Portable laser scanning solutions for 3D modelling of large buildings

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Abstract

Portable laser scanning systems (PLSSs) are a developing technology that is being used more frequently in various application domains. One notable characteristic of these systems is their capacity to gather 3D data while in motion. Additionally, unlike mobile mapping systems that are mounted to vehicles, they are particularly effective at capturing detailed information in tight, interior, and restricted spaces. This article presents two typical applications of this promising technology for modelling huge buildings. The purpose is to equip readers with fundamental information and comprehension of the capabilities and obstacles associated with this technology. A comparison is made of two methods of interior spatial data collection with lidar technology - ground-based laser scanning with a Trimble TX6 and a handheld GeoSLAM ZEB Horizon device. The technological process for creating a 3D model of two large buildings for future reconstruction is described.

1. Introduction

We live in a data-driven world. Our lives are full of data and every day we create more and more. With the growth of urban populations and the prevalence of large buildings, there is an increasing demand for up-to-date spatial information of indoor and outdoor environments. Traditionally, 2D floor maps have been used as the main source of indoor spatial information. In recent years, 3D modelling and reconstruction of the interior of buildings provide essential 3D models for applications, such as location-based services, building maintenance, disaster rescue, and building renovation planning.

Indoor 3D measurement can be collected with different sensors. Popular 3D point cloud measurement systems include stereo cameras, terrestrial laser scanning (TLS), hand-held laser scanning devices, and low-cost RGB-D cameras.

There is a consistent demand for the capability to obtain and document accurate, detailed, and location-referenced 3D data for a wide range of uses including civil engineering, construction, cultural heritage, environmental studies, and industrial applications. The optimal method to meet this requirement is through the utilisation of mobile mapping systems, which are platforms capable of dynamically capturing 3D data of extensive regions. A mobile laser scanning (MLS), as described by (Mickrenska, 2020), is a complex system composed of three primary components: a positioning and navigation unit for spatial referencing, mapping sensors for collecting 3D/2D data (such as point coordinates and images), and a time referencing unit that serves as the central system for synchronising and integrating the data.

The word 'MLS' was originally used to describe systems that are primarily designed for vehicles such as cars, vans, and boats. However, it is also used to refer to aerial light detection and ranging (lidar) systems and vessel-based acoustic systems used for seabed mapping.

The majority of mobile mapping systems primarily utilise lidar sensors as 3D mapping units. However, these systems also typically incorporate cameras to capture colour information of the surrounding environment. Mobile Mapping Systems (MMSs) installed on a vehicle may not be able to go via tiny tunnels and are not suitable for inside environments.

Currently, there is a high demand for MMSs that are specifically designed and modified to be conveniently transported or worn by those who are walking and, as a result, are able to map the desired surroundings. These systems are meeting the increasing demand for mapping and monitoring intricate areas that have challenging conditions and short time constraints. This necessitates the use of flexible systems that can be easily transported.

This paper specifically examines systems that possess unique characteristics that can be briefly described as follows: (1) The measurements are performed by an operator. (2) They can be easily carried around. (3) They can be moved within the area of interest without the need to stop and start measurements. (4) The navigation and mapping process is automated and relies on simultaneous localization and mapping (SLAM) algorithms. (5) The data provided is in 3D format. These systems are also referred to as portable scanning solutions or indoor mobile mapping systems - IMMs (Tucci et al., 2018). However, as its application is not limited to indoor situations, the term 'portable LSS' (PLSS) will be used in this context.

