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USING THE LASER SCANNING FOR CONSERVATION OF CULTURAL HERITAGE BUILDINGS

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Abstract: This work is part of the INTEREG IPA CBC Romania Serbia project entitled RORS394 Know to Develop – Through knowledge to business and smart development of Banat. The project's objective was to increase employment opportunities and employability of young people through the creation of organizational and institutional conditions for cross-border and networked improvement of education, knowledge and skills that will meet the needs of the economy and labour market. One of the modules of the project refers to 3D scanning as a high-resolution and accurate recording of the objects in 3D space is of high importance for many subjects of different domains of interest such as monitoring landslides, archaeology, cultural heritage etc. Traditional techniques for 3D data acquisition either restrict the size of the scanned objects or impose demands on the stability and structure of the surface. On the other hand, various society fields demand realistic 3D city models. For urban planning or historical buildings even ancient fortresses, analysing in a 3D virtual reality world is much more efficient than imaging the 2D information on maps. For public security, accurate 3D building models are indispensable to make strategies during emergency situations. Navigation systems and virtual tourism also benefit from realistic city models. Manual creation of city models is undoubtedly a rather slow and expensive procedure, because of the enormous number of buildings and complexity of building shapes. The rapid development of cities also adds to the cost of manual city model updating. Nowadays, a lot of research has been done to automate the procedure of city reconstruction, and a number of approaches have been proposed. These approaches differ with respect to input data, automation level, and object representation. In this context terrestrial 3D imaging laser scanning forms a method to acquire a large number of precise data points in 3D space representing the surface of the objects under investigation. These scanners are an effective tool for the collection of data to create a digital elevation model of the topography of a site as well as of the surface of a single archaeological deposit. The acquired data can be used for documentation purposes only, but the further processing provides the possibility for virtual reality modelling for public presentation, restoration planning or virtual reconstruction. Laser scanning technology and the final deliverable, materialized as the three dimensional model of the terrain, emphasises the importance and the applicability of geodesy in giving proactive solutions to architectural and engineering problems.
Keywords: laser scan, 3D modelling, digital reconstruction, cross-border project

INTRODUCTION

The RORS 394 project [1] aims at creating joint cross-border institutions for the promotion and maintenance of knowledge, and joint services of providing knowledge, primarily in the field of IT, as well as a rapidly growing industry, which contributes significantly to technological and sustainable inclusive development of the region. Raising the quality of education makes young people more employable; the collaboration between industry and institutions contributes to the adaptation of knowledge to the needs, and the existence of the place for informal education is an opportunity for these practice needs to be quickly transformed into knowledge.

Lifelong education through training of the trainers and online courses in the IT, entrepreneurship and management, contribute to the preservation and enhancement of the quality of knowledge which is a prerequisite for the sustainable inclusive growth, the growth based on the involvement and improving of knowledge of the local and regional participants.

In this context, different training sessions have been realized in Timisoara as follows: training in CNC programming (22-24.11.2019), training in Entrepreneurship (06-08.12.2019) and training in 3D scanning and printing (17-19.01.2020).

Three-dimensional data capture of objects on the Earth's surface is an important aspect of surveying and mapping, geospatial database construction, and 3D digital visualization. Currently, digital data acquisition is largely applied to 2D spatial databases. In this study, we present a new method that applies ground based laser scan survey and 3D digital building model construction. Previously, ground survey of spatial objects was mainly accomplished by a surveying total station. The method is relatively labour intensive and requires data conversions from analogue to digital to incorporate the results into a geospatial database [2].

3D scan data is useful in archaeology, paleontology and cultural heritage applications for dimensional analysis and study, providing a digital archival record, increased access to objects in remote locations, and to produce replicas useful for public exhibits. There is no way to record a complex object than with a high resolution 3D scan. The fringe projection method used in white light scanning allows non-contact digitization of art and sculpture and historical artefacts. Direct comparisons can be made of dimension and shape. Scanning allows revisitation of any object over time, including redrawing of cross sections, 3D volume calculations, and other analysis that would otherwise prove to be very difficult if not impossible [3].

Figure 1. Photos from the training sessions realized in Timisoara

Traditionally, archaeological or architectural information is published in a monograph or book. But this kind of documentation cannot (or is more difficult to) be distributed economically and does not adequately depict the complex visual and technical data needed for study [4].

