Integrating Data from Terrestrial Laser Scanning and Unmanned Aerial Vehicle with LiDAR for BIM Developing

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Abstract

The use of Building Information Modeling (BIM) in building construction and management is becoming increasingly common. Nevertheless, the generation of BIM models for already existing buildings is still an operation requiring a significant human effort. The generation of a geometrically reliable and complete BIM model requires geometric information on all the building parts. Since acquiring such information with a unique acquisition tool is quite hard, integration of data acquired with different acquisition tools and platforms is strongly recommended in order to obtain a geometrically complete 3D description of the building. This work presents a procedure for integrating data acquired with Terrestrial Laser Scanning (TLS), UAV (Unmanned Aerial Vehicle) LiDAR (Light Detection and Ranging) and Smartphone with LiDAR, showing the obtained results on two case studies, two buildings in the campus of the University of Warmia and Mazury in Olsztyn. Finally, a BIM model have been successfully generated in both the case studies by using the Blender software.

1. Introduction

Building Information Modeling (BIM) is a revolutionary approach to the design, construction, and management of structures within the architecture, engineering, and construction (AEC) industry. Unlike traditional methods that rely on 2D drawings, BIM involves creating a comprehensive digital representation of a building or infrastructure project. This intelligent 3D model encompasses not only the physical aspects but also incorporates valuable information about materials, components, and their interrelationships (Kensek & Noble, 2014; Panushev et al., 2010).

According to the National BIM standard (NBIMS), the BIM term represents three different functions (NIBS, 2015):

- building information modeling, i.e. the process for generating the building model
- building information model, i.e. the building digital representation,
- building information management, i.e. the building management process during the whole building lifecycle.

BIM is a digital representation including both physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards. BIM is based on an electronic record of full knowledge and data about a building object, for their use in the design, construction and subsequent use of the object information about each of the elements of the building - from visualisation, through the possibility of entering the interior, surface, volume, material consumption, costs, etc., providing the opportunity to quickly check many different variants (Leśniak et al., 2021).
BIM model generation can be a quite time consuming operation, usually requiring the intervention of an expert human operator. Recently, some 3D surveying methods have been successfully applied in order to support human operators in the BIM model creation, in particular for what concerns the generation of the 3D geometric model, by means of the so-called scan-to-BIM workflow. Such methods usually provides high-resolution 3D point clouds, from which it is possible to identify certain of the main building geometric features. However, given the geometric complexity of a building, the generation of a 3D model of the whole building usually implies the use of different acquisition techniques. Among these, Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicles (UAVs) equipped with Light Detection and Ranging (LiDAR) technology have emerged as suitable and powerful tools for such aim. Indeed, these advanced surveying methods offer unique advantages in capturing accurate and detailed spatial information for construction and infrastructure projects (Skrzypczak et al., 2022): given their different acquisition point of views, they provide complementary descriptions of the same building/infrastructure. Hence, data integration from such different acquisition tools is usually strongly recommended in order to obtain a complete building representation.

In addition to the devices mentioned above, certain quite popular smart devices, such as smartphones, can also be considered for 3D surveying purposes, in particular when equipped with LiDAR sensor (Smartphone with LiDAR - SwL). Indeed SwL, such as the recent iPhone models, can be considered as mobile scanning devices, opening up new possibilities for using smartphones in geodetic measurement processes, in particular when the use of a very portable device can be convenient (Błaszczak-Bąk et al., 2023a; Błaszczak-Bąk et al., 2023a; Eastman, C., Teicholz, P. Sacks, 2018).

In accordance with what mentioned above, data to be used for BIM model generation can come from different sources, hence they should be properly integrated before undergoing the BIM generation procedure. The geometric quality of the generated BIM is clearly strongly dependent on the accurate registration and combination of the datasets acquired by the above mentioned different sources. The proper integration in the obtained integrated outcome of color and laser intensity reflections is also an important factor, leading to more realistic virtual models: thanks to the use of geometrically accurate point clouds, it is possible to generate high resolution highly reliable geometric models, realistically reproducing object colors and texture as well.

This paper embarks on different methods of integration point clouds and comparison the results, shedding light on their usability within the context of preparing data for BIM. This is important from the Level of Development (LOD) perspective.
LOD refers to the degree of detail and reliability of information within BIM elements at different stages of a project. Integrating data from different sources allows for higher LOD (Abualdenien & Borrmann, 2022).

