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ACCURACY ASSESSMENT OF A SCAN TO BIM MODEL: A CASE STUDY OF THE BUILDING OF THE DEPARTMENT OF CIVIL ENGINEERING AND GEODESY

Abstract:

This paper presents the process of creating and analyzing the accuracy of the Scan to BIM model of the building of the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad based on data collected by terrestrial laser scanning. The point cloud was used to model the object in the BIM environment, while the accuracy of the model was evaluated using Cloud to Model analysis. In order to remove extreme values and noises, cloud filtering methods were applied, after which a statistical analysis of deviations was performed. The results show that most of the point cloud is within a small deviation interval, which confirms the good geometric fit of the BIM model and the point cloud.

Keywords: Scan to BIM, Terrestrial laser scanning, Point cloud, MAD filter.

АНАЛИЗА ТАЧНОСТИ SCAN TO BIM МОДЕЛА: СТУДИЈА СЛУЧАЈА ЗГРАДЕ ДЕПАРТМАНА ЗА ГРАЂЕВИНАРСТВО И ГЕОДЕЗИЈУ

Сажетак:

У овом раду приказан је поступак израде и анализе тачности Scan to BIM модела зграде Департмана за грађевинарство и геодезију, Факултета техничких наука, Универзитета у Новом Саду на основу података прикупљених терестричким ласерским скенирањем. Облак тачака коришћен је за моделовање објекта у BIM окружењу, док је тачност модела процењена применом Cloud to Model анализе. У циљу уклањања екстремних вредности и шумова примењене су методе за филтрирање облака, након чега је извршена статистичка анализа одступања. Резултати показују да се највећи део облака тачака налази унутар малог интервала одступања, што потврђује добру геометријску усклађеност BIM модела и облака тачака.

Кључне ријечи: Scan to BIM, Терестричко ласерско скенирање, Облак тачака, MAD filter.

1. INTRODUCTION

The development of modern technologies for the collection of spatial data has significantly influenced the field of construction, geodesy, architecture and infrastructure management. One of the technologies that has experienced intensive development in recent decades is the technology of terrestrial laser scanning (TLS) [1]. This technology enables quick and very precise collection of three-dimensional data about existing buildings and their surroundings [2]. The result of the laser scanning process is a point cloud that represents a set of a large number of three-dimensional coordinates and enables a detailed digital representation of the object's geometry [3].

At the same time, the development of the Building Information Modeling (BIM) methodology led to significant changes in the way of designing, managing information and maintaining buildings during their life cycle [4], [5], [6]. BIM represents a digital object model that integrates geometric information with additional attributes, parameters and data necessary to manage the object's life cycle [7]. This approach enables the improvement of the process of planning, designing, construction and maintenance of buildings, as well as more efficient management of information during the entire life cycle of the building. In this context, the integration of data obtained by terrestrial laser scanning methods with BIM models represents an important direction of development in the field of digitization of existing buildings [8].

With the development of technologies for mass data collection, such as laser scanning and digital photogrammetry, a process known as Scan to BIM was developed [9], [10], which involves the transformation of the cloud of points obtained by scanning into a BIM model using appropriate software tools [11]. This process usually includes several basic stages, including data collection, registration, georeferencing and point cloud processing, creating a three-dimensional model in a BIM environment, etc. The Scan to BIM approach enables effective digitization of existing buildings and is increasingly used in various areas, such as management, reconstruction and maintenance of buildings, as well as documenting the existing state of buildings [8], [12].

However, the process of transforming a point cloud into a BIM model is not fully automated and largely depends on the interpretation of the modeler, as well as the limitations of the software tools used for modeling [13]. Therefore, it is important to assess the extent to which the BIM model faithfully reproduces the geometry of the real object. During modeling, certain deviations may occur between model surfaces and point clouds, which may be due to geometry simplifications, noise in the data, or limitations of parametric models [14]. Because of all this, the assessment of the accuracy of the model is an important step in the verification of the quality of the Scan to BIM process [15].

