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José Antonio Barrera-Vera
Geographer and Building Engineer. Head of Graphic Engineering department at University of Seville (Spain). GIS, HBIM and surveying researcher.

José Antonio Benavides-López
Building Engineer and full professor at University of Granada (Spain). He is a specialist architectural surveyor and researcher on surveying, photogrammetry, laser scanning and heritage documentation.

Handheld mobile mapping applied to historical urban areas

Mapping historical urban areas is an assignment that can be tackled by using different systems and devices. In the last decade many surveying systems have emerged in this this ever-evolving market. So, despite having a wide spectrum of options to choose, the decision-making is not an easy task. It depends on the budget, the training, the experience, the available delivery term, the specific features of the streets and buildings, etc.
In this article a complete high-speed recording procedure, by using a handheld mobile mapping instrument to record a typical old town street, is going to be described. The aim is to enlighten the decision-making when choosing the appropriate methodology. The characteristics of this kind of streets, such as an extreme narrowness and accessibility difficulties make this type of areas more difficult to surveying.
Additionally, a comparison between this procedure and stop-and-go systems will be carried out. The research shows that the graphical documentation obtained fulfils perfectly the initial requirements and the fieldwork has turned out much less time-consuming by using mobile mapping devices than standard stop-and-go laser scanning systems and photogrammetry procedures.

Key words:
SLAM; mobile mapping; photogrammetry; city mapping; 3D laser scanner

INTRODUCTION

"Currently, the process of archeological drawing is undoubtedly the result of obtaining a high-quality 3D model" (Rodríguez-Navarro, 2017). We could paraphrase P. Rodríguez-Navarro's but extending his affirmation from archaeological drawing to heritage architectural drawing. According to him, to obtain this high-quality and hyper-realistic-appearance 3D models, "...it is essential to digitize the setting, the building, the object, ...". In this process the data recording phase is essential and the type of the object and its setting to be recorded has a great significance in the possible issues expected in the surveying (Mario Santana-Quintero, 2007).
Mapping historical urban areas is an assignment that can be tackled by using different systems and devices. In the last decade many surveying systems have emerged in this this ever-evolving market. So, despite having a wide spectrum of options to choose, the decision-making is not an easy task. It depends on the budget, the training, the experience, the available delivery term, the specific features of the streets and buildings, etc.
Specifically, in urban planning, mobile mapping systems, such as Leica Pegasus, are widely used nowadays. However, vehicle-mounted systems have a serious drawback when mapping heritage ancient quarters which is the aim of this research. Likewise, photogrammetry presents critical difficulties because the short range available and the wide surface to capture (Philip Sapirstein, 2017). Regarding the use of drones, the legal restrictions on flying drones in urban areas, and the presence of obstacles such as wires, antennas, etc. reduce its possibilities of use drastically. In this point handheld Simultaneous Localization and Mapping technologies (SLAM) emerge as one of the most suitable options fulfilling the data recording phase in this scenario (Fig. 1).

AIMS OF THE ARTICLE

In this article a complete high-speed recording procedure, by using a handheld mobile mapping instrument to record a typical old town street, is going to be described. The aim is to enlighten the decision-making when choosing the appropriate methodology. The characteristics of this kind of streets, such as an extreme narrowness and accessibility difficulties make this type of areas more difficult to surveying.
Additionally, a comparison between this procedure and stop-and-go systems will be carried out.

BACKGROUND

The University of Seville and the University of Granada, have been researching in surveying technologies and procedures for many years as shown by the numerous PhD Thesis that have been read in the last few years related with this topic (Barrera-Vera, 2006) (Cabrera-Revuelta, 2017), (Molero-Alonso, 2017), (Izquierdo-Toscano, 2017) (Benavides-López, 2017). Thus, we have had the opportunity to compare the different surveying systems technologies, including cutting-edge technologies such as handheld mobile mapping instruments and aerial photogrammetry by using state-of-the art drones.
Besides, our research group has a wide experience at surveying in many different environments including city planning, heritage and archaeology (Fig. 2, 3).
Among the different devices and systems, we have successfully tested handheld SLAM technology in narrow archaeological environments (Fig. 3), so the similar narrowness conditions of this Jewish-Muslim medieval streets in Seville (Fig. 1).
Simultaneous Localization and Mapping technology (SLAM), allows the fast and efficient survey by means of points clouds of buildings and their surroundings by means of continuous movement of a Light Detection and Ranging (LIDAR) sensor around them. This method

Fig. 1 - Barrio Sta. Cruz. Sevilla's orthophotos. Source: own elaboration from data provided by http://sig.urbanismosevilla.org/visorgis

Fig. 2 - State-of-the-art devices tested by the authors to build the point cloud in fig. 3. Source: authors

Fig. 3 - Point cloud of Antequera's Romeral Dolmen. Source: Authors.

