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# From 2D to 3D. From 3D to 2D. Towards a high-resolution representation of underground worlds

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## Abstract

Over the past two decades, the representation of the underground worlds has evolved considerably. Certainly, the classic cave topography, in plan, longitudinal section and cross-section, remains the rule. But the arrival of the 3D has offered new ways of representing karstics networks, but also galleries or detailed objects (wall, stalagmite ...). The recent arrival of lasergrammetry and photogrammetry allows us to rethink, in depth, the underground images produced: we have gone from 2D to 3D. Yet we continue to visualize things in articles, books and computer screens. We project 3D views. We separate the galleries by floor. We separate the bottom and the ceiling, to offer 2D images, but now with high resolution and adapted to scientific issues. So, we go from 3D to 2D. This shows that 3D is not superior to 2D. It is only an additional option, a complementary means to study and visualize caves. Like all tools, it requires learning and appropriate use.

## Résumé

**De la 2D à la 3D. De la 3D à la 2D. Vers une représentation haute résolution des mondes souterrains.** Depuis deux décennies environ, la représentation des mondes souterrains a considérablement évolué. Certes la topographie de grotte, classique, en plan, coupe et sections reste la règle. Mais l'arrivée de la 3D a offert de nouveaux modes de représentation à la fois des réseaux souterrains, mais aussi des galeries ou des objets de détail (paroi, stalagmite...). L'arrivée récente de la lasergrammétrie et de la photogrammétrie permet de repenser en profondeur les images produites sur les mondes souterrains : on est passé de la 2D à la 3D. Pourtant on continue à visualiser les choses dans des articles, sur des livres et sur des écrans d'ordinateur. On projette les vues 3D. On sépare les galeries par étage. On sépare le sol et le plafond, pour offrir des images 2D mais désormais à haute résolution et adaptées aux questions scientifiques. On passe ainsi de la 3D à la 2D. On montre ainsi que la 3D n'est pas supérieure à la 2D. Elle n'est qu'une option supplémentaire, un moyen complémentaire pour étudier et visualiser les grottes. Comme tous les outils, il nécessite apprentissage et usage adapté.

## 1. Introduction

For more than a century, speleologists have been producing cave topographies. Every time they are confronted to a major problem: representing an eminently 3D underground object in 2D (in plan). The 3D is expressed both at the network scale (sets of superimposed galleries), and the gallery scale (floor, walls and ceiling are to be represented on the same support). To solve this issue, they first sought to multiply the views: plans, cross-sections, and longitudinal section. They also sought to use perspective views or other 3D representation modes such as models (Fig. 1). Recently,

the advent of computer technology and the development and popularization of lasergrammetry and photogrammetry have renewed the use of 3D methods in caves. Models are manipulated on computer screens and karst is visualised at different scales from different points of view. But ultimately, we come back to 2D views, angles of view on a screen or projections on a plane. In this note, we briefly analyse this passage from 2D to 3D and then from 3D to 2D, to finally show that 3D is just one more tool for the underground topographer.

## 2. From 2D to 3D

Topographical surveys in speleology are now fairly well codified (HÄUSELMANN, 2008, 2011). The underground gallery is divided into sections between two stations. Each station is characterised by four lengths (LRUD – Left Right Up Down). This type of approach (Fig. 2) is fairly common in most of the topography software currently in use (*TurboTopo*, *Toporobot*, *Visual Topo*, *DPTopo*, *GHTopo*, *CyberTopo*, *Topo Calc'R*, *Compass*, *Winkarst*, *Survex*,

*CaveRender*, *Therion*, *Walls*, *Tunnel*, *Auriga*, *PocketTopo*, *TopoDroid*, *Cave3D*, *TopoDroid 3D sketching...* to name a few). On large networks, it is possible to propose very relevant representations of the passage organisation and then to analyse this 3D geometry for different purposes: speleogenetic phases, direction, relationship with tectonics, etc.