Vectorization is the process of making explicit, information in the raster image, by defining objects within the image using lines, arcs, closed polygons etc [5]. Vectorization of contours from a scanned topographical map is a complex procedure, requiring identification of features, rigorous image classification strategies and manipulation of spatial data structures like direction of line, boundaries and nodes, polygon vertices chain etc. the automatic extraction of contour lines from a scanned topographical map and its subsequent vectorization is one of the major research problems in computer cartography and GIS.

MATERIAL AND METHODS

— Mathematic method

In order to obtain 3D coordinates, we have to transform the coordinates from one system to another and there must be a connection between ellipsoids' origins and axes. From this information, the system origin translation in space X, Y, Z axis followed by rotation around X, Y, Z axis and the scale factor between the two ellipsoids can be determined. We denote the position vector of a point in space from the reference coordinate system XLOC and position vector of the same point in the secondary coordinate system with XGPS. Conform three dimensional transformation is described by the relation:

$$X^{LOC} = X_0 + mRX^{GPS} \qquad (1)$$

I denoted with "m" the scale factor, with X_0 translation vector between the origins of the two systems, and the "R" rotation matrix which consists of three successive rotations around the coordinate reference system axes. With the rotation angles α_x, α_y, α_z the rotation matrix has general form:

$$R = \begin{pmatrix} \cos\alpha_y \cos\alpha_x & \cos\alpha_x \sin\alpha_z + \sin\alpha_x \sin\alpha_y \cos\alpha_z & \sin\alpha_x \sin\alpha_z - \cos\alpha_x \sin\alpha_y \cos\alpha_z \\ -\cos\alpha_y \sin\alpha_z & \cos\alpha_x \cos\alpha_z - \sin\alpha_x \sin\alpha_y \sin\alpha_z & \sin\alpha_x \cos\alpha_z + \cos\alpha_x \sin\alpha_y \sin\alpha_z \\ \sin\alpha_y & -\sin\alpha_x \cos\alpha_y & \cos\alpha_x \cos\alpha_y \end{pmatrix} \qquad (2)$$

In order to solve the system, equation (1) must be linearized temporary values being needed for the unknown parameters. In the case of geocentric coordinate transformation into a national system of coordinates, there are some simplifications and the rotation matrix (2) becomes:

$$R = \begin{pmatrix} 1 & \varepsilon_Z & -\varepsilon_Y \\ -\varepsilon_Z & 1 & \varepsilon_X \\ \varepsilon_Y & -\varepsilon_X & 1 \end{pmatrix} = I + dR \qquad (3)$$

Where: ε_X, ε_Y, ε_Z –the rotation angles differential sizes; I - unit matrix; dR - differential matrix.

Also, instead the vector containing the origin translations of the two systems, $X_0 = (X_0) + dX_0$ can be introduced, and (X_0) after the provisional values introduction for a single point "$m_0 = 1$" and "R0 = I" becomes: (X_0) = XLOC + XGPS. All this will be introduced in equation (1) resulting the relation:

$$X^{LOC} = (X_0) + dX_0 + (1 + dm)(I + dR)X^{GPS} \qquad (4)$$

The Expression: dX_0 + dm X^{GPS} + dR X^{GPS} – can be represented as a configuration matrix, A, which is multiplied by the unknowns' vector, which contains the dx transformation parameters, thus the equation becoming:

$$X^{LOC} = Adx + X^{GPS} + (X_0) \qquad (5)$$

If there is no information regarding the terms size from provisional values vector for the translations (X_0), a zero size can be accepted and it results:

