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Plans Extraction from Complex Buildings 3D Acquisitions

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Abstract: Rehabilitation or in-depth transformation usually requires detailed accurate plans. Due to the state, the nature and the complexity of the site, it is sometimes difficult obtaining accurate plans with conventional techniques. The project purpose is the extraction of 2D plans from data acquired with 3D scanner devices.
A rehabilitation project aims to transform the bunker located in Brussels Park into a high-tech center for addressing new forms of warfare. Because of the site secrecy, it is impossible to find complete plans that incorporate the changes over time. A preliminary topographic survey resulted in the production of plans, with multiple inconsistencies in both geometry and topology.
A three-dimensional scanning campaign was conducted to satisfy two objectives: to obtain necessary measures to produce engineering drawings, and to allow conducting virtual visits. The acquisition process in the field has resulted in a high-quality 3D model. The precision of the registration of eighty-one scans, despite the risk of loop closure problem, guarantees the quality of the whole model and therefore the possibility to extract correct plans.
For this, filtration and primitive fitting techniques have been applied to this massive data set, containing 180 million points. Our approach consists in a 2D transformation of the problem, to accelerate the process. A strip of the model representing the walls is projected onto a flat surface. The results obtained can then be improved using techniques requiring less computing time and memory, as lines search instead of planes fitting.
We also developed a method to handle data from sites of large size, scanned in high definition, where conventional measuring methods are not appropriate. Moreover, such 3D data offer many possibilities without adding fieldwork (redeployment assumptions, building simulation, and understanding of the entire geometry).

Keywords: Plan extraction, rehabilitation project, primitive fitting, 3D scanner.

Introduction

Nowadays, we cannot live without certain services based on computer networks. This infrastructure could be lost, destroyed, or blocked by attacks in the virtual world, but whose consequences are real. Generally, the purpose of these cyber-attacks is to cause maximum damages, to steal information, or to have significant echoes in the population. Critical infrastructures of a country or an organization, such as production and distribution of energy, water, or gas, the regulation of transportation, telecommunications or information services, banking or emergency services, are prime targets for cyber-terrorists.
Faced with these threats becoming more prevalent, the European Center for Critical Resources Protection (ECCRP 2010) was given the mission "*to provide cyber security awareness and defensive capabilities of*

critical resources and infrastructure to national and international actors". In order to achieve these goals, they launched a project to transform the bunker located in Brussels Park into a conference, training and demonstration center for addressing new forms of warfare and threats against critical resources.
As a vestige of World War II, the bunker is a particularly appropriate location. Indeed, it directly evokes Belgian struggle in terms of protecting the population and the importance of telecommunications networks in wartime. One of the first stages of the rehabilitation project is to get accurate plans of the building. In this context, a three-dimensional digitization of the bunker was performed using a laser scanner to obtain specific topological and geometrical information. Plans can be extracted relatively easily from data acquired by the scanner.

Historical Background

The Interwar Period was marked by considerable technical progress, especially in aviation, which induced fears of massive aerial bombardment, possibly coupled with the use of poison gas. The construction of a bunker has been decided to fulfill the need of a site for aerial protection control and a secure location that can serve in case of attack as a refuge for Government members. To satisfy this need for proximity, the bunker is located in the center of the City of Brussels (Belgium), and localized more precisely in the Brussels Park (Fig. 1) near the Government offices. In the past, two underground corridors linked the Belgian Chamber of Representatives and the Belgian Senate with the cellars of the "Cercle Royal Gaulois", which are connected by a passage to the bunker (ECCRP 2010).
Because its existence has long been kept secret, it is difficult to retrieve detailed plans and documents about this building, and to ensure the accuracy of the related information. As a remnant of World War II, it is an integral part of the twentieth century Belgian history. Its construction, on an area of 400 m², was completed in 1939. It could shelter fifty persons.
It has only been used during a short time by the services of terrestrial defense against aircrafts, warning the population and the authorities from air threats weighing on strategic infrastructure and cities. Indeed, when Brussels was attacked by German troops in May 1940, a group of government members took refuge there. However they remained only a few hours before joining the Hotel Metropole for fear of being trapped and denounced. Germany invaded the city, on May 17th 1940, and put little time to discover it. They modernized and used it as a command post to locate pirate radio stations on the Belgian territory and to track allies' aircrafts movements on behalf of the Gestapo.
At the beginning of the Cold War, around 1950, the bunker was converted into a fallout shelter to be used, once again, as a refuge in case of major conflict. This update consisted mainly in increasing the concrete thickness and the construction of galleries around the main rooms, to reduce the blast effects and to absorb the gamma rays from an atomic explosion. Since 1960, the bunker hosted the controls of civil defense sirens to warn citizens about major risks. For nearly thirty years, these places were disused and require extensive renovations before any new assignment.