One of the most commonly used approaches to assess the accuracy of BIM models is Cloud to Model (C2M) distance analysis [11]. This method makes it possible to determine the deviation between the point cloud and the nearest surfaces of the model. The obtained values of deviations enable the implementation of statistical analysis, which can be used to evaluate the quality of modeling and the conformity of the model with the real geometry of the object. In addition to the quantitative assessment of accuracy, C2M analysis also enables the visual interpretation of deviations through thematic displays, which makes it easier to identify zones where there are greater differences between the model and the recorded state [16], [17]. In this way, it is possible to take a closer look at the geometric consistency of the model and identify potential sources of errors that occurred during the modeling process.

Research in the field of Scan to BIM processes indicates significant progress in automation and modeling accuracy, but there are still challenges regarding the geometric fidelity of the model. Most studies confirm that model accuracy varies significantly depending on the complexity of the object, the quality of the point cloud, and the level of modeling detail. In papers such as [15], [18], deviation values in the range of approximately 5 to 15 mm were reported for objects with relatively regular geometry, while for more complex facades and objects with a greater number of details, deviations can reach 20 mm or more [19], [20]. Also, numerous authors point out that parametric BIM models introduce certain approximations that affect the final accuracy, especially with elements of more complex geometry [21], [22]. In this context, the analysis of model accuracy represents a key step in the evaluation of the reliability of the Scan to BIM approach and enables comparison of the obtained results with reference values from the literature.

The aim of this paper is to analyze the accuracy of the Scan to BIM model of the building of the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad. For the purposes of the research, a terrestrial laser scan of the exterior of the object was performed, after which a BIM model was created based on the resulting point cloud and an assessment of the accuracy of the model was made using Cloud to Model analysis. The resulting deviations were then subjected to statistical processing and filtering in order to primarily remove noise in the data. The results of the research enable the assessment of the quality of Scan to BIM modeling and provide insight into the degree of agreement between the real geometry of the object and the created BIM model.

2. CASE STUDY

2.1. BUILDING OF THE DEPARTMENT OF CIVIL ENGINEERING AND GEODESY

The building of the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences is located on the campus of the University of Novi Sad (Figure 1). The facility is located within a complex of university buildings that make up one of the largest academic centers in the region. The arrangement of buildings within the campus provides relatively open space around the analyzed building, which is suitable for performing terrestrial laser scanning and ensuring good visibility of facade surfaces from multiple scanning positions. At the same time, the presence of surrounding buildings, and above all vegetation and urban elements, is an additional factor that affects the planning of the location of the stations from which the scanning will be performed.