$$\begin{pmatrix} \Delta X_1 \\ \Delta Y_1 \\ \Delta Z_1 \\ \dots \\ \Delta X_m \\ \Delta Y_m \\ \Delta Z_m \end{pmatrix} = \begin{pmatrix} \Delta X_1^{LOC} - \Delta X_1^{GPS} \\ \Delta Y_1^{LOC} - \Delta Y_1^{GPS} \\ \Delta Z_1^{LOC} - \Delta Z_1^{GPS} \\ \dots \\ \Delta X_m^{LOC} - \Delta X_m^{GPS} \\ \Delta Y_m^{LOC} - \Delta Y_m^{GPS} \\ \Delta Z_m^{LOC} - \Delta Z_m^{GPS} \end{pmatrix} = \begin{pmatrix} 100.X_1.0 - Z_1 Y_1 \\ 010.Y_1.Z_1 0 - X_1 \\ 001.Z_1.-Y_1 X_1 0 \\ \dots \\ 100.X_m.0 - Z_m Y_m \\ 010.Y_m.Z_m 0 - X_m \\ 001.Z_m.-Y_m X_m 0 \end{pmatrix} * \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \\ m \\ \varepsilon_X \\ \varepsilon_Y \\ \varepsilon_Z \end{pmatrix} \quad (6)$$

with: m ≥ 3, common points.

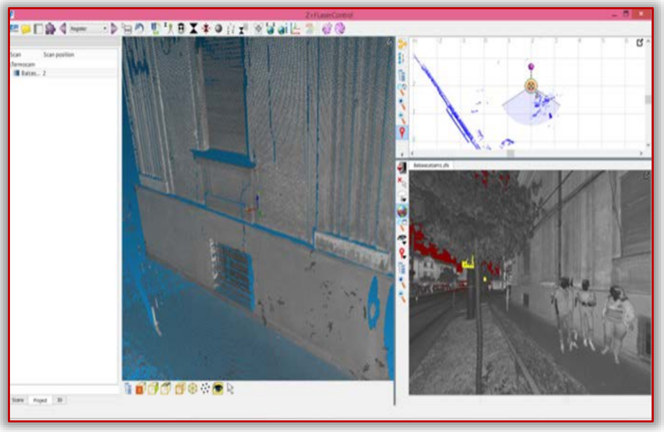
The system solving (6) leads to the seven unknown parameters determination X_0, Y_0, Z_0, m, ε_X, ε_Y, ε_Z. New points coordinate transformation determined only from satellite measurements will be now based on the seven parameters → X_0, Y_0, Z_0 (three translations), m (scale factor) ε_X, ε_Y, ε_Z (three rotations) with the transcalcul relationship from relation (1) [6].

RESULTS AND DISCUSSION

The case study refers to a residential building situated on 1 Decembrie 1918 Street, Timisoara municipality, an old building considered a historic monument. This building is located in a very frequented area by the citizens, being located near Balcescu Square and near "Grigore Moisil" theoretical high school. For this building, the terrestrial scanning operation (Fig. 2) was performed both before and after its rehabilitation.

Figure 2. Historical building under study and laser scanner station's location

The scanning session lasted approximately 30 minutes, around 6 minutes for each scanning station. Data collected on field was stored on one of the two external hard-disks in order to be further processed at the office. Several stages of the 3D modelling process are highlighted:



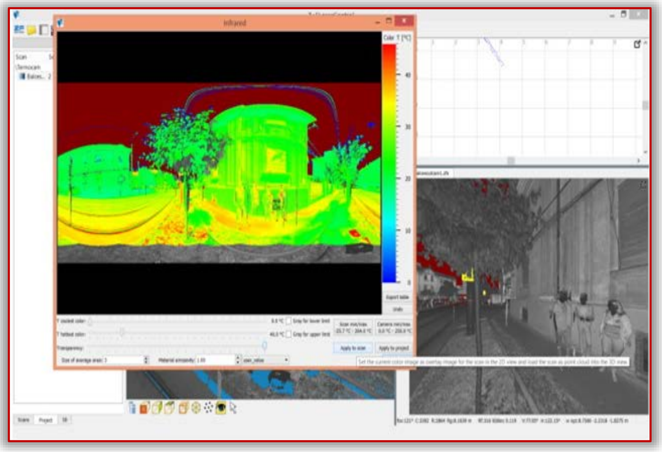


Figure 3. 3D View, Image space and station's sketch (top image) Temperature filters (bottom image)

The angle that the plane of the target with the laser beam should be neither not too obtuse nor too sharp, ideally 90o, but this is almost impossible for all targets. If registration quality is needed, the .png files are saved directly into the ".target" folder by the program.