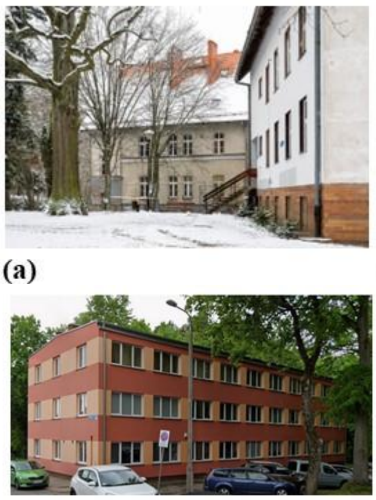
The main goal of this article is to present a methodology for integrating TLS point clouds and ULS data, along with a in depth investigation on the accuracy of the obtained outcome. Then, the integrated point cloud is used to obtain a BIM model by using ReCap Pro and Autodesk Revit software.

2. Materials and methods

2.1 Case studies, equipment and measurements

Two case studies are considered in this paper in order to test the proposed integration and BIM generation procedure, both located in the campus of the University of Warmia and Mazury in Olsztyn:

- a historic building, named Object 1 hereafter, that is undergoing renovation (Figure 1(a));
- the renovated building of the Faculty of Geoengineering (Object 2 in Figure 1(b)).



(a)

(b)

Figure 1. Case studies: Object 1 (a) and 2 (b).

The two objects shown in Figure 1 were surveyed by using three different acquisition methods and instruments: TLS, ULS and SwL. To be more specific, the following data are available in the two case studies (a) and (b):

a) TLS and ULS surveys
b) TLS, ULS and SwL.

TLS measurements were performed using a Leica ScanStation C10 laser scanner. TLS data acquisition was performed by four different scan station points for each object, hence leading to the collection of four independent point clouds. Measurements were made with resolution 1cm and the measurement set consisted of 12 430 052 points. Targets were used during the TLS survey in order to have a reliable way to properly register the TLS scans.

ULS data has been obtained by using a DJI Matrice 300 RTK UAV, provided with a GreenValley LiAir 50N laser scanner, where the latter uses a Velodyne VLP-16 LiDAR sensor and an RGB digital camera, a Sony A5100, for coloring the acquired point clouds. UAV surveys were conducted at height above the ground of approximately 70 m, with 30% overlap between strips, and a flying speed of 7 m/sec. The spatial density of the point clouds obtained with these settings was of approximately 700-800 points/m^2.

Additionally, a SwL data collection has been conducted in case study (b), by using a smartphone iPhone 12 Pro with a LiDAR sensor, exploiting a 3D Scanner App application, in order to obtain a 3D representation of the building interiors, which were practically inaccessible for the UAV, and long to survey with TLS. The total point cloud from the SwL count contained 18 045 304 points.

2.2 Methods

The acquired data were integrated according to the diagram shown in Figure 2.

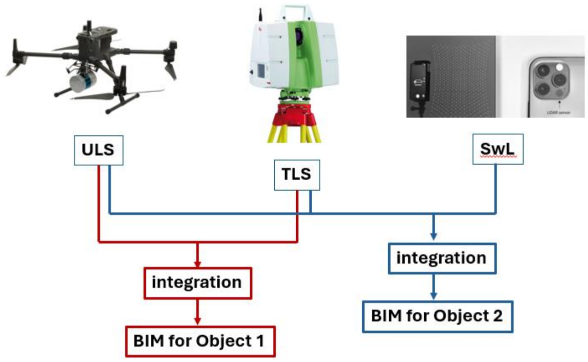


Figure 2. Point clouds integration for BIM

The process of integrating point clouds from different sources can be carried out in various ways, depending on the implemented approach and the used software. Details on the strategy implemented in this work are presented in the following.

Before starting the integration procedure, the acquired point clouds were converted in formats usable by the involved software. TLS point clouds were prepared as .ptx and .pts files. ULS data were pre-processed by the LiGeoreference (GreenValley) software and saved as .las files. SwL data sets were exported from the 3D Scanner App application as a .pts files.

In the first integration step, Cyclone software was used to properly register the scans acquired with the Leica ScanStation C10 laser scanner. In this software, TLS point clouds were registered by exploiting the targets used during the survey.