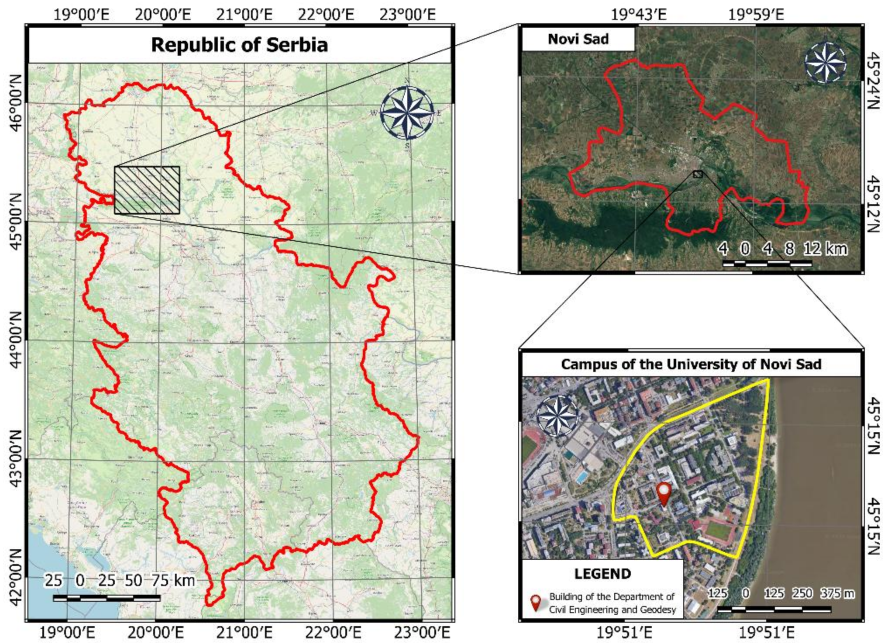


Figure 1. Location of the building of the Department of Civil Engineering and Geodesy within the University of Novi Sad campus

The building itself has a multi-story structure and is a typical example of a modern educational and research building intended for teaching and scientific research. From an architectural point of view, the building is characterized by a relatively regular geometry of facades with clearly defined openings. The facade of the building is characterized by a combination of aluminum facade elements and large glass surfaces (Figure 2), which represent a special challenge for terrestrial laser scanning due to the specific optical properties of the material. The transparency and reflectivity of the glass can cause the laser beam to pass through the surface or be reflected at different angles, which often results in the loss of points or the appearance of noise and false reflections in the point cloud. These phenomena can affect the quality of the collected data and represent one of the significant factors that affect the accuracy of the later geometric interpretation and modeling of the object. Such characteristics of the facade additionally affect the complexity of point cloud processing and represent a suitable example for analyzing the accuracy of modeling within the Scan to BIM process.

Figure 2. Building of the Department of Civil Engineering and Geodesy

2.2. DATA COLLECTION

2.2.1. BUILDING SURVEY

Data collection for the purposes of this research, ie. scanning of the exterior of the object of interest was carried out on July 21, 2020, in the time period from 08:00 to 14:00, with a terrestrial laser scanner Leica ScanStation P20. Scanning of the facades of the building was carried out with four stations (S1, S2, S3 and S4), which ensured adequate coverage of the analyzed building (Figure 3). As a result of the scanning process, a point cloud containing a total of 316 921 061 points was obtained.