2. Overview of portable scanning solutions

Portable scanning solutions were originally created as cost-effective and user-friendly substitutes for mapping that are placed on robots. Due to these attributes, they have been utilized in a growing range of applications. PLSS are mostly used for indoor mapping and modelling. They are the optimal choice when considering resolution, accuracy, time, and prices. In contrast, TLSs exhibit a precision that is ten times greater than portable LSSs. However, they are less efficient in mapping extensive regions that have limited spaces and obstructions. The process of creating three-dimensional representations and models of the inside of buildings (is directly connected to the use of building information models (BIM) software. The output

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models must adhere to the established formats for 3D city models and BIM (Lin, 2015) (Nocerino, 2017)

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The GeoSLAM team knew that there had to be a way to use 3D laser scanning and create 3D data, but make it faster, easier, and possible in places that previously would have been impossible to scan. The old tools were already an inadequate solution. In 2013 GeoSLAM in collaboration with CSIRO has launched the first handheld SLAM scanner for mobile 3D laser data collection ZEB1, powered by an intelligent algorithm that continues to evolve and becomes smarter every time it is used.

SLAM is an acronym for Simultaneous Localization and Mapping, which is also known as Synchronised Localization and Mapping. Geolocation is the act of creating a map of a specific region while simultaneously monitoring the precise location of the device within that region. This is the key factor that enables mobile mapping, facilitating the conversion of vast areas into digital format within much reduced timeframes. SLAM systems streamline data acquisition, offering a means to scan both outside and indoor areas.

SLAM is a very versatile technology that has a considerable impact on the gathering of geospatial data. It serves as a supplement to other methods of capturing 3D Lidar data, such as terrestrial laser scanning, by filling in the missing information for locations that are difficult to access.We utilise portable mapping technology to effortlessly navigate across any space, simultaneously creating a digital representation of the surroundings.

Using a SLAM mobile mapping device, one may effortlessly navigate through a space while simultaneously creating a digital map, resulting in time savings and a cost-efficient solution. A mobile mapping system based on SLAM technology is capable of capturing data at a speed that is 10 times faster than terrestrial laser scanning, but 10 times less accuracy.

SLAM software enables a device to do simultaneous localization and mapping by utilising SLAM algorithms. This allows the device to determine its own location within a map and construct a virtual representation of the surroundings.

The device utilises data from an Inertial Measurement Unit (IMU) sensor to calculate a highly accurate estimation of its current location. Positional information is collected at regular intervals, when features are aligned, and the estimation is enhanced.

There are various algorithms and approaches used in Simultaneous Localization and Mapping: Graph SLAM (Wagner at al., 2014), EFK SLAM, Fast SLAM, Topological SLAM, Visual SLAM (Scona at al., 2017), 2D Lidar SLAM, 3D Lidar SLAM, ORB SLAM (Mur-Artal at al, 2015), LSD SLAM (Engel et al., 2014). Mobile mapping devices utilise Visual and Lidar SLAM techniques to generate point clouds.

Visual Simultaneous Localization and Mapping (VSLAM) is a technique that determines the position and orientation of a device relative to its surroundings. It achieves this by utilising visual information from a camera to simultaneously create a map of the environment.

A Lidar-based Simultaneous Localization and Mapping (LSLAM) system utilises a laser sensor to provide a three-dimensional representation of its surroundings. Lidar, also known as Light Detection and Ranging, is a method of measuring the distance to an object. It works by emitting a light pulse, which is then reflected off the item and detected by a sensor. The time it takes for the light to travel to the object and back is recorded as the Time of Flight (ToF). Lidar is a rapid and precise technology that is well-suited for many situations and conditions. The laser sensor point cloud produced with this technique is extremely precise and well-suited for various sectors.

Understanding SLAM algorithms can be difficult for non-technical persons. SLAM algorithms can be assessed using specific criteria. These criteria will facilitate the differentiation of various SLAM algorithms, offering the essential information to narrow down the choices. The key variables include the speed of processing, the integration of sensors, and the ability to add colour. The SLAM approach does a significant number of computations per second. The system tracks your movement inside a certain area by gathering data from many sensors and integrating this information to coordinate the various measurements received by the Lidar. The challenge is challenging, and each SLAM algorithm will approach it in a distinct manner, leading to different processing times.

The SLAM algorithms process the scan in real-time to generate a point cloud that can be downloaded once the entire area has been captured. This approach compromises reliability, hence heightening the algorithm's vulnerability to errors in challenging settings. This method is optimal when you need a quick turnaround on your data.

