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3D LASER SCANNING FOR RECONSTRUCTION AND RENOVATION OF BUILDINGS

Abstract

Buildings and their infrastructure are one of the foundations of every civilized society for a normal and comfortable life. Since the lifespan of buildings also passes over time, they need to be maintained and after a certain time, renovation or reconstructed. Reconstruction and renovation of a building includes the performance of construction and other works for the purpose of its renovation. An important step in the reconstruction and renovation is the collection of geospatial data. 3D laser scanning is an advanced geomatic technology for collecting geospatial data for the purpose of analyzing geospatial information and creating the necessary technical basis for further design work.

Keywords: geomatics, 3D laser scanning, reconstruction, renovation, geospatial data

3Д ЛАСЕРСКО СКЕНИРАЊЕ ЗА ПОТРЕБЕ РЕКОНСТРУКЦИЈЕ и САНАЦИЈЕ ГРАЂЕВИНЕ

Сажетак

Зграде и њихова инфраструктура један су од темеља сваког цивилизованог друштва за нормалан и удобан живот. Пошто и век трајања објеката пролази временом, потребно их је одржавати и после одређеног времена поправљати или реконструисати. Реконструкција и санација објекта обухвата извођење грађевинских и других радова у циљу његове рестаурације. Важан корак у реконструкцији и рехабилитацији је прикупљање геопросторних података. 3Д ласерско скенирање је напредна геоматска технологија за прикупљање геопросторних података у сврху анализе геопросторних информација и стварања неопходне техничке основе за даље пројектовање.

Кључне ријечи: геоматика, 3Д ласерско скенирање, реконструкција, реновирање, геопросторни подаци

1. INTRODUCTION

Managing business processes in construction is an extremely complex and demanding task or project [1]. In addition to professional, scientific and experiential assumptions, the project requires coordinated cooperation and communication of the entire project team and an interdisciplinary approach of technical professions in order to meet all project objectives [3]. The basic parts of planning each project are making a plan, defining the required level of detail to be built into the plan, identifying milestones in the project, preparing various detailed elements of the plan and using available tools to prepare and monitor the plan [13]. In order to overcome the organizational and technical complexity of the project, a big step forward in the last few years is the application of 3D geospatial and information technologies (IT). Advanced technologies accelerate the procedures and the realization of set goals. Building Information Modeling (BIM) and the creation of 3D building models is a modern approach to project design in construction, an excellent digital tool for improving, accuracy, and speed of project implementation [2]. Also, since each building has its own lifespan and after some time requires renovation or reconstruction, the 3D model allows you to define the status of damage, monitor the progress of damage, and greatly facilitate the remediation and reconstruction project. This approach to project preparation and implementation contributes to reducing the costs of project preparation and implementation [14].

2. RECONSTRUCTION AND REHABILITATION OF BUILDINGS

Reconstruction and rehabilitation of the building occupies a special part of business processes in civil construction. Given the daily needs of the market, reconstruction and rehabilitation are expanding rapidly in the construction industry. Reconstruction and rehabilitation procedures include reconnaissance of the building, planning of works and preparation of the project, collection of geospatial data, elaboration of project documentation, project execution, renovation and reuse of buildings [1]. Advanced geomatic technology in terms of digital collection of geospatial data enables efficient processing, analysis, and implementation to prepare and implement further project processes. Laser 3D scanning allows complete digital documentation of the building, outside and inside. Using this advanced technology is key to creating new approaches to civil construction business processes.

2.1. RECONSTRUCTION OF BUILDINGS

Reconstruction of a building means the renovation of an existing building or its entirety. It is actually the performance of construction and other works on an existing building that affect the fulfillment of basic requirements for that building or that change the compliance of that building with the location conditions in accordance with which it was built (extension, upgrade, removal of the outer part of the building, changes in the purpose of the building or technological process, etc.), ie the performance of construction and other works on the ruins of an existing building for the purpose of its renovation [8].

The most common interventions in the form of reconstruction are related to improving or changing the load-bearing structure of the building. Modern reconstruction is divided into exact (exact) reconstruction (based on building documentation), analog reconstruction (based on comparison and determination of similarities with another example) and hypothetical reconstruction (based on the assumption of the shape of elements and parts of the building that no longer exists, and which will be rebuilt).