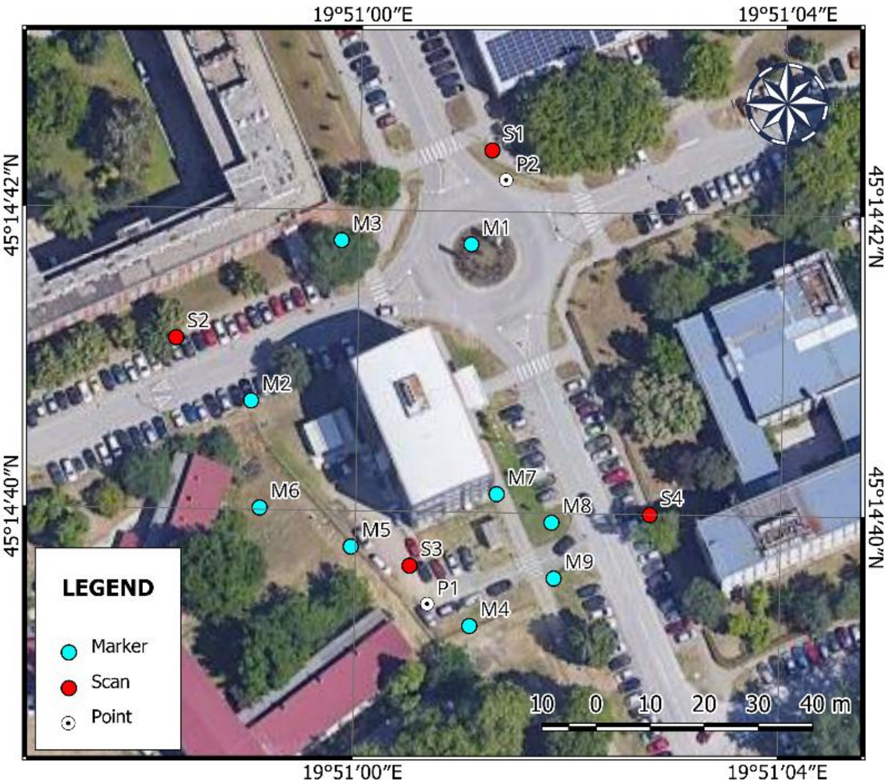


Figure 3. Locations of scanner and targets

During the recording, the scanner was set to the standard operating mode, where the basic parameters of the instrument's position (Northing, Easting and Height) were defined. The recording was realized in a full horizontal range of 360°, with a resolution of 3.1 mm at a distance of 10 m and scanning quality 2, with simultaneous photo recording (Scan & Image mode). The quality parameter determines the number of measurements performed for each point, on the basis of which the mean value of the measurements is calculated [23]. For quality 1, one measurement is performed per point, while for quality 2, 3 and 4, several measurements are performed, the results of which are averaged. A higher quality level allows for a reduction in noise in the data and an increase in the accuracy of the results, but at the same time increases the time required to perform the scan. Estimated recording time of one scan at the selected resolution and quality was approximately 6 minutes and 37 seconds. For the purposes of point cloud registration, reflective targets (M1 - M9) were used, which, due to the need for georeferencing, were also recorded with a robotic total station Leica TCRP 1201+. The position of the target was determined in relation to two geodetic points (P1 and P2) placed on the ground based on the points of the existing polygon network.

2.2.2. DATA PROCESSING

Point cloud registration is the process of integrating individual scans into a unique coordinate system. This process is based on the establishment of a system of constraints consisting of pairs of corresponding points identified on the overlapping parts of two or more scans [24]. Based on these constraints, optimal transformations are determined that align the individual scans so that the overlap between them is minimized. As part of this research, registration with georeferencing was performed (Figure 4), whereby reflective targets recorded by classical geodetic methods were used as control points for transforming the point cloud into a coordinate reference system.