Post-capture processing refers to the activities that take place after capturing data. Many SLAM algorithms employ this method, requiring the start of scan processing only when the capture is complete. Despite its slower processing speed compared to real-time processing, it ensures greater reliability in the scan results. The impact of the additional processing may vary depending on your schedule.

Some SLAM systems include the flexibility to select either real-time or post-capture data processing, enabling you to customise your approach based on individual circumstances.

SLAM implementations differ depending on the hardware they use, specifically the sensors that capture the data needed for the algorithm's calculations. The SLAM approach, when combined with an Inertial Measurement Unit (IMU) and a Lidar sensor, demonstrates exceptional efficiency in open environments that contain distinct 3D features such as chairs, pipelines, railings, and trees. SLAM systems may face challenges in situations with prominent planar structures, such as walls. Corridors, storage facilities, and other areas are susceptible to mistakes and can result in unreliable data. Although it has the ability to monitor two-dimensional shapes, it often has difficulties when it comes to detecting empty walls.

Some SLAM algorithms offer the capability to incorporate colour into your point cloud. The result is clearer than an unprocessed point cloud, approximating a vivid 3D image, making it easier to recognise ambient elements such as columns, reinforcement bars, doors, trees, vehicles, etc. After the scanning procedure is over, various SLAM algorithms can enhance your point cloud data by adding colour. Scanners employing this method usually require you to attach a secondary camera to the device and perform supplementary processing steps in your workflow to achieve the desired results. Some SLAM techniques have the capability to automatically incorporate colour into your scan throughout the capture process. However, not all handheld scanners do this function in the same way.

3. From Physical to Digital: The Scan-to-CAD Process

The process known as "SCAN-to-BIM" is employing laser scanning technology to gather extensive information about the actual building structure, turning it into a digital 3D model, and then turning that model into a BIM (Building Information Modelling) model (Antova, Tanev, 2020). This makes it possible for engineers and architects to evaluate the structure before preparing for a remodel or renovation.

Step 1: Examining the structure using a portable mapping system.
The building must first be surveyed by a surveyor using a specialised laser scanner. The scanner uses reflected signals from laser beams it emits to measure the lengths and locations of surface points in space. After that, a point cloud is created using these data to depict the building's geometry in three dimensions. Before the data is converted into a BIM model, it must also be registered or located, which is the process of connecting the 3D scan data and bringing it to a common reference level.

Step 2: Registration and Data Export
The process of merging several point clouds into a single point model is known as point cloud registration (Rramezani, 2020). This stage is crucial to guaranteeing the correctness of the final digital model and to enhance the quality of the CAD model that is produced from the 3D laser scan.
Registration can be done manually or with the use of specialised software. While automated methods utilise Iterative Closest Point (ICP) algorithms that automatically compare and register the data based on geometric or textual aspects, human approaches use visual features in the data to create correspondence between distinct scan data.

Step 3: CAD and BIM Modelling
Making a CAD and BIM model starts when the data has been exported and registered. Specific CAD programmes like Revit or ArchiCAD are used for this process. After scanning, the data is saved in a point cloud format that may be processed further to create CAD and BIM models. The file formats E57 and RCP, which are frequently used to exchange laser scan data, are frequently utilised for this purpose.
The point cloud serves as the foundation for our 3D modellers' digital recreation of the building. In addition to creating and adding materials and textures to make the model more realistic and authentic, they can also precisely design walls, doors, windows, and other components based on the point cloud. To make sure the digital model matches the real building, or any other model needs as precisely as possible, pictures are also employed in this step.

3.1 Case study 1: Semkovo

The aim of the project is renovation of a building for educational and sports facilities of the University of Architecture, Civil Engineering and Geodesy. The task goes through several stages:

1. ARCHITECTURAL SURVEYING
The object of the task is the preparation of a floor plan and 3D models of the building, based on the provided spatial coordinates from laser scanning.