Project documentation for the reconstruction of the building should be performed in such a way as to achieve the ability of the building as a whole and each of its parts and elements, to withstand all planned activities, or retain important technical properties in accordance with regulations, norms and standards. The reconstruction project should contain all the necessary plans for the existing condition of the building and a presentation and description of all types of damage and the method of renovation [9], [10]. In this step, the great application of 3D technology is seen, which enables the digital view of the required documentation both in the point cloud and in the photography that the instrument takes at the required location.

2.2. RENOVATION OF BUILDINGS

Renovation of buildings, as one of the main elements of the organization of construction sites and construction, is a series of construction and other works on an existing facility in order to prepare the facility for the function intended for it, which does not change the original form and material and does not affect safety neighboring buildings, environment and traffic [8].

Renovation interventions on the building primarily depend on the degree of deterioration or neglect of the building, with the overall picture of the current state of the building having a decisive role in the choice of remedial interventions.

The renovation project is implemented according to the remediation project, using all positive previous experiences, appropriate remediation technology, and proven materials with which manufacturers attach precise technological instructions and give a certain guarantee.

Rehabilitation is required in case of: deterioration of the building due to environmental loads (freezing, moisture, corrosion, etc.), damage due to earthquakes, fire, shifting foundations, errors due to poor design and construction, material deterioration or conversion of the object due to a change in use or a change in budget procedures in the applicable standards.

Renovation phases are anamnesis (object data, damage identification and hypothesis of damage causes), diagnosis (field and laboratory tests), therapy (recommendation of renovation methods and materials, renovation design) and control (project audit, performance supervision and control performed, renovation and monitoring and management of the rehabilitated facility). The renovation project should also include all textual, computational and graphic attachments [4].

The study on the review and assessment of the existing condition of the structure is of paramount importance for the preparation of the renovation project and should include a recording of all structural damage, volume, intensity and causes of damage, testing of mechanical properties, deformation of the structure, quality, condition and degree of corrosion, condition of the structure and the proposed method of renovation [5].

In this step, the great application of 3D technology is seen, which enables the digital view of the required documentation both in the point cloud and in the photography that the instrument takes at the required location. Reconstruction and renovation occupy a special part of business processes in civil construction. Given the daily needs of the market, renovation and reconstruction is expanding rapidly in the civil construction industry. Reconstruction and renovation procedures include reconnaissance of the building, planning works and project preparation, collecting geospatial data, elaboration of project documentation, execution of the reconstruction project, and reuse. Advanced geomatic technology of digital geospatial data collection enables efficient processing, analysis, and implementation to prepare and implement further project processes.

Such is the case with the 3D laser scanner, which enables digital documentation of buildings, locations and physical objects for reconstruction and renovation. These advanced technologies are key to creating new approaches to business processes [7].

3. 3D LASER SCANNING

Laser scanning has many advantages over traditional methods because the observer can quickly and easily collect a large amount of data in a relatively short period of time. The collected data are a set of millions of points that form the image of the so-called “point clouds” of the research area. In addition to collecting data quickly, laser scanning is the perfect solution for relatively inaccessible areas, complex details, or may be dangerous and/or unsafe to survey in the traditional way. Laser scanners capture all structure elements and create a photographic record during recording. After the scan is completed, the data is processed by visualization and modeling software to ensure a reliable and accurate 3D view of the surface or object being observed.

3.1. 3D LASER SCANNER MODELS

The history of simple laser scanners dates back to the 1960s. Then in 1985, simple scanners were replaced by LiDAR (Light Detection And Ranging) systems with high-quality scanners that use laser beams to collect data related to objects and surfaces. Modern laser scanners can collect detailed point clouds, and by subsequent processing in point cloud processing software, these geospatial datasets create digital 3D models of the scanned environment or relationships of topographic features and structures.