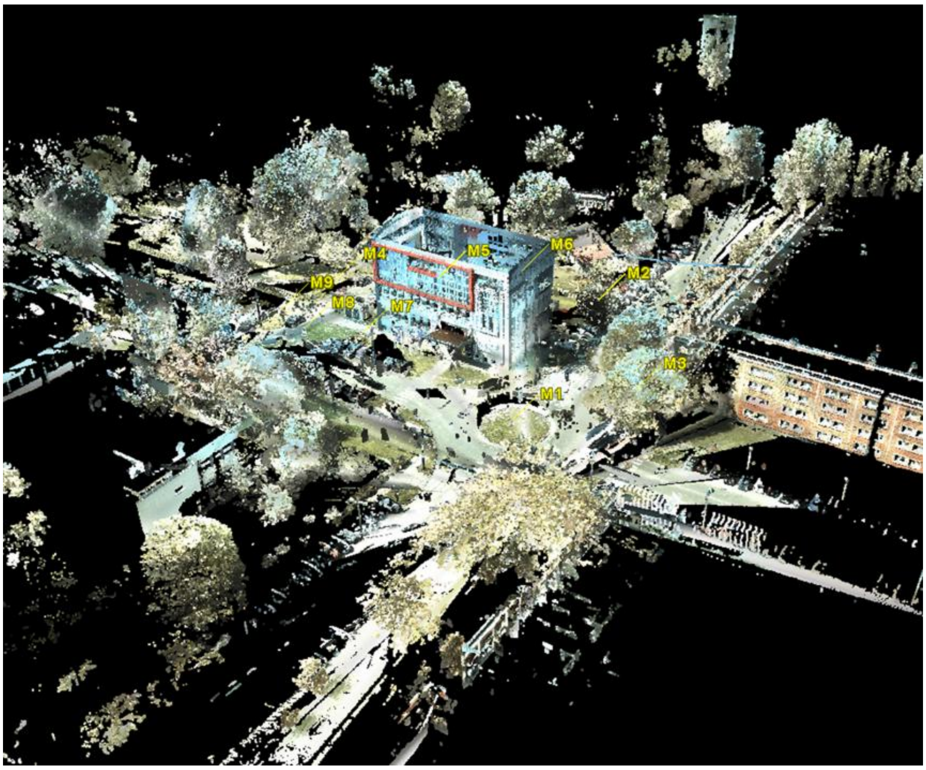


Figure 4. Point cloud after registration and georeferencing

3. BIM MODELING

After processing the point cloud, the construction of the model of the object was started. A registered and georeferenced point cloud representing a detailed geometric representation of the exterior of the analyzed object was used as input data for modeling. The point cloud was used as a reference source of information on the basis of which the geometric characteristics of the object's elements were defined. The modeling process was performed in the Autodesk Revit software environment, using the Scan to BIM methodology. Within this process, the elements are modeled based on the geometry identified in the point cloud, whereby the basic constructive and architectural elements of the object are defined. Modeling included facade walls, openings, as well as other characteristic elements that define the external appearance of the building.

During the modeling process, special attention was paid to matching the geometry of the model with the available data from the point cloud. Modeling was done using parametric BIM elements, i.e. families available in Autodesk Revit software. However, due to the parametric nature of these elements and their geometric limitations, it is not always possible to fully reproduce all the irregularities and details identified in the point cloud [25]. Therefore, certain deviations between the model and the point cloud may arise as a consequence of the approximation of the geometry, the simplification of complex shapes or the limitation of the parameter families [26].

Modeling was performed by interpreting the geometry of the point cloud in characteristic cross-sectional planes, which enabled a more precise definition of the basic structural elements of the object. Modeling of facade walls was performed using parametric wall families. The geometry of the walls was determined based on the intersection of the point cloud and the visual interpretation of the facade planes. In this way, the position, height and dimensions of the wall elements are defined.

Also, based on the cross section of the point cloud, the position and basic geometry of the opening was defined, after which the corresponding parametric window family was inserted into the model. This approach enables relatively fast modeling of facade elements while preserving the basic dimensions and positions identified in the point cloud. However, due to the parametric nature of BIM elements and family limitations, the geometry of the modeled element may not completely match the actual geometry registered in the point cloud. In the specific case, the window family used in the model has a thinner frame compared to the actual window on the object. As a consequence, there is a local deviation between the model and the cloud of points (Figure 5). In the analyzed example, a deviation of approximately 40 mm was observed, which is the result of the difference between the geometry of the actual window frame and the geometry of the parametric family used in the BIM model. Such cases represent a typical example of limitations of Scan to BIM modeling, where simplified or standardized geometry of BIM elements can lead to deviations from the actual state of the object.