2. ANALYSIS AND ESTABLISHMENT OF AN ASSESSMENT OF THE EXISTING STATE OF THE HOLIDAY STATION.
Study and create a real assessment of the condition of the existing material environment of the building and the interior.

3. PROJECT PROPOSAL FOR RECONSTRUCTION
The integration of the building spaces and the solution of existing problems can be achieved after analysis and a precise architectural design for reconstruction.

3.1.1 Description of the building

With the first sod on June 15, 1966. The construction of the training and rehabilitation base of UACEG begins.
The station was built on a foreman basis by employees, professors and students, and the first shift welcomed there the new 1970. Arch. Tanko Serafimov, adding a second block of accommodation for staff, a cafe, a ski warehouse, as well as an annex to the canteen in 90's.

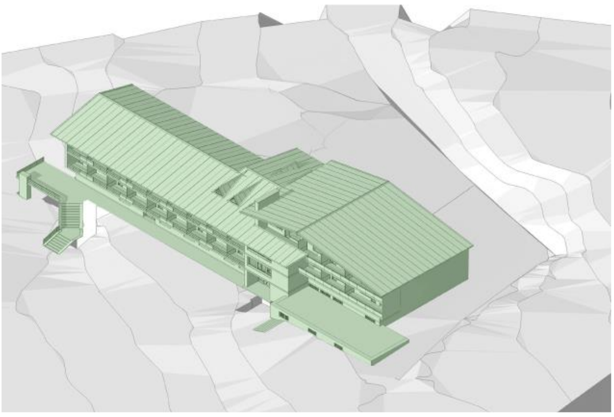

Figure 1. First stage of construction - 1966-1970

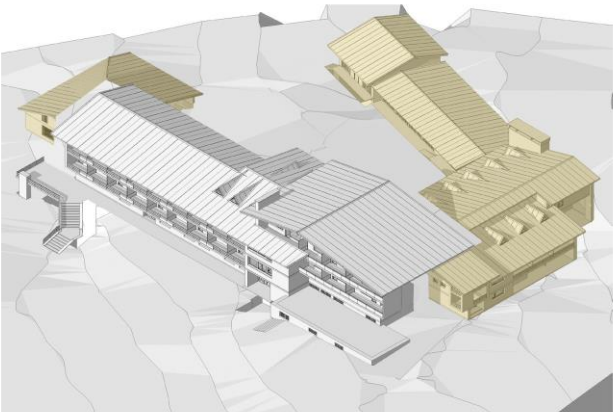

Figure 2. Second stage of construction - the 1990s

3.1.2 Measurements

Laser scanning was performed by two different technologies: terrestrial laser scanning with Trimble TX6 and mobile SLAM with Geo Slam Zeb Horizon handheld scanner. Due to its slower speed and the requirement for more time of the technology itself, a ground-based laser scan was used to capture the facades, common areas, corridors and staircases without entering the rooms. The resulting point cloud has a density of 5 mm. In addition to spatial coordinates, the points also contain information about the intensity of the reflected signal and color. The scan was performed by 56 stations and took 3 days. For georeferencing of the cloud, marks were used, which were previously coordinated with a total station. The cloud processing was carried out at Trimble Realworks.

The portable mobile mapping scan was performed on the entire building externally and internally, including basements and attics on a total built-up area of 3600 sqm. The shooting took 3 sessions of 20 minutes and 1 hour of coordination with GNSS. Due to the limitations of the mobile scanner model used, the dot cloud is black and white. A georeferenced point cloud and georeferenced cuts in PDF format is provided, which can be used as a pad for drawing the 3D model in ArchiCAD.
It is important to know that a prominent example of localization failure when mapping indoor environments is to navigate a path between two rooms. In this case two consecutive 3D LIDAR observations of the two rooms will have very little in common to determine the motion. Similarly, when trying to localize within a long corridor without any distinctive features, the registration will likely fail. For that reason, it is recommended walking with small turns alternating between entering a room and exiting into a corridor.