In the second stage, point clouds from all scanning devices were imported into the CloudCompare software, which is a free, open source software that enables key stages of data processing and it offers advanced registration mechanisms that allow for accurate matching of individual point clouds. This process involves both translating, rotating, and scaling the data to obtain a consistent and integrated point cloud.

The point-to-point method available in CloudCompare was used to obtain an initial registration of all the point clouds. Such rough registration is obtained by determining the registration transformation between two clouds by picking at least 4 point pairs in the scans. After such initial alignment, the scan registration can be improved by exploiting the Iterative Closest Point (ICP) algorithm. ICP is a widely used technique, initially proposed by the computer vision and robotics communities, for finely aligning two already roughly registered sets of 3D points.

ICP is an iterative alignment procedure between two clouds, where the second one is referred as the reference one, that, in its most simple version, repeats the following steps until convergence:

- Find matches between points in the two clouds (the current version of the first cloud and the reference one).
- Find the roto-translation (and scaling factor, if needed) that minimizes the distance between the matched points.
- Apply the estimated transformation to the first cloud, and update the overall estimated transformation between the original and the reference clouds.

For what concerns the first ICP step, point pairing is re-executed at every iteration, hence pairs may change in different iterations. In addition to the shortest Euclidian distance criterion, normals, colors and descriptors can be used for point pairing. Then, outliers can be rejected from the found matches in order to make the registration procedure more robust (Bai, 2023; Li et al., 2020).
The matched pairs resulting from the first step are then used in order to determine the best transformation between the two clouds, for instance minimizing the root mean square (RMS) of the distances between the matched points.
The algorithm ends either after convergence, e.g. when the two clouds are sufficiently close to each other, when the transformation is not significantly changing any more in successive iterations, or when a maximum number of iterations has been reached.

Interestingly, the metrics to be used in order to assess the registration performance can be adapted to make it more effective when there isn't a one-to-one correspondence between the points in the two clouds, e.g. using a point to locally fit surface distance. Nevertheless, the ICP result may be quite sensitive to the initial condition, hence requiring a quite reasonable initial alignment, and to the point cloud extents, i.e. the more they represent the same object areas the better the result.

It is worth to notice that ICP can also be used in LiDAR SLAM (Simultaneous Localization and Mapping) methods, in particular when the LiDAR platform speed is relatively slow with respect to the scan acquisition, i.e. when the scanner movement during the acquisition of a single scan is mostly negligible. In this case, the LiDAR pose can be updated at each iteration by combining the LiDAR pose at the previous step with the relative pose of the new scan with respect to the previous one, determined for instance by means of the ICP algorithm (Bai, 2023). In this kind of application the LiDAR dynamic previously estimated can be used as a prior in the estimation of the successive LiDAR movements.

3. Tests and results

3.1 Integration process

Figure 3 shows ULS (a) and TLS (b) point clouds of Object 1, whereas the one obtained from their integration (PC1) is shown in Figure 4.

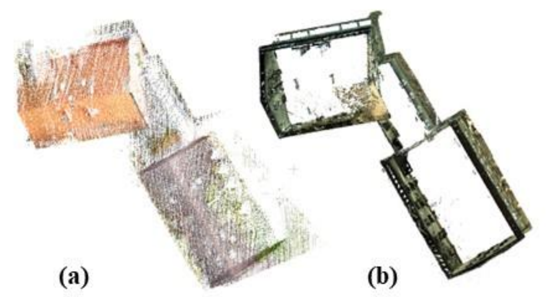


Figure 3. Point clouds representing object 1, (a) ULS point cloud and (b) TLS point cloud.

Figure 4. Integrated point cloud PC1 for Object 1.

The RMS error in point-to-point registration of PC1 was 0.02 m.

Figure 5 presents the TLS (a) and ULS (b) acquired point clouds of Object 2.

Figure 6 shows the SwL point clouds, which were used to develop BIM for the building interiors of Object 2. For this purpose, all the floors were surveyed with the smartphone LiDAR sensor.

TLS and ULS cloud registration lead to an RMS error of 0.03 m. The registration of SwL point clouds gave the following RMS errors: 0.05 m (for ground floor), 0.03 m (first floor), 0.03 m (entrance to the building) and 0.04 m (second floor).