provides a single dense cloud with a quasi-uniform resolution that will depend on the speed of the displacement and the distance to the object. Unlike previous methods such as High Definition Laser Scanning (HDLS), it does not require fixed setting-ups of the instrument in several positions nor subsequent processing in order to register and unify the different scans. SLAM technology emerged at the 1986 IEEE conference thanks to different researchers' contributions about the introduction of probabilistic methods applied to robotics and Artificial Intelligence (AI). Due to the complexity of the problem of location and simultaneous mapping researchers separates the problem in two: the location on one side and the mapping on the other. Publications by Randall Smith (Smith, Self, & Cheeseman, 1990) and Hugh Durrant-Whyte (Durrant-Whyte & Bailey, 2006) describe the relationships between the location of the device and the landmarks. Further Tim Bailey's work will delve into the relationships between location and mapping (Bailey & Durrant-Whyte, 2006). The approach is a smart mix of geometry, graph theory, optimization and probabilistic. SLAM aims to build a global and consistent representation of the environment, taking advantage of both the measurements of its own movement and, fundamentally, closing the loop. Since location by means of measurements based on the movement of wheels (odometry) was found to be not as good as needed, it has been solved by means of tracking external visual references and by means inertial measurement units (IMU) to work out the position and balance the underway drift (Lynen, Sattler, Bosse, J. Hesch, & Siegwart, 2015). These visual reference points must fulfil the following requirements: to be easily re-observable, easily distinguishable and stationary.

This procedure includes the simultaneous estimation of the position of the instrument in an unknown environment and the construction of a 3D model (mapping) of the environment. SLAM technology has been widely studied in the robotic industry, although it has been little spread due to patents. Currently it is having a great development thanks to the use of open-source platforms and cheaper equipment prices. Among the platforms that are used to perform SLAM we can highlight ROS (Robot Operating System) and Hector-Slam. ROS is an open source operating system developed in 2007 by the Stanford Artificial Intelligence Laboratory for the STAIR project (Stanford AI Robot). Hector SLAM is a platform belonging to ROS that carries out mappings from the measurements made by a LIDAR sensor and estimation of the position based on inertial sensors. In this system, the representation of the environment uses a grid map combining the data of the scans of the new positions respect to the previous results.

SLAM devices are not as accurate as HDLS equipment but are accurate enough for most real-world scenarios. They are especially useful for surveys in heritage and complex environments (narrow streets, caves, underground galleries, forests, etc). This has led to a rising number of lidar sensor manufacturers, making

Fig. 4 - ZEB-REVO from GeoSLAM Scanner 3D provided by Geoavance S.L. Seville. Source authors

Fig 5 - Point cloud con textura realizado mediante el equipo SLAM PX80 de la firma Paracosm. Source: https://paracosm.io/px-80.html

them smaller and smaller for their implementation on UAVs and opening the opportunity to handheld them by the operator. The drawback in current SLAM devices is the difficulties to simultaneously capture the RGB feature of the point cloud.The complexity of the simultaneous location and colouring system makes the additional application of RGB textures on the cloud points and subsequent application on meshes very complicated. The instrument used in this work, GeoSlam Zeb Revo (Fig. 4), has a wide-angle camera to record video but it is not possible to transfer the textures yet. Nevertheless, presumably, this weakness will be solved soon. In fact, ZEB-CAM option for ZEB GeoSLAM devices and other systems such as PX80 by Occipital's Paracosm already allows the application of the texture but still achieving low resolution (Fig. 5).

METHODOLOGY

In the case study carried out, we have followed the steeps below:

1. Selection of the proper object that has the appropriate features for the objective of our research.

The street has been chosen according to the features we are looking for such as architectural interest and narrowness. Justino de Neve Street one of the Sevilla's most typical streets located in the real core of Santa Cruz neighbourhood has been the case study (Fig. 6). It is 57,44 long and between 1.24 and 2.43 m wide. The façades are between 11.53 and 7.03 m high.
In addition to the special dimensional characteristics of the street, many obstacles such as street lights, security grills, cables, imposts, balconies and cornices make more difficult the recording and surveying tasks.

2. Study of the range of suitable technologies that can fulfil the field work requirements.

Regarding the resolution, accuracy, field work time and processing time we have considered different equipment to use.

2.1. Traditional surveying methodology has been directly ruled out because the lack of orthogonality of the object of study, regarding not only to the top views but also the plummeting walls and general features in ancient building. Even by using total station or any other Electronic Distance Measurement (EDM) the narrowness of the street would force poor ricochet angles that would lead to a lack of accuracy.