3.1.3 Modelling

The resulting point clouds as a result of the measurements made with a terrestrial laser scanner require further processing to be able to obtain the desired results for which the given measurements were performed. The processing process itself is carried out in specialized software products that allow the manipulation of this type of spatial data. CloudCompare is a free software product that allows performing complex analyses, processing clouds of points and working with irregular surfaces. This software was used to cut the cloud from points of the building to floors, which facilitated the processing in the architectural software later. The parts of the cloud were used as a pad on which a 3D model of the building was built. The dot cloud contains a large amount of data, including furnishings, allowing the construction of a detailed and precise model. Since all points are visualized in black, the problem is the overlay of too many points of different elements, so it turned out to be the most optimal operation of small sections with many cuts in order to track the most accurately sought points. This problem is not the case with the use of a cloud of points obtained from NLS. However, there is another problem – the large file size due to the high density of dots and colouring. In this case, it is good to use the capabilities of the software for processing cloud points to preserve the details. In this way, the density of points in the plains sections is reduced.

Used software for modeling the cloud of points: CloudCompare, ArchiCAD. The modeling of the building and the interior takes 2 months per person.

Figure 3. Visualization of the finished digital model

Figure 4. The façade of the south

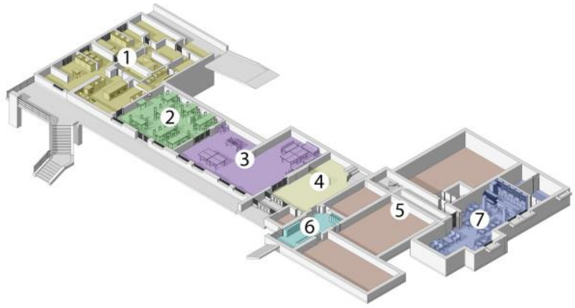

Figure 5. AXONOMETRIC CUT elevation ± 0.00 (1.Kitchen, 2. Canteen, 3. Common space, 4. Lounge, 5. Technical premises, 6. Ski wardrobe, 7. Cafe in underground elevation level -1.14)

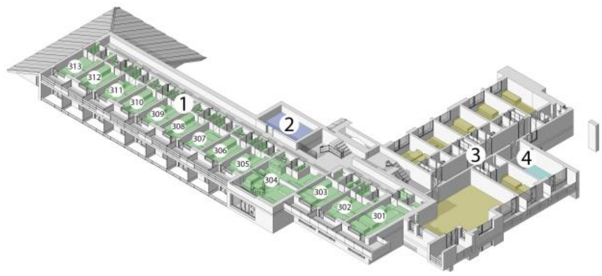

Figure 6. AXONOMETRIC CUT elevation + 6.00 (1. Guest rooms, 2. Maid warehouse, 3. Staff rooms, 4. Doctor's office)

3.2 Case study 2: Vratsa

3.2.1 Description of the building

The building was built in the 70s of the last century, as an administrative building of a former Anti-Plague Plant. Its built-up area is 289 sqm. building 1 and 316 sqm building 2 Total built-up area 2077 sqm. The first building has 48 offices, auxiliary rooms, bathrooms, vertical communication two-arm staircase, basement technical rooms, bar and auxiliary rooms on basement level. Second building has a kitchen, dining room, theatre hall on the first floor and underground garage and auxiliary rooms.

The goal is to organize the building into a hospice. Hospice is a medical institution in which medical and other specialists carry out continuous medical monitoring, maintaining treatment prescribed by a doctor to persons with chronic debilitating diseases, terminal conditions and medical social problems.

3.2.2 Measurements

Tape measure shooting
A survey was conducted to record the architecture of a specific section of Building 2, focusing on the first level, using traditional measurement techniques. A comprehensive 2D floor plan has been created, showcasing all the intricate components of the theatre hall. In order to achieve this objective, electronic

tape measures were utilised to get measurements, and an adequate quantity of control distances were recorded.