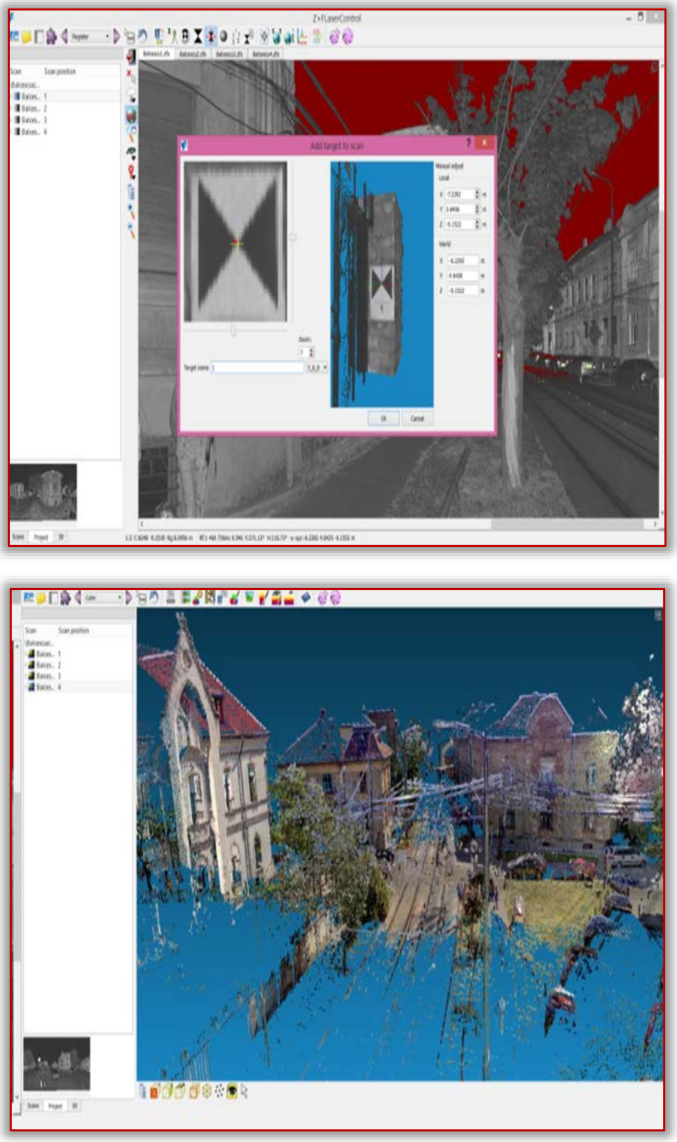


Figure 4. Manual registration of the targets (top image) Coloured point clouds (bottom image)

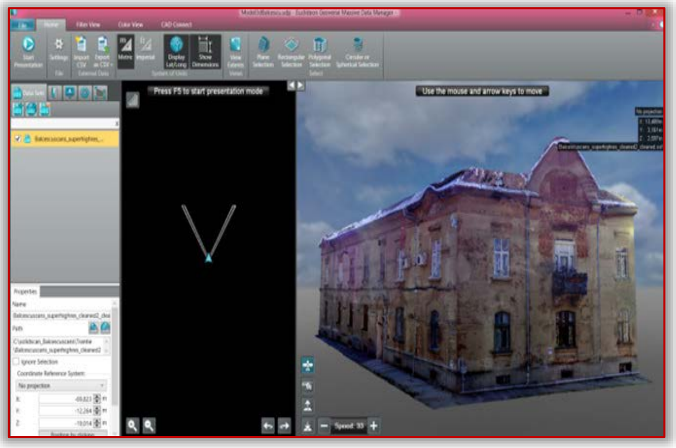


Figure 5. Reducing the noise – cleaning the point clouds (left image) Final 3D model (right image)