Fig. 1 – Location of the bunker in the Brussels Park, in the center of the city. Simplified map of the bunker surroundings.

Current Interests

The Brussels Park bunker was built to alleviate the fears inherent in two periods: World War I and the Cold War. On the one side, World War I showed the dangers of poison gas, as well as threats of attacks inherent in this type of weapon. When built, the bunker was equipped with anti-gas and air renewal system for the occupants. A complex piping covers the entire infrastructure starting from a large filtration system (Fig. 2).

Fig. 2 – Rooms of filters for poison gas (ECCRP 2010).

Fig. 3 – Left anti-blast gallery (ECCRP 2010).

On the other hand, fears of nuclear weapons at the beginning of the Cold War led to increase the bunker protection: the walls were reinforced up to a three meters thickness of reinforced concrete and peripheral galleries were built to reduce the impact of a shock wave and to absorb the radiation produced by an atomic explosion (Fig.3).

Furthermore, this place has traversed all important events of the second part of last century with very short periods of use. Currently, it is a perfect support for evoking the Belgian's struggle in terms of civilians' protection in wartime, air defense, and population's fears at the time of the Cold War, and the need for maintaining an efficient telecommunication network in any circumstances (Fig. 4).

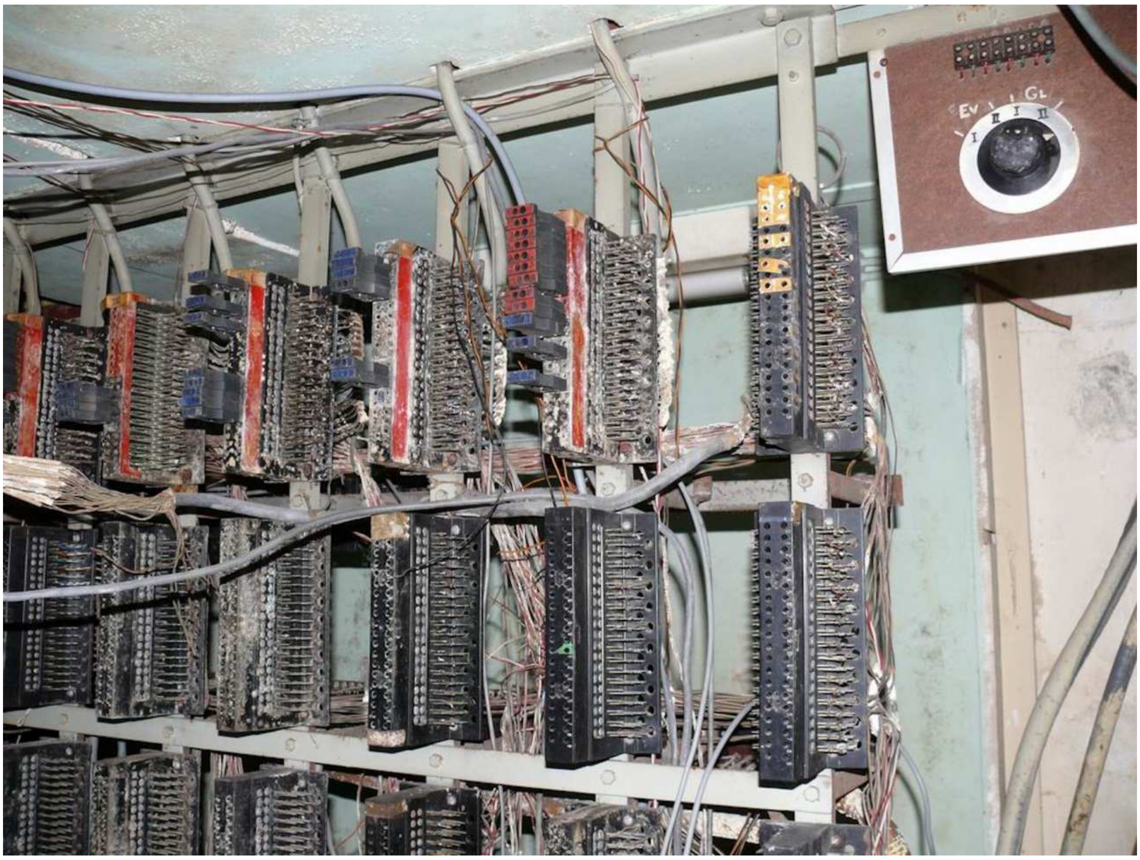

Fig. 4 – Communication room (ECCRP 2010).