Capturing images of a theatre hall with the PolyCam mobile application

•LIDAR SCANNING: Utilising the LiDAR sensor on Pro iOS devices, you may scan any object of your choice. •PHOTOGRAMMETRY: Photo Mode transforms both iPhone and Android handsets into effective tools for photogrammetric analysis You can utilise this tool to capture an object with exceptional precision and intricacy. By selecting Photo Mode, we can rapidly generate top-notch 3D models and showcase them in our Explore stream to distribute them throughout our global audience. Models are utilised in several applications such as scene creation, game development, VFX, and other related fields. Images can be uploaded using the Polycam web application or captured using other devices, such as professional cameras or drones.

360-DEGREE PHOTOS: The 360 mode enables you to capture comprehensive 360-degree panoramas of any given location. This method offers the most rapid and effortless means of producing 360 degree photos. The study articles can be directly published in the research stream, allowing others to easily access and download them. This export can be utilised in any 3D software that is compatible with skybox backgrounds, such as Blender, Unity, Unreal, and Cinema 4D.

Figure 7. Two-dimensional representation of point cloud obtained from PolyCam App

Mobile laser scanning with GeoSLAM technology ZEB Horizon

The use of GeoSLAM ZEB Horizon for laser scanning of buildings gives extremely accurate and detailed results Figure 8. The system can collect large number of points from the high-density environment, allowing the creation of of high-resolution three-dimensional models of buildings. This allows surveyors and engineers to receive information about geometry, the dimensions and structure of the building, as well as to carry out precise measurements and analyses Figure 9 and 10.

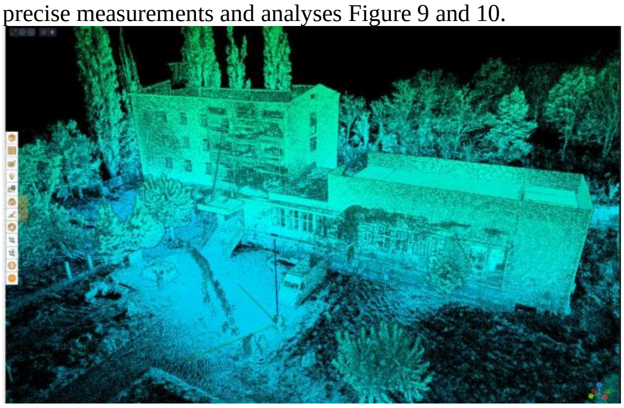

Figure 8. Point cloud from Mobile laser scanning with GeoSLAM technology ZEB Horizon

Figure 9. Section of a points cloud of facade northwest

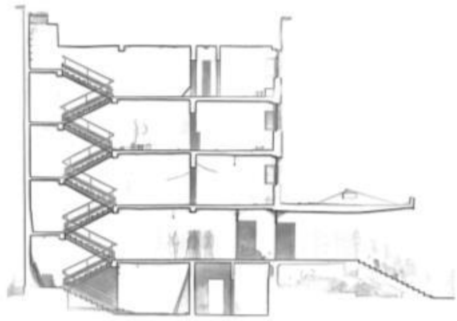

Figure 10. Vertical section of points cloud

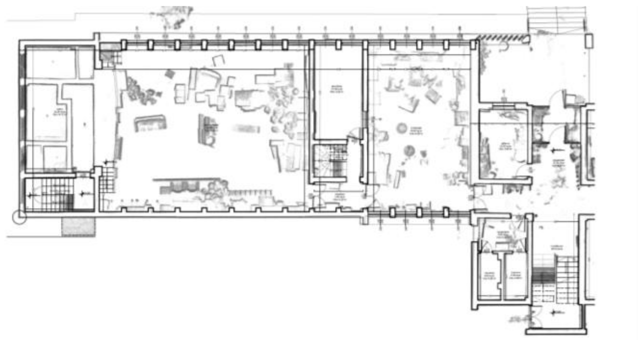

Figure 11. Digital model of the 1-st floor

4. Results

For the purposes of the project, a study of the accuracy of the digital model obtained from SLAM was made. Root mean square (RMS) is defined as the square root of the mean square (the arithmetic mean of the squares) of the set of differences between distances measured directly with tape and digital model obtained from GeoSLAM point cloud Figure 11. RMS = 1,9 cm defines the accuracy of SLAM technology. In Figure 12 comparison of the three methods of data capture is given: in cyan - architectural tape measurements, in magenta – GeoSLAM, in blue – cell phone measurements, in red – idealistic building model.