2.2. Arguing the same reason, mapping the street by means HDLS must be discarded. Even worst, the suitability would be seriously touched by the minimum measurement range that is usually between 0,20 and 1m, when the street is less than 2 m. wide. So, the average distance from the HDLS device to the facades. Furthermore, ricochet angles are good (between 90 and 45º) just in a very short area, so it would be necessary to perform setting-ups so close, making

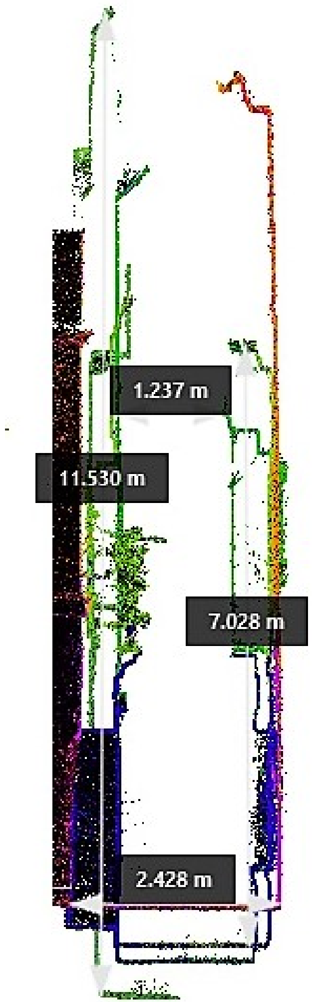

Fig. 6 - Point cloud overlapped cross sections showing extreme dimensions

unfeasible this option (Fig. 7). This assertion is more evident bearing in mind the average height of the buildings and the number of obstacles above mentioned. The weight of the equipment makes unfeasible setting it up at high level without using auxiliary facilities that would be inappropriate in this environment.

2.3. Concerning the budget SFM photogrammetry would be the best option since the needed equipment is just a camera and SFM software. Specially, considering the wide spectre of available commercial and no-commercial SFM software solutions existing nowadays.
However, the extremely close range would need such a high number of pictures that both the field work and the processing times would make unsuitable this methodology. Specifically, we would have to survey about 1300 m^2 of façades. Bear in mind that having such a short ground distance (in this case distance from the camera to the façade), namely 2.00 maximum. In this scenario, to obtain the complete coverage we would need a great number of pictures.
According with the parameters we could manage in this case study, for a 16mm fish-eye lens and 36x24 mm sensor camera (Nikon D800):

$$\frac{film\ size}{focal\ length} = \frac{field\ of\ view}{ground\ distance}$$

So, the maximum portion of façade recorded by a single picture is

$$field\ of\ view = \left(\frac{2.00^2 * 0.036 * 0.024}{0.016^2}\right) = 13.50\ m^2$$

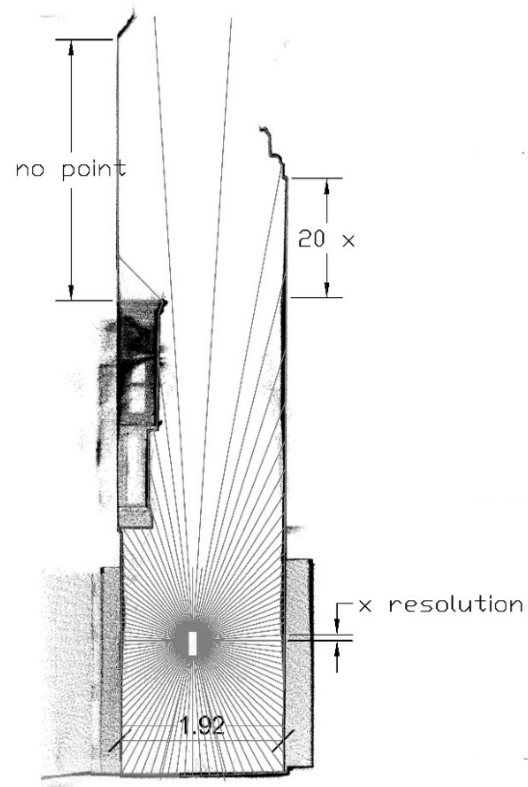

Fig. 7 - Section sketch of Justino de Neve street showing the resolution gap between the nearest and farthest points, and points in the occlusion area. Source: authors.

Fig. 8 - Leica C10 HDLS, provided by Graphic Engineering Department, University of Seville. Source: authors.

Fig. 9 - Photogrammetric survey fieldwork. Source: authors

Consequently, and following the recommended overlapping (60-80 %), we would need, at least:

$$number\ of\ pictures = \frac{1300}{13.50*0,20} = \ 482\ pictures$$

This minimum number of pictures has been calculated supposing a completely flat façade and taken in ideal conditions which is not the case at all, since at least two third of them should have to be taken by means a five-meter pole in order to reach the height of the walls (Fig. 9). Drones are not suitable in this area since it is a very crowded touristic place, so flying drones are totally banned by the authority. Anyway, due to the plentiful obstacles such as aerial wires, streetlights, balconies, etc. it would be impossible to fly drones between façades.