In relationship with this last point, the bunker could be a particularly suitable place for teaching how to address new forms of cyber-wars and threats to critical resources (telecommunications, electricity, information...) for society and economy. Therefore, a renovation project proposes to convert the shelter into a conference center for executives (GASPARD & HUBRECHT 2010). By cons, to renovate such a place and adapt it to current regulations, it is necessary to have complete and accurate plans of the whole site.

Retrieving Engineering Site Drawings

A construction plan, dating from 1939, was retrieved and is available for us (Fig. 5 - left). The plan only covers the main part of the bunker, without the secondary rooms and the access paths. However, there is no plan of subsequent changes, such as the thickening of the walls, the construction of underground anti-blast galleries, or the addition of separative walls. A recent site visit can emphasize the modifications made and the importance to integrate them in a digital plan of the building.

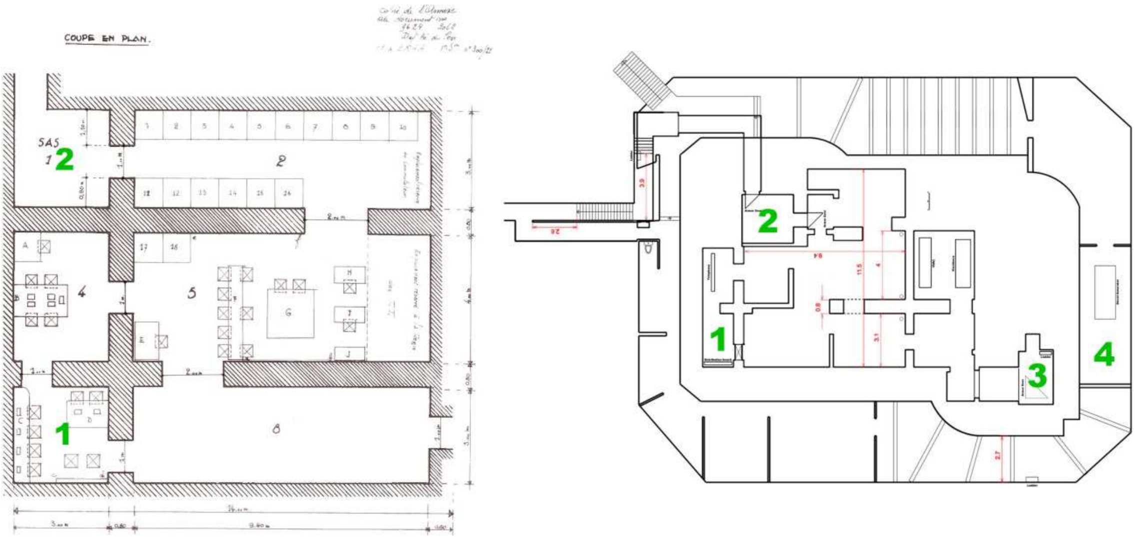

Fig. 5 – Part of bunker plan dating from 1939 (left); bunker plan redrawn in 2010 from topographic measurements (right).

At the end of 2010, a preliminary topographic survey was conducted by an architect to produce a more comprehensive plan of the shelter (Fig. 5 - right). A superposition of both plans (Fig. 6), using the same scale, was performed for comparative purposes. The image registration is based on exterior walls to maximize matchings. Another method is to focus on the entry lock, but this method introduces numerous and important geometrical shifts. Using the plans of 1939 and 2010, and on the basis of observations, we can detect some inconsistencies in the geometry and in the arrangement of the different bunker areas.