Laser (Light Amplification by Stymulated Emission of Radiation) is an amplification of light by stimulated emission of radiation. Device that creates and amplifies coherent electromagnetic, most often monochromatic, narrowly directed radiation [2]. The main feature of this light is the ability to focus on a point of small diameter (<1 mm), which is impossible with natural light. Laser scanning is a completely efficient and automated method of collecting spatial data. The common name for this data collection method is LiDAR (Light Detection and Ranging). LiDAR is an automated, active, optical-mechanical process of collecting spatial data available from current recording sites [7].

There are several types of laser scanners on the market depending on their operating platforms, and they are divided into three categories [2]:

- Terrestrial Laser Scanner (TLS) - A laser scanner is also known as a terrestrial LiDAR. It is usually placed on a tripod to perform static laser measurements. They have the highest accuracy among all types of scanners available on the market.
- Airborne Laser Scanner (ALS) - known as Airborne LiDAR, refers to a laser scanning device installed on an aircraft or unmanned aerial vehicle. It is known as mobile LiDAR because it can be easily transported from one place to another. The accuracy of air scanners is relatively low due to its mobility.
- Mobile Laser Scanner (MLS) - a hand-held scanner. They are relatively smaller in size and lighter in weight so they can be easily transported from one place to another.

The main steps in terrestrial scanning are defining measurement parameters in a laser scanner, placing the scanner in the position from which the object or part of the object will be scanned, starting the scanning process, collecting point cloud data, data transfer and processing in software and creating 3D BIM models using point cloud data.

3.2. LASER SCANNER LEICA BLK360

The Leica BLK360 (Figure 1) is a 3D laser scanner with integrated spherical image capture and panoramic thermographic sensor that quickly and reliably creates a point cloud. It is easy to use where a quick and efficient scan of the subject starts at the touch of a button. Depending on the measurement setting from one point of view, it only takes a few minutes to record the intended part for scanning. The usual time per point of observation is approx. 3 min.

Figure 1. *Laser scanner Leica BLK360*

The scanner has small dimensions, height 165 mm (height) x 100 mm (diameter) and weighs only 1.1 kg, which allows easy and fast transfer of the instrument from point of observation to point of observation and easy manipulation in the field. The Leica BLK360 records 360 000 points per second. The minimum distance of the scanned surface is 0.5 m, and the maximum is 60 m, which makes it a scanner for indoor but also less demanding external scans. The field of view is 360 ° (horizontal) × 300 ° (vertical), while the temperature range is from +5 ° C to +40 ° C [11].

3.3. SOFTWARE LEICA CYCLONE REGISTER360

The Leica Cyclone REGISTER 360 (Figure 2) is a module for processing point clouds of 3D laser scanning projects. The module enables automatic or individual loading of scanned data, fast and easy data processing, which is manifested in defining the overlap of "cloud points" in horizontal and vertical sense, analysis of data in the form of statistical indicators of overlap percentage and accuracy of the obtained 3D model. The software allows easy manipulation of scanned models and a clear and simple 3D display [12].

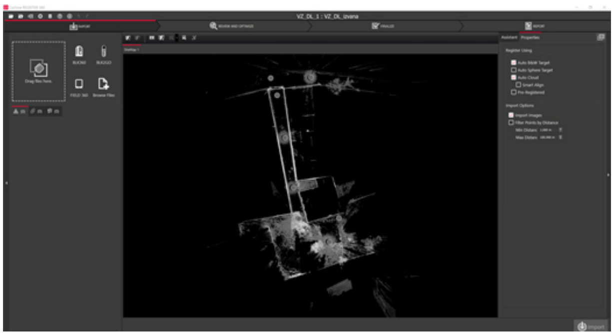

Figure 2. *Main screen in Leica Cyclone360 software*

4. 3D LASER SCANNING OF THE BUILDING FOR THE PURPOSE OF REHABILITATION AND RECONSTRUCTION

In reconnaissance of the scanning area, it is necessary to check that the whole environment is visible and clean for scanning to obtain a sufficient number of points and that there are any obstacles that need to be removed or taken into account during scanning. Inspection is mandatory for the needs of good scanning planning and all to ensure good connections between each room, floor or outdoor area provided for scanning.