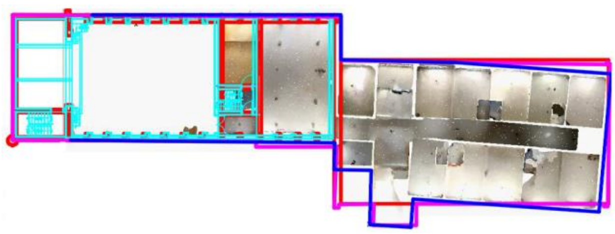

Figure 12. Comparison of the three methods of data capture. Base: points cloud of cell phone scan

1. Regardless of the accuracy of architectural survey using standard methods, it always deviates from the actual distorted

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structural elements of a building. Only precise geodetic surveying could establish this.
2. The most accurate of the three methods is Mobile Laser Scanning with GeoSLAM ZEB Horizon technology with a baseline accuracy of spatially defined points of 10-20 mm.

3. Imperfections in the inertial module of the Iphone 13 Pro Max, which was used to perform the scan with the PolyCam mobile application, resulted in distortion (breakage) of the model at the transition points from one room to another. This makes the application useful when capturing single rooms and impractical when capturing buildings with large square footage and a large number of rooms.

4. The algorithms of spatial point location calculation with GeoSLAM mobile laser scanning technology are based on constant control during the measurement with reference points predefined with GPS. This makes the final result a georeferenced point cloud showing the absolute reality in plan, horizontal and vertical terms. The generated sections in this cloud become an indispensable assistant in the determination of deformation in the vertical and horizontal structural elements of the building.

5. In tasks related to the reconstruction of buildings and their passporting, a model of the building should be prepared, fully corresponding to its actual contours, and building elements. This helps to draw the best possible conclusions about its suitability and select the most appropriate methods for its reconstruction if necessary.

6. In tasks related to the change of use of buildings, some generalization / approximation of the model to its idealistic orthogonal image is permissible, and the difference in the resulting RR could be compensated by a foreseen finesse of materials. For a building such as the one under consideration with a floor area of 2077 sqm, deviations of up to 50 cm in plan from one end of the building to the other would result in a difference in quantities of no more than 3%.

7. The use of a mobile laser scanner or even a mobile application in the capture of buildings is a much-needed check on conventional capture methods in order to minimize the human factor, inaccuracy and frequent generalization that each model typically receives when plotted due to inconsistency in measured distances.

8. Determining factors for the accuracy of the resulting model is the accuracy of the inertia module that owns the mobile device, as well as the speed of shooting and Robust Registration of loop Closure algorithm (Rramezani, 2020).

5. Conclusions

Although the same portable mobile laser scanning system was used at both sites, the approach to building the digital model was different. In object 1, the full use of the point cloud was made, with cuts being made and small parts of it inserted into ArchiCAD. At site 2, the sections were generated in a GeoSlam software in PDF format and used as a georeferenced pad in ArchiCAD. The time difference between the two approaches depends on the skill of the designer.

However, utilizing the terrestrial laser scanning point cloud data allows for the integration of finer architectural elements in the model of the building.

In general, it can be stated that the process of indoor mapping is an efficient and precise method for converting physical buildings into digital 3D models and BIM models. Using portable laser scanning technology and subsequent modelling of the data, architects and engineers can fast and accurately analyze and simulate buildings before beginning planning for renovations or remodels. Scan-to-BIM is the centimetre-accurate digital re-creation of buildings of all types and an extremely useful tool for efficiently and effectively creating a digital twin of an existing building.

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