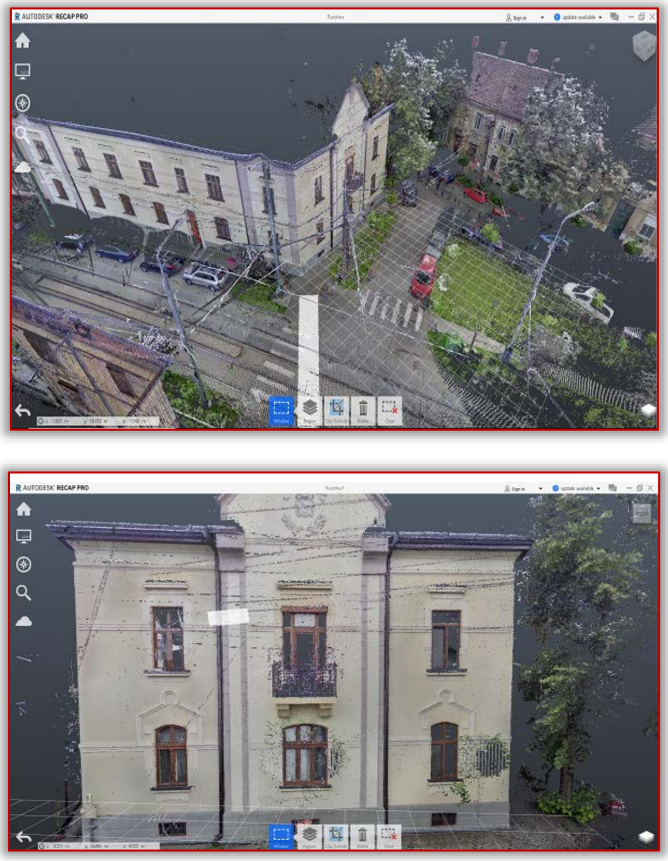


Figure 6. 3D model after the rehabilitation works

In order to realize a complete digital documentation, the cultural heritage building was also scanned after the rehabilitation works have been effected.

CONCLUSIONS

Comparing laser scanning method with traditional topographic surveys realized by total stations or with GNSS we can see that the later are much less expensive, offer very high accuracy but their application time is much higher. On the other hand, although laser scanning is much more expensive, it adds extra speed and efficiency to the surveying processes. At the same time, the amount of information received is far greater thus offering varied functionality to laser scanner data. Depending on the complexity of the work, the need for precision and the funds needed for a specific work, we can choose one method or another.

From the financial point of view, topographic methods are far cheaper than 3D laser scanning, since one of the cheapest scanners on the market along with the data processing software can be bought approximately with € 50,000. Instead, measurements can be made with any total station, or GNSSS receivers and their costs do not exceed € 10,000.

3D laser scanning technology can acquire 3D point cloud quickly with high accuracy. This meets the needs of historical architecture surveying and protection. 3D laser scanning technology can replace traditional measuring methods completely in historical architecture surveying. 3D point cloud can be gained by laser scanner, then construct the 3D model. In addition, detail structure can be got by close-range photogrammetry method, which produces the orthoimage and linear drawing [7].

Surveying of Historical architecture based on 3D laser scanning technology can not only reduce field work, improve efficiency but also provide different kinds of products such as 3D model, CAD construction drawing and so on. 3D laser scanner is growing towards high speed, high accuracy, large range and multi-information etc. at present. All these will impulse laser scanning application to historical architecture surveying and protection.

As regard the IPA project, it gave everyone involved the opportunity to work with educated adults who very easily mastered the information that was passed on and worked with visible enthusiasm, eager to improve. Thus, the project created the opportunity for teachers of different nationalities to interact and communicate, to exchange information, share ideas, feelings, research results. Moreover, the project answer to the challenges faced in academia at the moment, namely: the diversification of the student population and its needs, the rapid expansion of the use of technology, the motivation of students for learning, the pressure to develop new skills for future graduates, required by employers and the evolution of society.

The added value of the Cross Border dimension is reflected into the following:

- promoting multidisciplinary teams;
- promoting an integrated program for youngsters: training session, online platform and activities to support youngster in seeking jobs;

- promoting a favourable climate: emphasising that an environment which promotes innovation is a crucial requirement in order to attain goals in terms of technology and innovation;
- promoting motivation: increasing the motivation for youngsters and academic employees in universities and research institutions to enter into self-employment; Increasing the motivation for young people to develop entrepreneurial abilities and competencies in order to become independent (to enter into self-employment);
- promoting skills training and qualifications: strengthening knowledge and skills required in order to set up a business and manage a new company by consolidating the qualifications gained in schools and promoting further training.

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