For the needs of test 3D laser scanning, a building was selected that is intended for reconstruction and renovation. The location itself is divided into a courtyard and a residential part. In order to obtain a reliable 3D model of the exterior of the building was observed with a total of 8, and the interior with 18 points of observation – two point of observation were rejected (Figure 3).

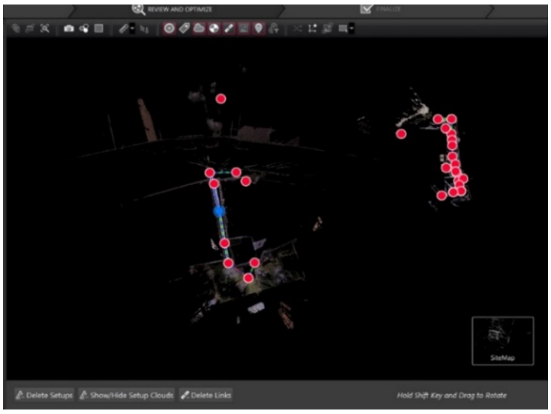

Figure 3. *Schedule raw processing points of observation outside and inside the building*

Scanning of the inner and outer part was done without technical problems and obstacles. Measurement at one point observation took approximately four minutes. During the measurement, special attention was paid to the reliable overlaps of the scanned material between the stops. If the need arose after processing, additional scans were observed. The first step of the analysis is to review the raw data (Figure 4), which were then processed in the Cyclone REGISTER 360 software.

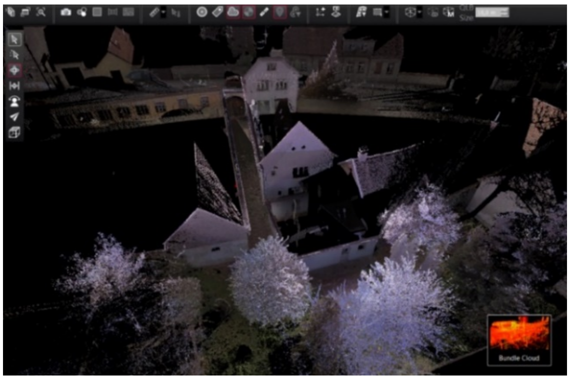

Figure 4. *Display of raw cloud data*

Data processing is performed by selecting the two closest interconnected points of observation. After "cleaning" the scanning model from excess point clouds that do not belong to the model itself, the connection between the two point of observations is created by a link that is automatically defined during basic loading. Based on the defined link, the geometry of adjacent scans is checked. Comparison and overlap of "cloud data" is done manually (by selecting identical points) because the originally loaded data is not completely overlapped in a way that follows the geometry of the observed space (Figure 5) [6].

Figure 5. *Example of cloud model overlap*

Manual overlapping can be done in horizontal and vertical planes. The software also allows point cloud rotation for the purpose of easier and simpler overlapping of scanned parts. After the data from two points of view are overlapped, the option of optimizing them is started, and after the end of the procedure, the data of the percentage overlap of point clouds is obtained, as well as the reference value of overlaping accuracy. After final processing, the connections between the stops scanned outside the building (Table 1) and inside the building (Table 2) were defined. From the statistics, it can be concluded that the percentage overlap is higher at shorter distances, while at longer distances, it is lower.

Table 1.3D model link statistics - outside scanning

Link	Distance from the point of observation (m)	Realized percentage of overlap (%)
Link 1	20.566	48.26
Link 2	9.498	79.07
Link 3	4.002	40.47
Link 4	11.070	53.90
Link 5	6.901	40.19
Link 6	17.969	27.03
Link 7	13.455	38.20
Link 8	8.871	51.42
Link 9	8.420	14.66
Link 10	5.621	40.38

What is definitely to be recommended is that the person who performed the scan should also process the scanned data. Namely, if it is a simpler object, then photographs and scanned data are quite enough for a person who has not seen the object to perform data processing. However, for more complex objects and buildings, it is recommended that the person who scanned also perform data processing because he knows best what surfaces, surfaces and parts of the object are scanned. It is also recommended to keep a log or sketch with the layout of the standpoint in order to facilitate the identification of the overlap of the scanned data. This is especially important in parts where there is no high percentage of scan data overlap.