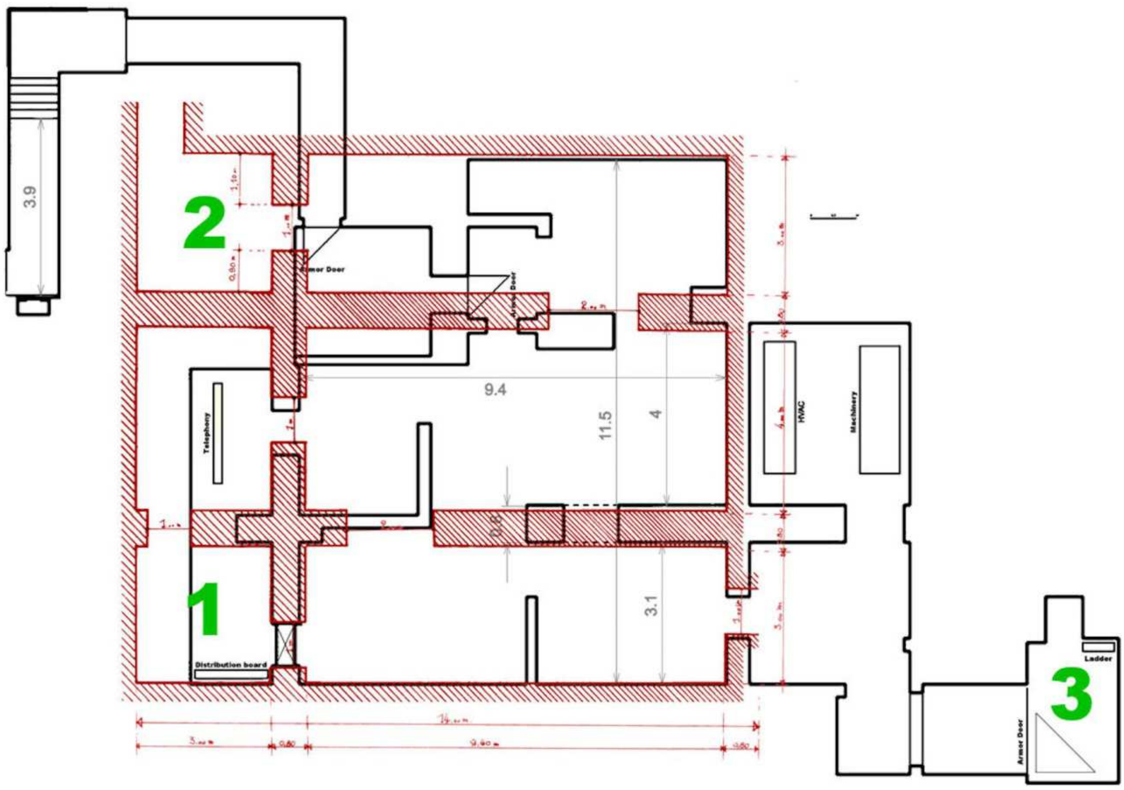

Fig. 6 – Comparison of 1939 and 2010 plans of the lower level.

Several critical differences can be identified by comparing the different plans. As shown in Fig. 5 and Fig. 6, in the telephony room (1), one-meter difference appears between both plans. Similarly, geometry, position and topology of the entry lock (2) diverge significantly. The ladder (3), in the last room of the lower, should communicate with the diesel generator room (4). There is an approximate three-meter gap between plans and reality.
These errors could be due to different factors like: an accumulation of inaccuracies or rounded measurements between rooms, difficulties due to the thickness of the walls, problems with curvature, imprecision due to the use of different coordinate systems during the survey, noise in measurements due to surfaces irregularities, error resulting from a lack of measurements, or geometric simplifications... None of these plans can serve as a basis for the renovation and the redevelopment.