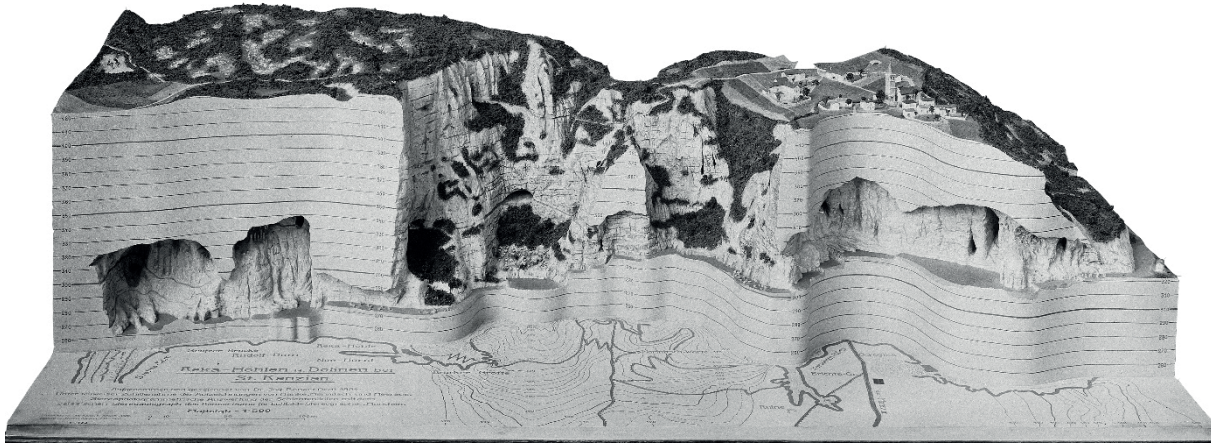


Figure 1: 3D model of Škocjanske jame (Slovenia), made in 1924 by Robert Oedl (1898-1978, student engineer at the University of Munich). The village of Škojan, the Mala and Velika sinkholes and the natural bridge can be recognized. Size: 167 cm x 71 cm x 50 cm, photo no. 2069 from the German Museum (Munich).

With this type of approach, it is already possible to switch from 2D to 3D while remaining at resolutions of the order of 10 m (average distance between two stations).

At a finer scale, that of galleries and walls, the arrival of lasergrammetry has made it possible to document shapes at metric to millimetric scales (OLUDARE IDREES *et al.*, 2016; WALTERS, 2017). Terrestrial lidars are then used to acquire dense point clouds which are then consolidated by the sphere or best-fit method. Recently, portable mobile lidars have become even more timesaving. This approach, with better resolutions, is suitable for caves of reasonable dimensions or sections of galleries. It is then possible to analyse the wall morphologies (fig. 2). When the aim is to analyse even smaller elements (stalagmites, cave art), photogrammetry is often used. Based on image recognition (SIFT) and matching algorithms (SFM), this method makes it possible to generate dense clouds or meshes at very fine

scales (fig. 2). Increasingly, the methods are not seen as opposed; on the contrary, they complement each other and are used at different scales.

When the cave survey is complete and coloured, it is sometimes referred as a digital clone. However, very few 3D cave survey projects actually achieve this rank of digital clone. We consider that this rank is achieved when the project meets at least three criteria: (1) completeness of the project (the entire cave is surveyed); (2) complete meshing without holes and triangles of the TIN model always ten times smaller than the average mesh size of the point cloud; (3) complete texturing (RGB colorimetry) of the model by texels (smallest element of a texture applied to a surface), themselves smaller than the triangles of the TIN model. All Not 3D models produced on caves are therefore clones. They are often limited to a portion of the cave and answer a specific question.




Object	Methods	Software (examples)	Resolution Accuracy	Image
<b>Karstic massif, speleological network</b>	Speleological topography (skeleton + gallery dimensions)	speleological software (Visual Topo, DPTopo, GHTopo, Compass, Therion...)	~ 10 m ~ 10 m	
<b>Underground gallery, chamber, large volumes</b>	Lasergrammetry (terrestrial lidar or mobile lidar). Photogrammetry available	Reverse Engineering software (3DReshaper, CloudCompare, Cyclone...)	~ 1 cm ~ 5 mm	
<b>Wall, stalagmite, rock art</b>	Photogrammetry (Photo acquisition high recovery rate). Lasergrammetry available	SIFT (Scale-invariant feature transform) & SFM (Structure From Motion), Agisoft Metashape	~ 1 mm ~ 0.5 mm	

Figure 2: Different 3D methodologies adapted to different scales of karst investigation and underground galleries. Speleological topography, lasergrammetry and photogrammetry complement each other according to the representation projects envisaged.