Table 2.3D model link statistics - inside scanning

Link	Distance from point of observation (m)	Realized percentage of overlap (%)
Link 1	0.744	76.64
Link 2	1.441	58.20
Link 3	1.877	70.91
Link 4	2.119	77.32
Link 5	3.773	58.65
Link 6	2.751	48.42
Link 7	3.395	28.55
Link 8	2.478	60.16
Link 9	3.995	54.64
Link 10	2.660	56.42
Link 11	1.826	44.11
Link 12	2.566	43.20
Link 13	2.177	62.87
Link 14	2.601	20.16
Link 15	2.606	16.26
Link 16	3.372	47.25
Link 17	5.018	68.42
Link 18	7.125	45.43
Link 19	4.334	52.77
Link 20	3.945	61.09
Link 21	9.002	29.82

After processing all the defined connections between point clouds and meeting the statistical criteria for outside scanning (Figure 6 up) [6] and inside (Figure 6 down), a final 3D model with approximately 197 million points was created. Data for further use in some of the BIM software can be exported in several data models, which allows a wider application of this type of laser scanning.

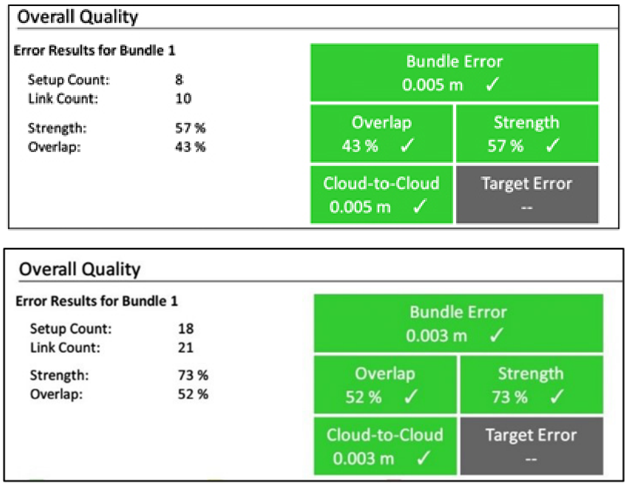

Figure 6. *Outside(up) and inside (down) scan cloud model overlap statistics*

The achieved results of the accuracy of scanned models from the outside and inside are shown in Figure 6 (statistics for outside - up and especially for inside scanning - down are shown separately). The manufacturer claims an accuracy of 6 mm at a distance of 10 m and 8 mm at a distance of 20 m, with the performance having been noted to adhere to the specifications [11]. A comparison of the accuracy of the model shows that the accuracy of the 3D inside model is 3 mm and the outside is 5 mm, which fully corresponds to the official factory specifications.

Figure 7. *Created 3D model - view from the outside*

In further analysis, the created 3D model (Figure 7) enables obtaining geometric information from point clouds that can be further used in preparation for renovation or reconstruction or provide all the necessary information for project implementation. From the model, the length between the characteristic points can be determined (Figure 8), ie the area of the selected part of the observed object.

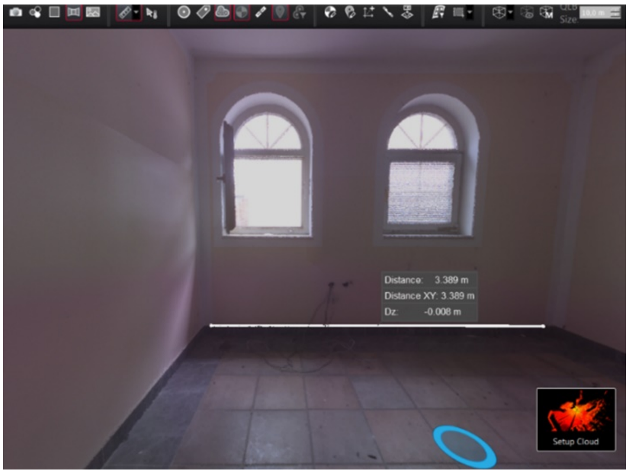

Figure 8. *Determining the distance between characteristic points*

For additional analysis and observation of the scanned area, it is possible to display a total of five types color of cloud points, one of which is the Intensity cloud model (Figure 9). Other one are Color from Scanner, Grayscale Intensity Map, Color By Bundle and Color By Setup. ach of these models provides commendable visual data that helps define and identify scanned surfaces, especially when it comes to surfaces that have more demanding relief. The scanned area is easily recognized using one of these modules, and further data processing is facilitated.