Integrated point cloud PC2 for Object 2 is presented in Figure 7.

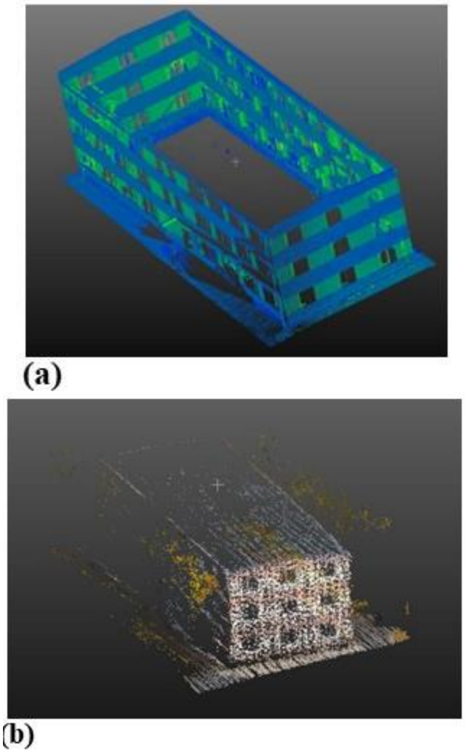


Figure 5. Point clouds representing object 2, (a) TLS and (b) ULS point clouds.

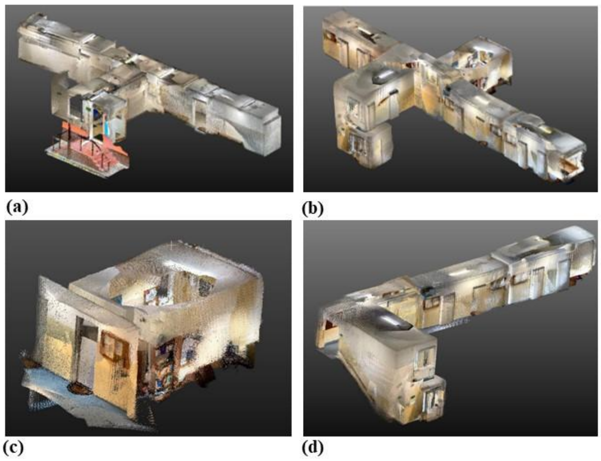


Figure 6. SwL point cloud , (a) ground and (b) first floor, (c) entrance to the building, (d) second floor.

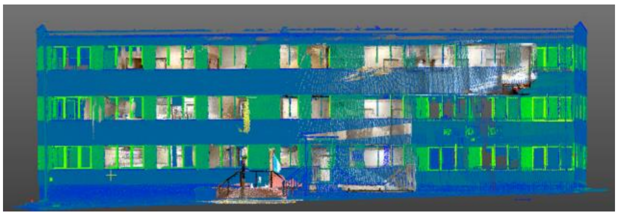


Figure 7. Integrated point cloud PC2 for Object 2

3.2 BIM creation and results

In the context of developing practices related to the creation of BIM models, the object modeling process is possible using a variety of software offered on the market, both with commercial licence and free. In order to implement the assumptions of the presented study, the Blender software was used (Pottier et al., 2023; Zając & Paszkiel, 2020). Blender is a free software, and its advanced features and the development feedbacks from a quite large user community make it a solid 3D modeling tool. The modeling process in Blender includes several key steps, as described in the following.

The first step is to import measurement data in the form of a point cloud.

Then, thanks to Blender's editing functions, the model structure is created, taking into account of the geometric details. During modeling, it is important to focus on eliminating errors and inaccuracies. Blender offers tools for point data correction, outlier removal, and customization model details.

The next step is to apply the texturing function and broadcasting appropriate properties, which contributes to obtaining a realistic appearance of the model. This process requires precision and advanced knowledge of Blender functions, but after properly going through these stages, the final result is a comprehensive BIM model, which accurately reflects the structure and details of the examined object. The choice of Blender as the tool for this process is due to its ability to handle point data, advanced modeling features, and the ability to adapt to the specific requirements of a BIM project.

Figure 8 presents BIM for object 1.

Figure 8. BIM for object 1

Figure 9 presents BIM for object 2, and Figures 10-12 are illustrated BIM inside the building.