Additionally, the lack of appropriate texture in walls is another drawback of this option. In fact, due to the homogeneous pigmentation it is quite difficult the matching process. As a result, the only zone where an accurately successful 3d model has been achieved is the lowest part of the walls where we can find better textures than in the rest of the façade (Fig. 10)

2.4. SLAM technology.

According to the description of SLAM technology above, cutting edge technologies in SLAM produces smaller and smaller devices, so they can be designed to be mounted in drones or to be handheld which is the case of the model we have used in this research, the Geoslam ZEB-REVO. According to Nocerino (Nocerino, Menna, Remondino, Toschi, & Rodríguez-Gonzálvez, 2017) the Geoslam performance suits perfectly this kind of projects, so we reckon is the best option among portable mobile mapping systems (MMSs) available nowadays.

The technical specifications of the SLAM that has been tested for this work are shown below:

Data Acquisition Speed: 43,200 measurement points/sec.
3D Measurement Accuracy: +/- 0.1% (typically)
Maximum Range: Up to 30m (15m outdoors)
Laser Safety Class: Class 1 Eye Safe
Angular Field of View: 270 x 360 degrees
Weight of Scanner Head: 1.0 kg
Dimensions of Scanner Head: 86 x 113 x 287mm

The ZEB-REVO consists of a 2D time-of-flight laser range scanner rigidly coupled to an inertial measurement unit mounted on a motor drive. The motion of the scanning head on the motor drive provides the third dimension required to generate 3D information.

Data is captured as the we walk through the street whit the only restriction that we must perform a close loop in our track, starting and finishing exactly in the same point. The ZEB-REVO does not need time-consuming scanner set-ups and data registration associated with HDLS methods.

These characteristics, especially the little weight and recording speed, make the system really suitable to carry out this work.

3. Fieldwork planning

Planning is an essential step in surveying since many times a successful and efficient work depend on it, especially when dealing with buildings located in

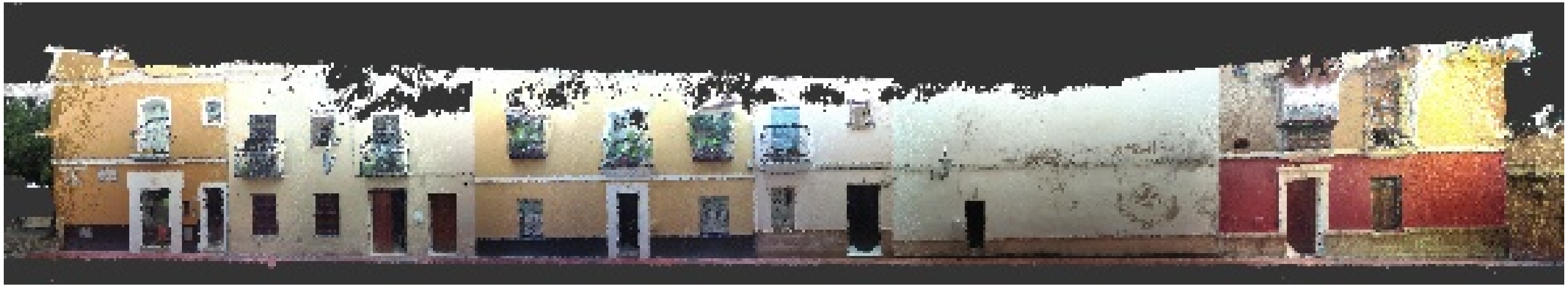

Fig. 10 - Point cloud of Justino de Neve street obtained by means of SFM photogrammetry, Agisoft Photoscan pro. Source: authors

inaccessible areas or with difficulties to perform the fieldwork (Cabrera Revuelta, 2017). In this case, instead of the tides the actual difficulties are, on one hand, the geometric nature, i.e. the narrowness of the street that is the self-constraint intended by this approach and, on the other hand, the continuous affluence of tourists that makes impossible to work at an usual time table, so the fieldwork must be done in the short gap of time between sunrise and tourists turning up that is usually very early in the morning. Thus, it was necessary to visit previously the site at different hours to control the light conditions, the affluence of people, the minimum and maximum height and the clear useable width. In this previous inspection some manual sketches were made with the necessary written down information in order to be able to organise the equipment that would be required. In our case, apart from preparing memory sticks, memory cards, tripods, batteries, cameras, HDLS unit, extensible camera poles, and the GeoSLAM, the most unusual thing was the adaptation of the 5-metre pole to stand the handheld laser scanner at 5 m above the ground. The device consists of two main parts (Fig. 11): the rotating SLAM system itself that include the IMU and the laser sensor, and the Data Logger unit which is the brain of the system and where de data is stored, and the battery is attached. It is also the heavier part and its connected to the SLAM unit by means a 1.3-meter-long wire so that it can be placed in the backpack (Fig. 11).

