquired targets are still within sight.

Stations are also made outside the structure. Computer processing creates an automatic reconstruction of the structure and its exterior environment. We use Autodesk software to do this.

4. Application Scope

Two tunnels of the south Cantal were our experimental sites.

4.1. The Tunnel of Mourjou

The first tunnel is located in the municipality of Mourjou. In the late 1980s two closely located tunnels, caved in the granitic arena, were uncovered after the ground collapsed under the weight of heavy machinery. At the time a map was drafted. One of the galleries was then filled in, the other remained accessible through an artificial entrance in the form of a concrete duct.

The accessible passageway splits into two sections. The actual entrance gives way to a narrow curved passageway with a downward slope, later giving way to a straight and wide gallery of considerable length gently sloping downwards and accommodating three lateral storage spaces: one silo, one nook, and a small chamber with a diverticulum. The tunnel ceiling has four small ventilation holes. The original access was unknown.

There was an old collapsed area in the gallery behind a bottleneck, which could be interpreted as the original surface entry. The importance of precisely locating this area three dimensionally was paramount. The idea was to precisely locate this area on the surface and open a test pit to allow to a more accurate understanding of the underground network, including its depth below ground as well as the degree of...
danger it presented to any potential vehicle traffic above it. A ground-penetrating radar (GPR) survey was carried out by Eileen Ernenwein and Jeremy Menzer of East Tennessee State University [7]. While the GPR survey revealed the presence of nearby tunnels, it did not disclose useful data on this particular tunnel, due to its depth below ground (5 m).

4.2. The Montvert Tunnel

This tunnel was carved into a shist bedrock and measures more than 100m in length, making it one of the largest known medieval tunnels in this area of the Massif Central [8]. It was initially uncovered in 1983 during a road works project. The primary part was essentially directly under the road. The road works services restored part of the gallery’s vault and built two access manholes.

The shortest branch finished abruptly in a dead end. The survey carried out in 1983 revealed a 4m distance between the two galleries, leaving open the question of why the two sections were never joined.

A recent survey showed the existence of a collapsed area near the northern manhole probably due to water damage. As in the case of the Mourjou tunnel, the laser survey had a twofold purpose: one relating to archaeology and the other to preservation. Refined precision had to be brought to the original map, and a survey of the tunnel’s condition was required in order to verify it’s safety concerning the road above due to increased vehicle traffic.

5. Results

5.1. Mourjou

The laser measurements revealed an orientation error on the original map and accurately disclosed the various depth measurements of all the different areas of the tunnel. It also enabled an accurate survey of the entirety of the tunnel’s details and modifications, including the ventilation holes in the ceiling (figure 5).

Finally, the laser survey revealed the exact location of the collapsed end (figure 6).
A quick survey confirmed the 3D laser’s measuring precision. An excavation showed that the location of the collapse was at a junction between the underground section of the tunnel and an open trench housing a drain to evacuate infiltration water. This same trench was likely used as a technical access to remove construction rubble before being filled in to avoid vandalism. Charcoal recovered at the base of the drain allowed for radiocarbon dating of the tunnel’s creation to the 12th century, the period most tunnels were made. Surveys in other sections of the gallery revealed that the present access was probably also the original entrance, corresponding to a recurrent pattern found in many other tunnels in the Massif Central and southwestern France. The structure consists of a narrow access tunnel closed by a solid wooden door giving way to a large gallery certainly intended for the storage of goods such as crops.

5.2. Montvert

Again the 3D laser scanner provided a precise mapping of this large and complex underground structure (figures 7, 8 and 9).

Figure 7. 3D image of Montvert’s tunnel. The red arrows indicate the air vents. Doc. J.-B. Chalin & F. Surmely.

Figure 8. 3D reconstruction of Montvert’s tunnel and its exterior environment. Doc. J.-B. Chalin & F. Surmely.
Significant results include the reduction of the estimated distance between the two tunnels from 4m, on the original map, to 1.395m (figure 10).

This raises an hypothesis that the excavation of the second gallery was undertaken in a haphazard manner, and the abrupt interruption was due to the workers realizing the risk of breaking into the first gallery, by changes in sound and...
tone of the pickaxes against the bedrock.

As in Mourjou, the 3D laser scan aided in drawing a precise plan of the shape and modifications such as the locations of the nooks, anchors for lock fittings; it also allowed us to see the dip in the galleries’ floors.

In essence the architecture is similar to the Mourjou tunnel, showing three principal components: a narrow secured access passageway, a large gallery including smaller appendages and modifications, and a drainage system. The hypothesis of the identical function of safe storage in both sites can be reasonably envisaged;

As for preservation, the 3D laser scan revealed that a localized caving in of the gallery’s roof placed it less than 0.3m below the road’s tarmac layer, thus providing important cause for roadwork services to repair the damage (figure 8).

6. Conclusion

The 3D laser scanner is an important tool for precise survey of underground tunnels. By crossing internal and external views, the tunnel can be positioned in reference to the surface, offering useful data aiding in the preservation and understanding of these widely known but poorly researched structures. The 3D laser scan enabled us to draw up a very precise plan of the shape and modifications such as the locations of the nooks, anchors for lock fittings; it also allowed us to see the dip in the galleries’ floors. In association with the GPR, which could reveal inaccessible galleries, the 3D laser scanner should be used to study all the historical tunnels.

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