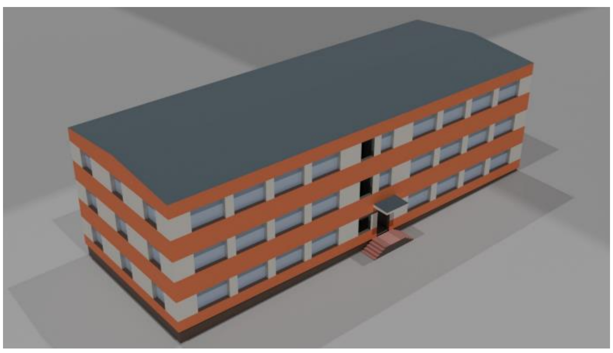


Figure 9. BIM for object 2

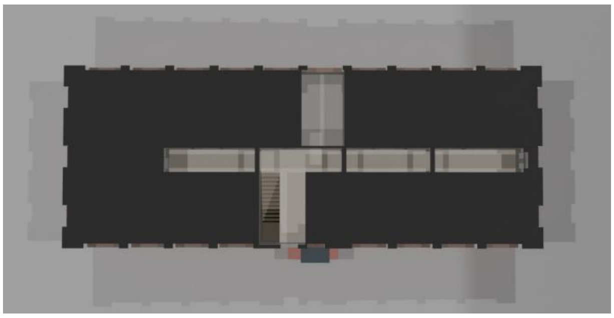


Figure 10. BIM for ground floor and entrance to the building

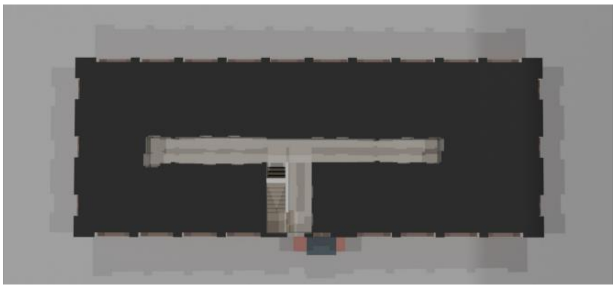


Figure 11. BIM for first floor

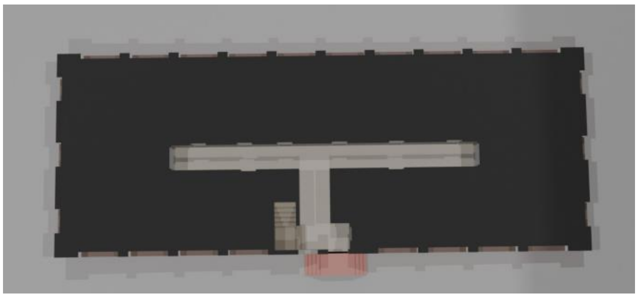


Figure 12. BIM for second floor

Creating 3D models of building interiors can be useful for several applications, among them it is worth to notice also indoor navigation (Rueppel & Stuebbe, 2008).

4. CONCLUSION

Integration of point clouds from different sources is very important in the process of preparing data for BIM. The completeness level and spatial resolution of the 3D model required for BIM generation depend on the purpose of the model, however BIM production typically requires comprehensive measurements, in order to obtain complete models also in the case of quite complicated structures.
In this study, BIM was created for two different buildings. The data used in the model generation process came from TLS and ULS measurements in the first case study, whereas SwL was also considered in the second case. The integration of the data coming from such three sources allowed in the second case study to develop a complete 3D model of the building, including both its exterior and interior parts. ULS data were used to obtain points representing building roofs because they were not sufficiently visible in the TLS point cloud.

The following conclusions and recommendations can be formulated:

1. Integration of point clouds from various sources increases the efficiency of BIM development.
2. The integrated point cloud provides complete and reliable data sets and the possibility of visibility in the point cloud of all elements of the building structure, such as walls, roof and interior.
3. Depending on the type of integrated data, it is possible to generate BIM in different LOD.
4. Due to BIM's ability to systematically capture multi-dimensional computer-aided design (CAD) information, building data can be updated and used for various purposes.

BIM prepared for facilities is used to create and manage data in the design, construction and operation processes. Integrates cross-industry data, enabling the creation of detailed digital representations managed in an open cloud platform for real-time collaboration.

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