In our case, providing that we have to use a 5-meter pole, it would be great to have a long wire connector but, being something no standard, we decide to fix the SLAM part in the top of the pole fixing the Data Logger 1.3 m lower in order to avoid so much weight on the tip of the pole and prevent from excessive flexion and risks operating it.

4. Fieldwork implementation

The itinerary has been performed by holding the device terminal at an average height of 4.50 m in the outward path and 2.00 m in the return one. In this way we perform a loop, that usually tend to be horizontal, in a vertical position.

This vertical track has been decided not only to be able to avoid occlusions generated by cornices and balconies but also to accomplish the recommendation that the range is kept to less than 10m where possible to ensure good point density and to assist the SLAM algorithm.

5. Processing work and layouts production

A novel 3D simultaneous localization and mapping (SLAM) algorithm is used to combine the 2D laser scan data with the IMU data to generate accurate 3D point clouds. The ZEB-REVO captures raw laser range measurement and inertial data. This data must be processed by using GeoSLAM HUB software that uses a SLAM algorithm to convert the raw data into a 3D point cloud. The data can be processed either using the GeoSLAM cloud data processing server or (optionally) using the GeoSLAM Desktop SLAM processing software. In the case of study, the point cloud has been obtained by means the server option.

The GeoSLAM processing server is accessed using the ZEB-REVO Uploader desktop application that runs on a PC with a Microsoft Windows operating system (Windows XP or later) and internet access. The file containing the raw data is a zip file stored in a memory stick that is plugged into the Data Logger.

After uploading the zip file, we must wait for the data to be processed by the server. The actual waiting time will be dependent on the number of processing jobs in the queue on the GEOSLAM server. In our case it was just 15 minutes.

The *.ply and *.laz files obtained after processing can be viewed in many point cloud software suites, such as Autodesk Recap, or free programs e.g. MeshLab and CloudCompare. Views of the point cloud have been produced in Recap. Some of them are shown below (Fig. 13, 14 and 15).

Fig. 11 - GeoSlam, Left: Data Logger unit. Right: ZEV-REVO complete kit. Source: https://geoslam.com/

6. Assessment and discussion of the work

Comparing the different systems, we have considered, the GeoSlam is far rapid and efficient than photogrammetry and HDLS, since the fieldwork took less than 30 minutes and the processing time for the raw data by means GeoSlam Hub server was 15 minutes. The photogrammetric process took us one and hour a half and the processing by using Agisoft Photoscan half an hour (but taking into account that it was successful just 25% of the whole street, due to the poor textures and difficulties in good overlapping ratios). The HDLS process was totally unsuccessful as reported above. About resolution and accuracy, despite the fact that it is a bit below state-of-the-art HDLS and control-point-aided photogrammetry, the 0.03 m of accuracy and the 1.8º of resolution are perfectly admissible for this type of projects.

However, we can mention some drawbacks in the procedure.

Firstly, we do not think processing by means the GeoSLAM remote server is the best option. Processing remotely makes the user depend on the server and loose the process control and results. The only advantage is that it is unnecessary purchase the Hub software. Remotely, paying just the processing credits as needed, is cheaper though. This is not a minor issue considering that a gold rule in surveying is not leaving the site without doublechecking all the needed data have been captured successfully.

Secondly, the point cloud provided by SLAM devices is not structured as HDSH data usually is which is a drawback when managing the point cloud in several software programs.

Thirdly, the we have to bear in mind that the point cloud is no dense enough to georenference points below a centimetre of accuracy, so we must use ad-hoc spheres supplies by the SLAM manufacturer that we set in the points to refence and scan specifically around them. Finally, as mentioned above, the impossibility of capture and apply the real colour to the point cloud is an important disadvantage respect of other systems. According to manufactures this weakness is being solved soon though. Ultimately, we can colourise the point cloud afterward by using software ad-hoc, but it would be a very tedious task.