### 3. From 3D to 2D

However, the 3D model or digital clone is still a document that is usually viewed on a computer screen. In order to produce publishable and exchangeable images, it is necessary to project them. The selection of viewing angles and perspectives proposed for these 2D restitutions, made from 3D models, implies choices made by an operator who has mastered the handling of the model. Thus, the level of technicality required to produce these 3D images implies that a small community is the actor in the image production, while several people remain passive spectators, prisoners of choices made by the specialists. In some cases, however, the online publication of 3D models on free consultation platforms (e.g., <https://sketchfab.com/3d-models>) offers the possibility for the spectator to become once again an actor of the image production. He then chooses his or her own angles of view, zooms, lights and partially produces his or her own representations.

More generally, the 3D model is separated for the needs of a specific question. For example, if we wish to map elements present on the floor of the gallery, then the model of this gallery is cut in two parts and only the lower part is kept. This has been done, for example, in the Chauvet cave to carry out detailed mapping of the cave floor at a very fine scale (DELANNOY *et al.*, 2020). In other cases, if the ceiling of the cave is of interest, the gallery is segmented and planar views of the 3D model, projected on an XY plane, are provided (fig. 3). These views allow the generation of dense images and offer the possibility of analysing particular morphologies in detail. These solutions make it possible to generate projected views. Here we go back from 3D to 2D. This is not a loss of quality, it is the continuation of a work whose objective is the production of high-resolution documents and of which 3D is only a step (JAILLET *et al.*, 2014).

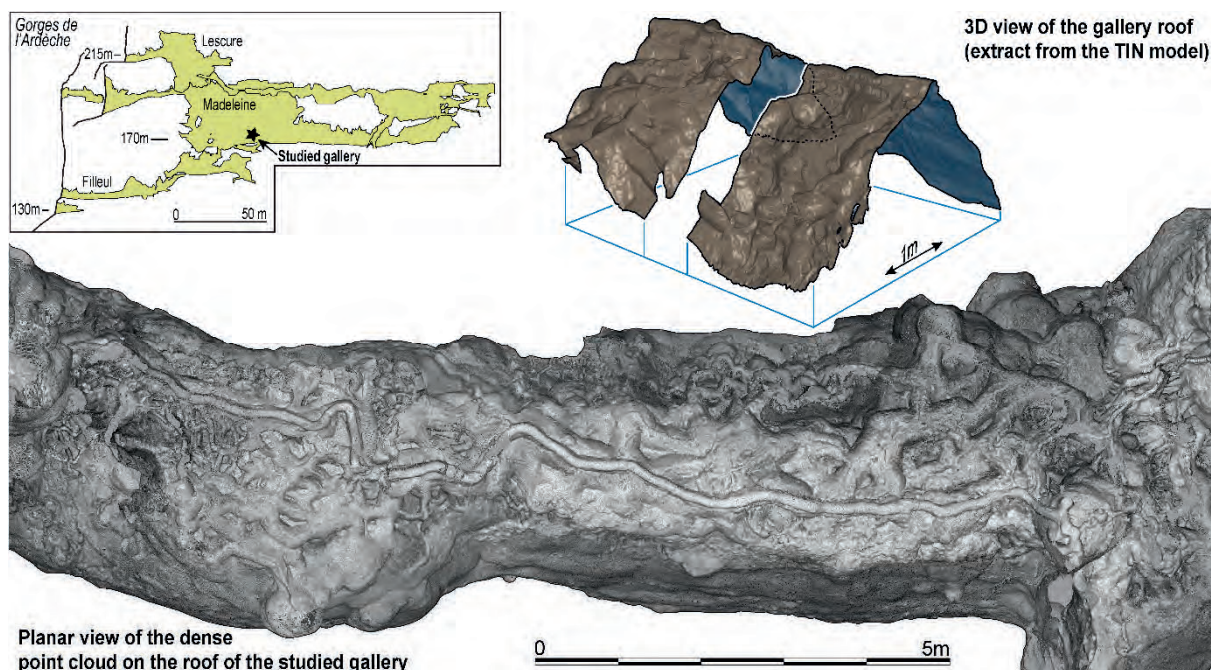


Figure 3: Extract from the 3D model of one of the galleries of the Grotte de la Madeleine (Ardèche). The ceiling alone is preserved and is projected on an XY plane. This view allows to visualize, from the top, the detailed morphologies of the gallery ceiling (anastomosing half-tube, cupolas), but not the other elements of the gallery, present on the floor.