Materials and Methods

Many measurement and topographical survey techniques were developed during the twentieth century, in parallel to various technology advances (e.g. laser, satellite, digital photography...). The literature (ANDERSON & MIKHAIL 1997, SCHERER 2002, USACE 2007) gives an overview of instruments and methods used in the past and nowadays, to perform sites, infrastructures or facilities surveying.
The underground nature of the site coupled with its complexity (number of rooms, narrowness, walls curvature, uneven surfaces...) severely limits the number of applicable methods. Photogrammetric methods are often used, due to these characteristics (BOEHLER & HEINZ 1999, YILMAZ et al. 2007) for the documentation of cultural heritage and for three-dimensional representation of valuable sites (REMONDINO & EL-HAKIM 2006). For our application, due to low light intensity and complex geometry, we chose not to use these techniques. Another method based on “time-of-flight” approach (KOLB et al. 2009) used by laser measuring devices (total stations, terrestrial 3D scanners) (LERONES et al. 2010) is more appropriate to the situation.
Laser scanners provide an excellent solution (Remondino & El-Hakim 2006). Scanning the whole field of view can be achieved in 5 to 15 minutes per setting. Several adjustments and scanning positions can be necessary to capture all the details of a structure and multiple scans are typically required to acquire the whole building geometry (SCOPIGNO & CIGNONI 2005). This method has an extra advantage: it does not require any knowledge of scanning positions, because it works with a coordinate system relative to the instrument instead of the absolute coordinates (USACE 2007).

Instruments

The scans inside the bunker were performed using a laser scanner Riegl model LMS-Z360i. In addition, it is coupled with a high resolution digital camera, allowing simultaneous acquisition of pictures, which can be used to associate colors to the point cloud or textures to a three-dimensional triangulated mesh.
The use of 3D scanner requires the placement of reflectors at key points of the site (e.g. doors, staircases, corners), firstly, to improve camera calibration relatively to the scanner and, secondly, to register together the different scans acquired by the device.

Scanning Works

The complete digitization of the interior and the peripheral rooms of the bunker required eighty scans using different positions or parameters (orientation, configuration...) and produced a point cloud model composed of 180 million valid points.

Each scan provides a wide field of view, using constant angular steps of 0.12 degrees around horizontal and vertical axes to obtain a dense point cloud composed of 2,250,000 points. The rotations around the vertical axis are mainly used to scan the walls, and those around the horizontal axis for floors and ceilings.