Fig. 12 - Start and go process in field. Source: authors

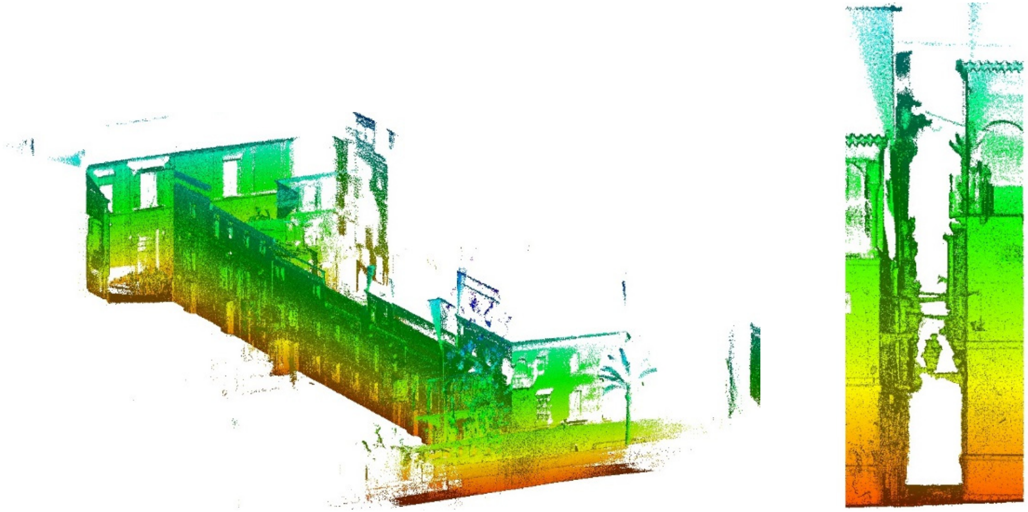

Fig.13 - Noise points cleaning up in Autodesk Recap. Source: authors

Fig. 14 - Top view of the point cloud in Autodesk Recap. Source: authors

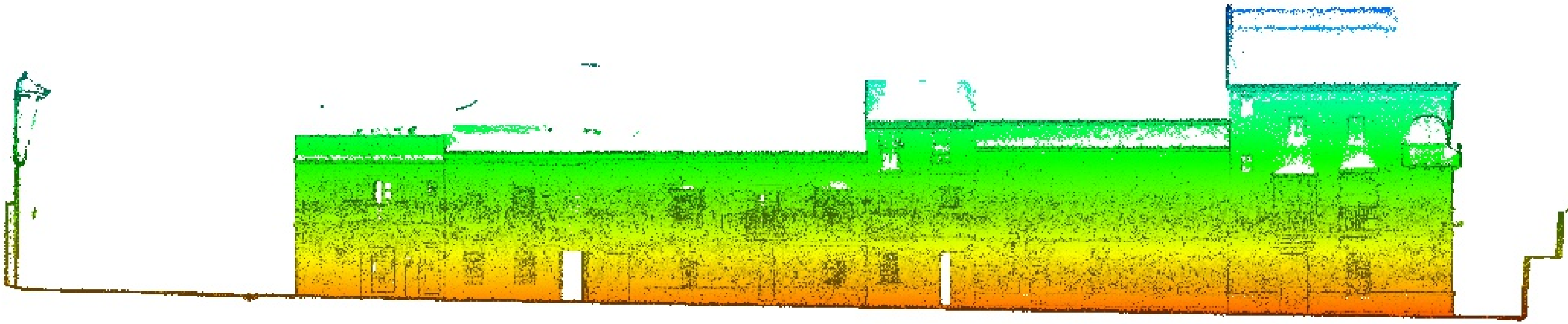

Fig. 15 - Elevation of the South-East façade in Autodesk Recap. Source: authors

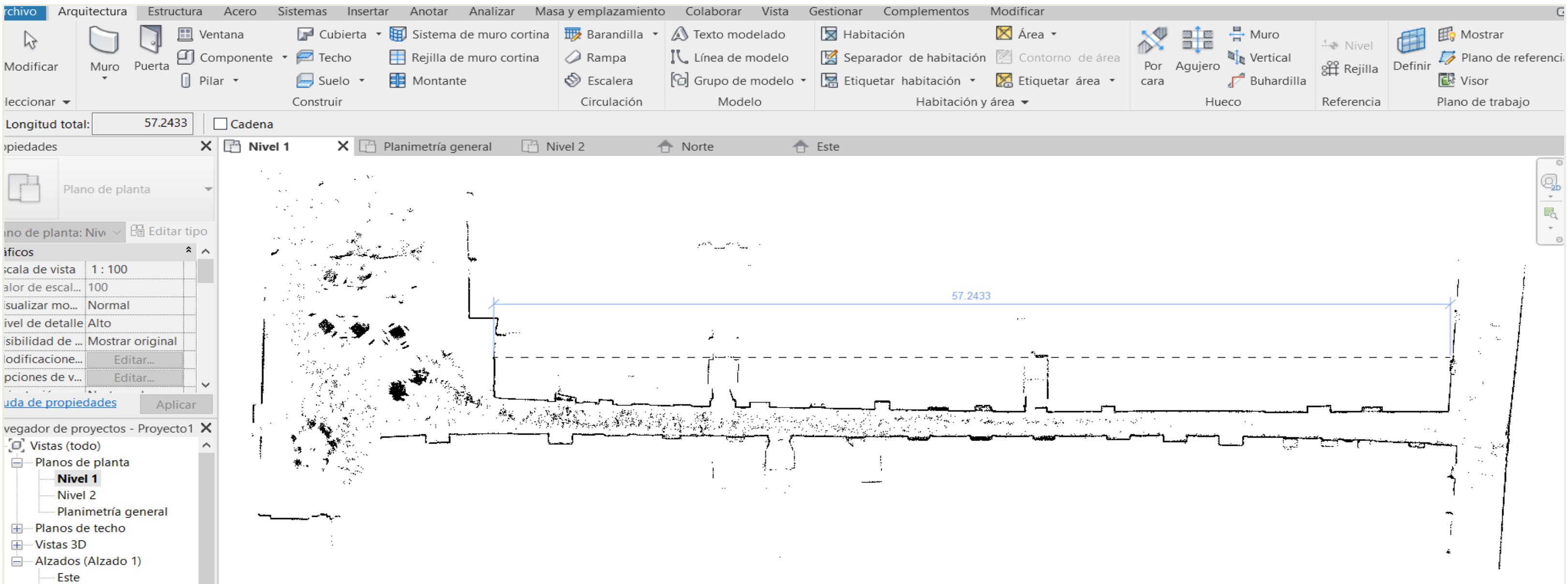

Fig. 16 - Point cloud top view by using Autodesk Revit 2019. Level 1 (1 m above the ground). Source: authors

RESULTS

In this section we will reveal the combination of latest mobile scanning technology and relatively traditional device to carry out an optimized data recording procedure. Furthermore, layouts and models obtained will be shown. Additionally, we will expose the strengths and weakness of the methodology proposed.
The technical treatment of the data was carried out using the software Autodesk Revit-2019. To do this, the point cloud has been imported in its original coordinates, which allows georeferencing the different surveys in the same project. Subsequently, different user coordinates systems have been created in order to perform optimal positions for top views and elevations (Fig. 16).