### 4. Towards high resolution

Thus, 3D is not a goal in itself but a step in a cave documentation project. The acquisition obtained by lasergrammetry or photogrammetry makes it possible to obtain dense point clouds. These are segmented and cleaned in order to keep only the essential elements for a high-resolution topographic project. Figure 4 illustrates this. A conventional topographic survey is carried out over the same sector (right). It allows the wall and blocks to be mapped. In some cases, these blocks are actually measured, in others they are just drawn. On the same sector, a 3D

lasergrammetric survey is carried out (left). Here, two dense point clouds can be acquired. The lower part of the cloud is kept and then rasterised to generate a DTM (2.5 D image = Digital Terrain Model with fixed mesh). Two raster grids are proposed, one at 5 mm, the other at 0.1 m. Elements are drawn from these raster grids (wall, blocks). In conventional topography, the ground survey and the cartography are carried out at the same time. In 3D surveying, the mapping is carried out on a computer after processing (raster grid). This example shows that there is no project of better quality

than another. The 3D survey documents the entire cavity but does not produce a cavity map. This is done afterwards. Conventional topography can sometimes be less accurate. On the other hand it is more economical because it allows to take only the points necessary for the cartographic

representation (here blocks and a wall). The "conventional" topographer can interpret the cave and its sediments better in terms of deposition or genesis.

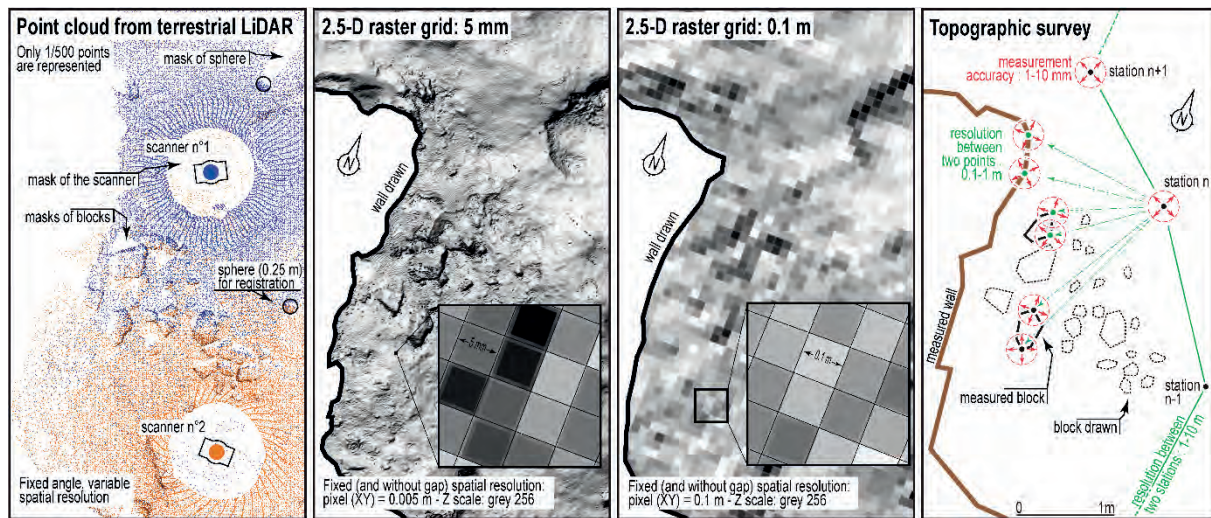


Figure 4: Discretization, segmentation and cartography of a cave (here, a section of the floor). In the field survey (right), discretization and segmentation were carried out simultaneously with a 10 cm-scale resolution. In the LiDAR survey (left), the dataset provided by oversampling was used to produce 2.5D and 3D images at density levels suited to the purpose of the survey. However, segmentation had to be carried out later, either on the basis of the field survey or from the 2.5D or 3D images (JAILLET et al. 2017).

## 5. Conclusions

We have tried here to show that 3D (3D of large networks, lasergrammetry and photogrammetry) is a remarkable tool for caves and karst representation. When used appropriately, this tool allows to propose high-resolution representations. But it is just one more tool. Just as a photograph allows to obtain a very dense image of a space (for example a gallery in a cave), it is indeed the analysis of this image (cartography, segmentation) that allows to

separate the elements of this image and to identify the interesting elements (stalagmite for some, blocks for others). 3D thus appears as a new means of high-resolution representation. It does not replace topography, it complements it. The expected popularization of these tools towards the greatest number of people encourages the development of training courses adapted to their use.

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