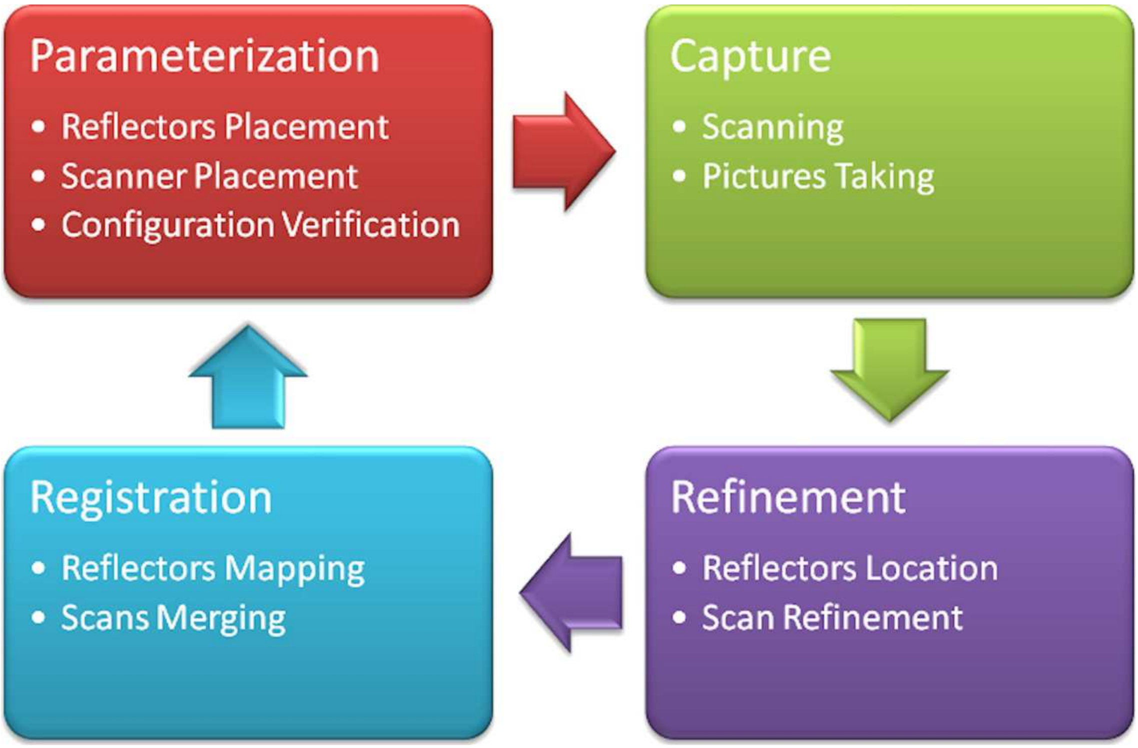

Fig. 7 – Scanning workflow.

The workflow of our methodology consists of different standard steps performed for each scan as schematized in Fig. 7. The most important steps to be able to represent all the scans in a same coordinate system and to produce a complete model of the site after the fieldwork are:

- to place correctly a set of reflectors to define reference points used to facilitate the assembly of successive acquisitions.
- to localize the reflectors in the acquired data, based on their reflectivity and the laser beam intensity returned by an object, when the device uses wavelengths close to infrared.
- to refine the scan to accurately determine the positions of the retro-reflective objects.
- to map the reference points between scans using a least squares method (GHILANI & WOLF 2006).

Data Process

After the fieldwork, all point clouds are referenced in the same coordinate system to obtain a complete model of the bunker. Practically, to merge two point clouds, at least four corresponding registration points should be identified in the acquired data. These points can be defined by the reflective objects location in space or by the use of specific details, like a wall corner, a crack, or a stair. Once these points are selected, the geometric transformation between the coordinate system of a scan and the global reference system can be computed.

Furthermore, scans were performed in loop. In this sense, the different scans, which were taken from the diesel generator room, through the right anti-blast gallery, the access corridors, to the bottom of the bunker, were successively mapped together. But the first and last scans performed in the area have also been registered with an accuracy of the order of one centimeter, ensuring at the same time the precision of the entire model.

The final three-dimensional model of the building, after assembling and coloring, represents a volume of 35m x 17m x 36m. Fig. 8 shows a point-based rendering of the model.

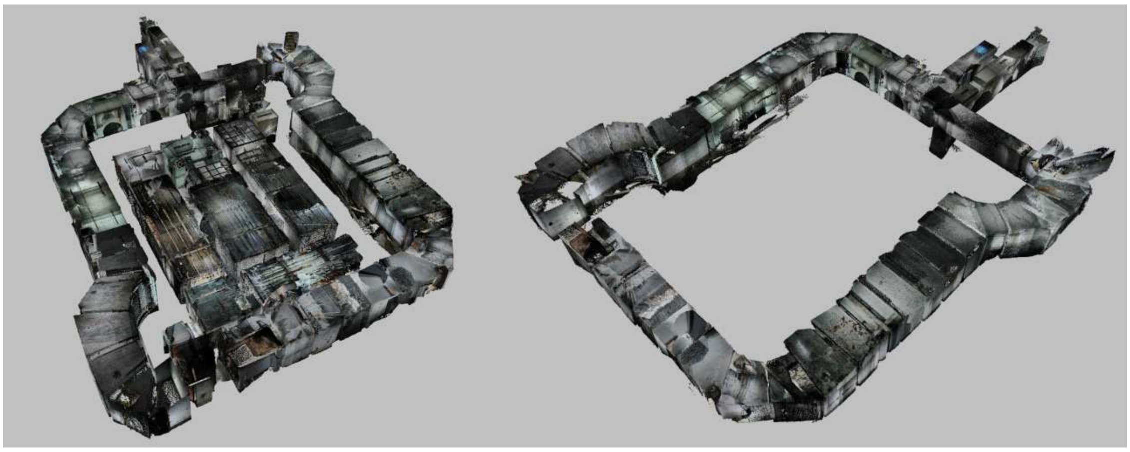

Fig. 8 – Laser scanning model: view of the complete model (left); details of the upper level (right).