Through the management of the different floor levels we have been able to obtain the top views according to the documentation needs. We have also made different longitudinal sections that have allowed us to obtain elevations orthoimages of the North-East and South-West façades of the street as well as cross sections in different points.
The complexity of the shapes characteristic of these traditional architectures makes complicated and tedious the BIM virtual reconstruction by means of parametric families. That is why we consider more logical to vectorise directly on the point cloud to obtain the graphic documentation.
The following images show the results obtained from the point clouds captured with the GEO-SLAM system and managed by the Autodesk Revit-2019 application: Scaled blueprints of top views and elevations (Fig. 17, 18 and 19).

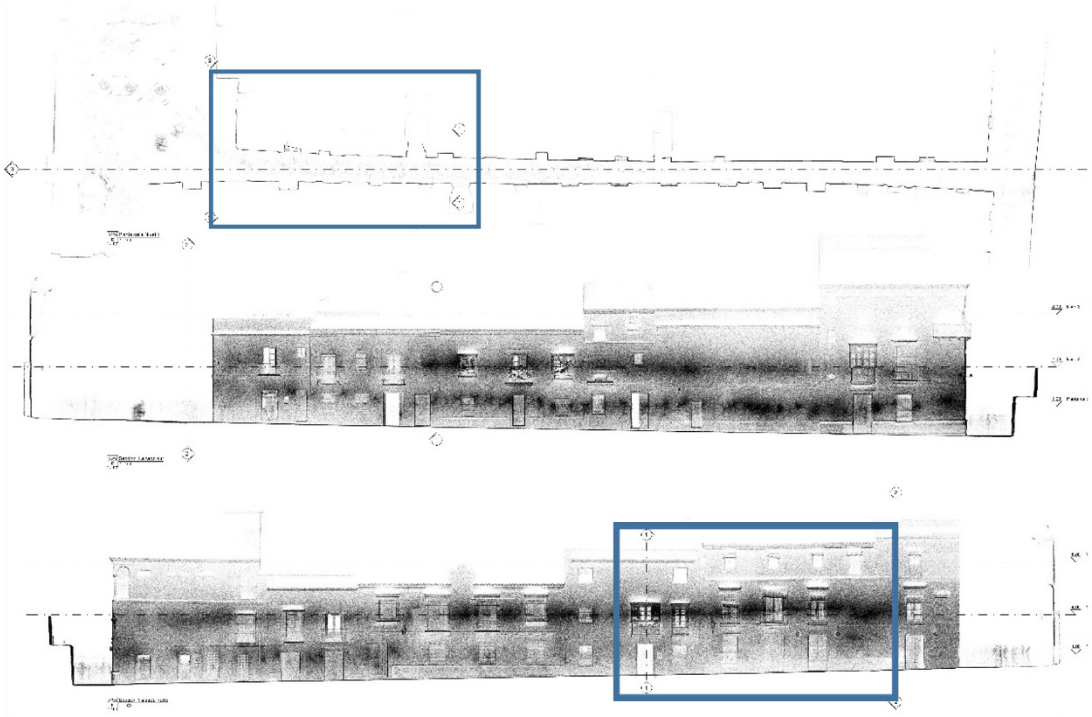

Fig. 17 - Top view and elevations with sections markers printed in Autodesk Revit 2019. Details zoomed below are marked up in them. Source: authors