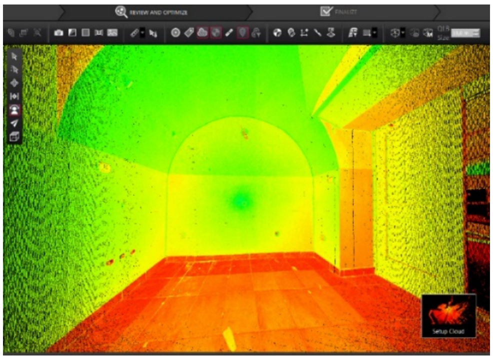

Figure 9. *Intensity cloud model*

In addition to point clouds, the instrument has the ability to create high-resolution photographs of the selected object, which can greatly facilitate the project of renovation or reconstruction (Figure 10). Enlarging, reducing, or rotating a selected portion of a photo allows for review and analysis, reliable planning down to the smallest detail.

Photographs taken by a panoramic camera also give special value to project documentation because they provide reliable information about the condition of each part's scanned object. In addition to current information, this kind of data provides valuable archival material for the future.

Figure 10. *Photo of part of the scanned model from BLK360*

Creating a report gives the project's final report with all the necessary information for its analysis. It is important to emphasize that the point cloud model can provide all the necessary dimensions in the observed object and export the final point cloud model in appropriate formats (.e57, .pts, .ptg and .ptx) which can be further loaded into other BIM software [12].

5. DISCUSSION AND CONCLUSION

For the needs of renovation or reconstruction of the building, the key step is to analyze and assess the building or its actual condition. Knowledge of the position, geometry, size, shape, and components is required for reliable design, further analysis, and planning. Currently, several laser scanning methods are used and the choice of technique depends on the appearance, complexity and size of the building and the measurement conditions. Terrestrial 3D laser scanning is a method that is widely used in practice today. This is especially true for older buildings, which often have no documentation or are incomplete and there is no reliable geospatial information. The laser scanning method is often used for documentation and supervision in civil construction projects. The large number of collected data points results in a high content of information which allows quick and detailed analysis of even the most complex objects, especially hard-to-reach ones, such as facades or parts of roof structures. In addition to scanning, an important piece of information in renovation and reconstruction projects are high-quality photographs that add value to this method of collecting geospatial data. It is also important to emphasize that conventional geodetic methods are accurate and reliable, but they are time consuming and creating 3D models from such collected data is an extremely complex and time consuming process.

With the development of new geomatic technologies in terms of collecting the necessary geospatial data, the paradigm of the process and procedures of renovation and reconstruction of the building is changing. The application of terrestrial laser scanning provides additional value for faster and easier analysis of the existing condition of the building, and application in further processes of project management and implementation in the form of BIM technology.

The paper clearly presents the application of 3D technology, terrestrial laser scanning and point clouds, as advanced geomatic technologies for collecting geospatial data. This method provides an excellent basis and wealth of information for planning and implementation of business processes in terms of geometric analysis of the building. The application of advanced additional analyzes from accurate photographs of the building provides an overview of the actual condition and excellent geospatial information for the preparation of technical bases needed for reconstruction or renovation.

The advantages of 3D laser scanning in terms of productivity and cost-effectiveness can be clearly seen from the implemented project. Special emphasis should be placed on saving time in relation to conventional geodetic methods. Also accuracy and precision are at a high level because modern technique is far more accurate and precise compared to traditional measurement, where frequent human error is eliminated. The performed laser measurements provide digital detailed documentation where the probability of any omission is minimized. Disadvantages of 3D laser scanning as seen in this example is the lack of digital information of the upper outer surfaces such as roof or chimney but the same can be compensated by additional measurements of mobile laser scanning by drone and integrated into the final 3D model.

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