Drawings Extraction

The bunker survey was conducted primarily for the purpose of gathering metric and geometric information of the site to provide support for the proposed restoration and development of the shelter. The point cloud, forming the three-dimensional model, has not been thoroughly cleaned of all its noisy points (noise in the measurements, parasitic elements...). This cleaning work requires relatively tedious manual labor, is very time consuming and is not essential for our application. However, a thorough cleaning of data and the computation of a triangulated and textured model of the site could be done in the future to obtain a photorealistic representation of the shelter, usable for heritage conservation or explorations in virtual reality.
After the merging step, plans were directly derived from the three-dimensional point cloud model. The initial aim was to obtain quickly plans without performing important manual processing. Thus, our approach transforms the 3D problem in 2D. An early draft (Fig. 9), while keeping the accuracy achieved by three-dimensional scanning, is obtained by projecting the points constituting the walls on a plane surface.

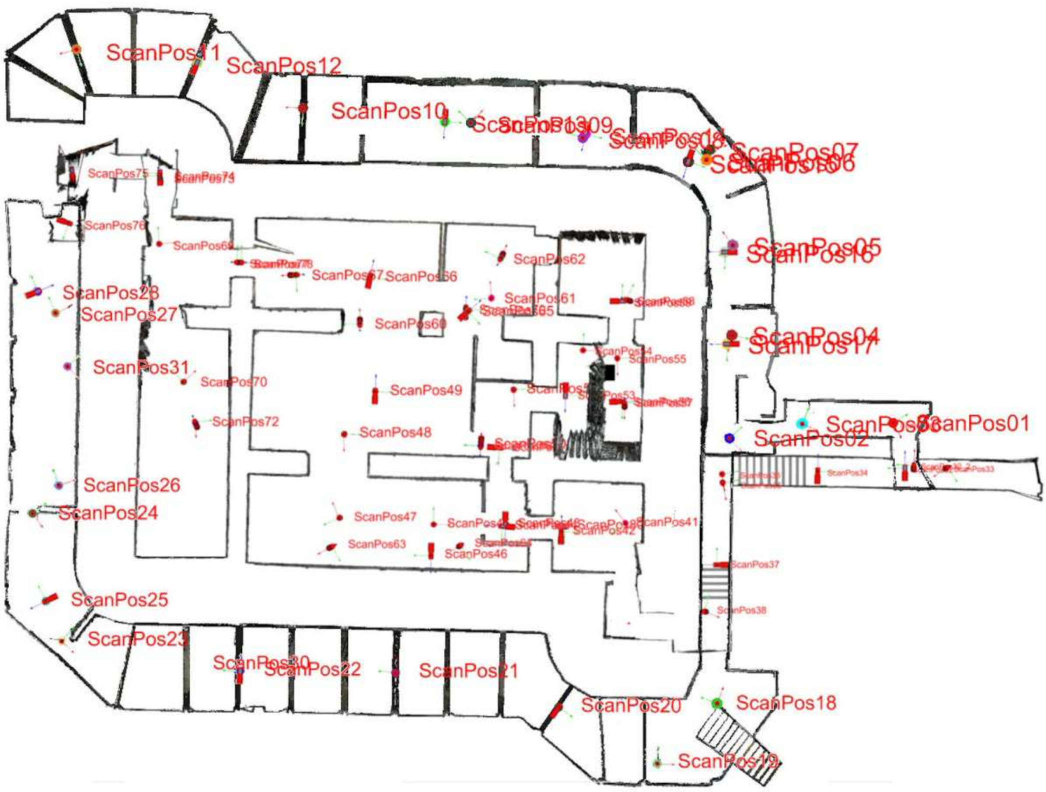

Fig. 9 – Draft extracted from the scanning model with all scan's positions.

We developed a methodology to improve the quality of the extracted plan, and to obtain a vectored plan. The first step consists in a layer selection (Fig. 10). For this, we detect floors and ceilings by computing point density for a discrete number of levels. Thus, a point's layer can be selected, generally centered between a floor and a ceiling, and with one meter thick. A median filter is also used to quickly reduce noise.