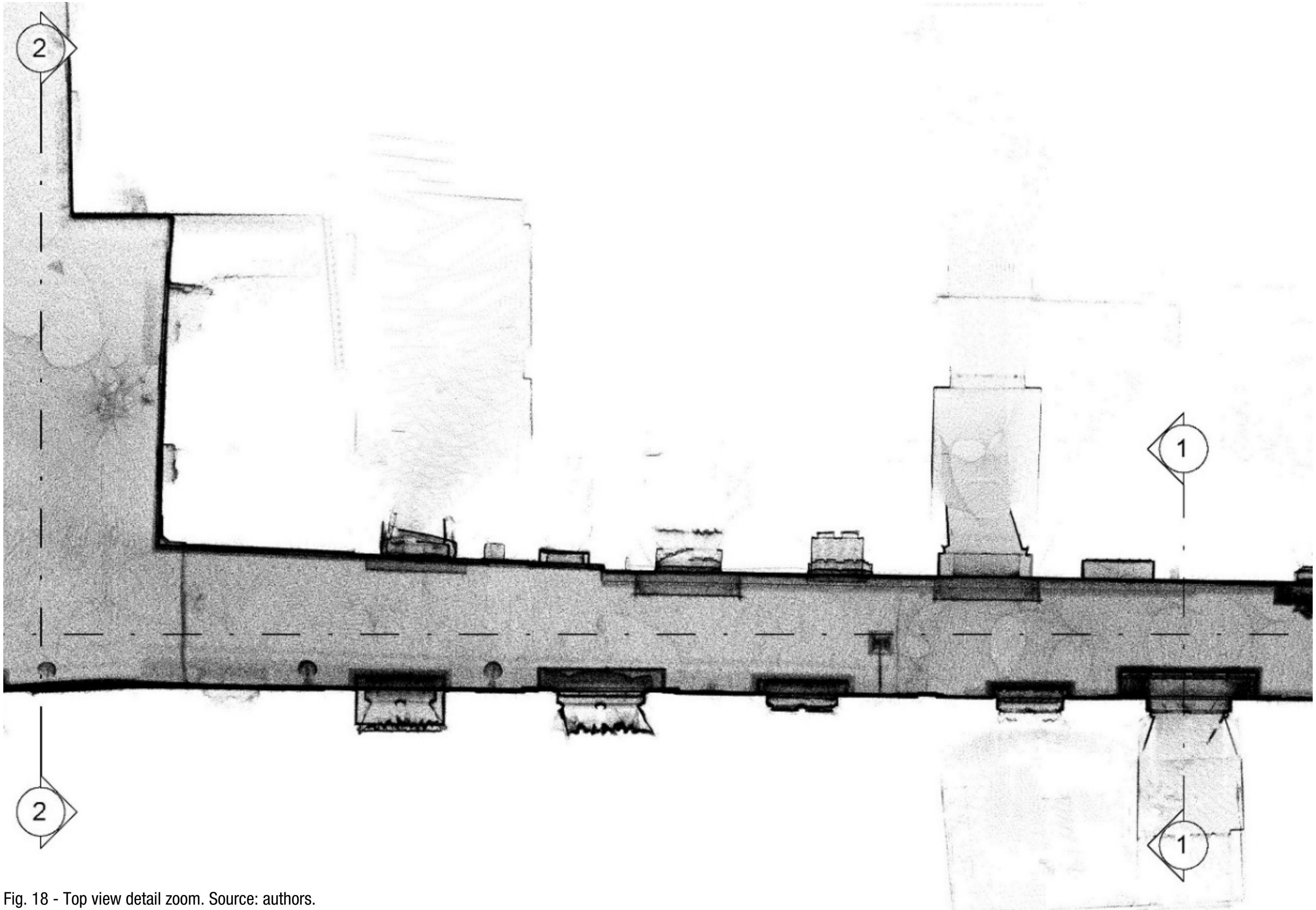

Fig. 18 - Top view detail zoom. Source: authors.

Fig. 19 - Elevation detail zoom. Source: authors.

CONCLUSIONS

Given that, except GeoSLAM, none of the systems above could completely fulfil the requirement of the project, and considering the SLAM potential, we conclude to opt for this technology in order to carry out this kind of projects. Even though the system retains the weakness we mentioned, this work reveals that nowadays it is the best option for this kind of specific projects.

By means this case study, it has been established that, in this kind of scenarios, accurate 3D point clouds can be generated in a fraction of the time taken with traditional terrestrial laser scanning or SFM photogrammetric methods.

As a conclusion, the procedure carried out shows that the graphical documentation obtained perfectly fulfils the initial requirements and the fieldwork has turned out much less time-consuming than standard stop-and-go laser scanning systems. Considering that both drone-aided photogrammetry and car-mounted laser scanning are not suitable due to the narrowness of the street, we must be satisfied about the success of the methodology proposed. Furthermore, the innovative and original aspect will be highlighted, considering the further capabilities that will be added in the near future.

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