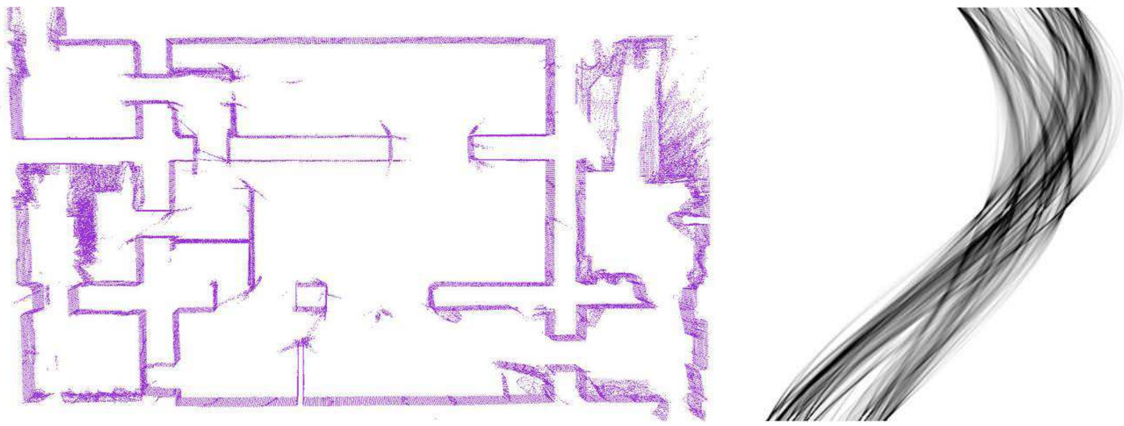

Fig. 10 – Example of selected points' layer (left) and corresponding Hough accumulator for lines detection (right).

From these points, we can apply a bidimensional primitives fitting, using only two of the three coordinates. The proposed approach is first used to extract lines, but it can also detect an arbitrary object described with its model (e.g. circle…). We thus obtain Hough accumulator representing all lines of the plan (Fig. 10).

Instead of searching all local maxima to define all segments, an iterative selection of global maxima is performed. Then we identify a set of points belonging to the model related to this maximum with a delta tolerance, and we decrement the accumulator elements related to these points. By repeating this sequence, it is possible to quickly and easily find all segments and identify the different walls. However, this segmentation will depend heavily on the tolerance value: a too high value leads to a sub-segmentation and a too low an over-segmentation (Fig. 11). A detail of the sub-segmentation shows multiple aligned parts identifying a same line, illustrated by a single color. To avoid this, we correct the segmentation by using, on the points, a region growing method based on the Euclidean distance and, on the small segments, a merging algorithm.

Fig. 11 – Model segmentation: over-segmentation (δ=8) (left); sub-segmentation (δ=20) (right).

A RANSAC model optimization is then performed on each segment to compute the final segmentation. Calculating an error measure (based on residual average) defines the model quality (Fig. 12 - left). It indicates if another model (curve, circle) has to be adjusted, if there is too much noise, or if the Hough space accuracy has to be increased. Finally the extremities of the vectors are properly defined to obtain a vectorized map (Fig. 12 - right).

Fig. 12 – Model quality (left); corrected vectorized map (right).

Results and Conclusions

The first result is a three-dimensional model of the whole interior of the bunker of Brussels Park. It provides, with the appropriate software, a large number of topographic and geometric data (e.g. length, height) and the positions of different parts. It can also serve as a basis for its virtual representation, directly as colored point clouds or as a textured mesh.

Site map is obtained directly from the model. This plan allows to correct the errors made during the survey of 2010 with standard techniques. It shows that the two ends of the anti-blast galleries have a gap near three meters and even in reality, this area contains the top of an airlock of the shelter. Moreover, by comparing the model with the plan of 1939, we can notice that the central part of the bunker has undergone very little changes since its construction, except for the drilling of an additional door. However it is incomplete, the accesses to the bunker and the peripheral rooms are missing. These similarities also show the accuracy of the resulting plan.

The digitization project of the bunker of Brussels Park helped to provide the necessary data for drawing accurate construction plan, planning for renovation and development. In addition, the provision of information in three-dimensional space allows collecting a plethora of measurements and information with no extra cost of fieldwork. Indeed, working with a virtual model permits to extract an amount of information, which can simulate a visit to a place from a single workstation, for example, to help understand space in which we work (arrangement of parts, wiring, specific pieces...) or simulate the changes, and to test construction and redevelopment hypotheses.

The site digitization facilitates its analysis to produce accurate plans, to make modifications, to simulate these changes and to preview the results. The project also demonstrated the advantage of 3D scanning compared with standard surveying techniques.

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