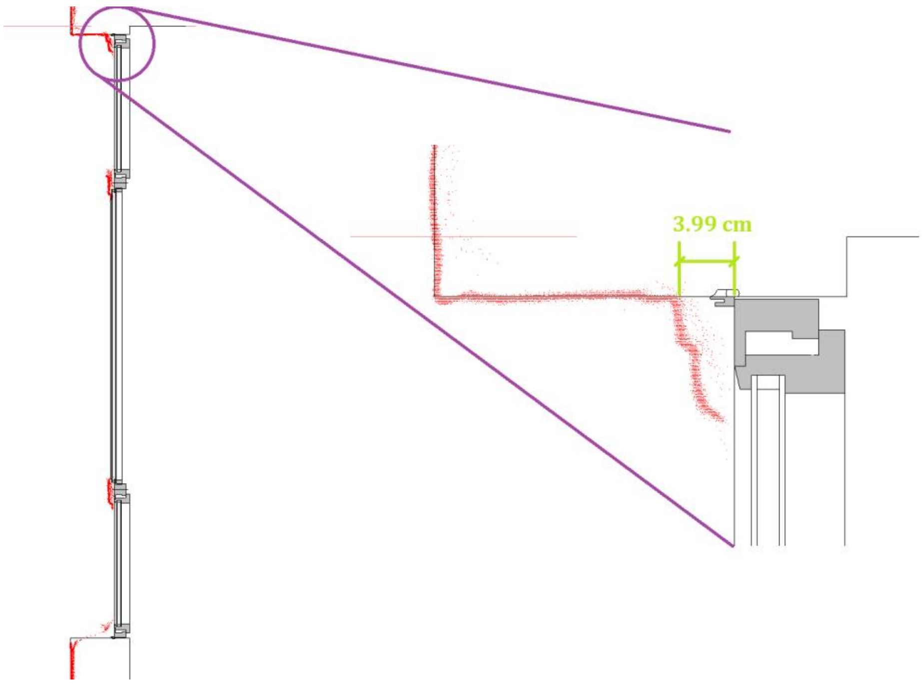


Figure 5. Window modeling and deviation from the point cloud

One of the problems that occurs during terrestrial laser scanning is the occurrence of occlusions, i.e. the obscuring of parts of the object by other elements in space. In the specific case, the presence of vegetation in the immediate vicinity of the building led to the fact that certain parts of the facade were not fully registered in the cloud of points. As a consequence, in those zones there is a reduced density of points or a complete lack of data as can be seen in Figure 6. Such a lack of data in the point cloud represents an additional challenge during Scan to BIM modeling, because in such situations the modeler has to reconstruct the geometry of the object based on limited information or based on assumptions about the geometry. Such situations can lead to local deviations between the BIM model and the actual geometry of the object, which is important to consider when analyzing the accuracy of the modeling later.

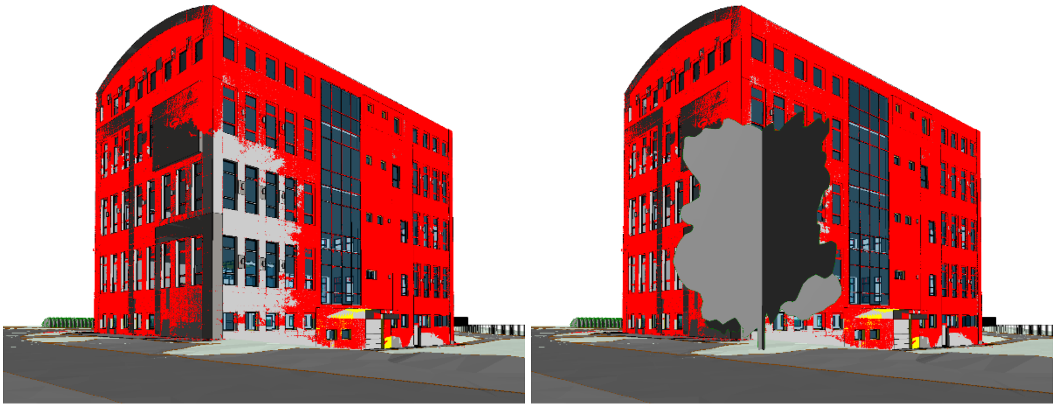


Figure 6. The effect of occlusion of the object of interest caused by another object

Given that the terrestrial laser scanning was performed in a full horizontal range of 360°, the point cloud includes not only the object of interest but also elements of its immediate environment, such as terrain, vegetation, traffic areas, fences, etc. In order to provide a more complete spatial context of the model and enable a better visualization of the object, part of the environment was also modeled. These elements were added to the BIM model using appropriate parametric families. During their modeling, the dimensions and position of the elements were modeled to be as close as possible to the actual situation on the ground at the time of the recording (Figure 7). However, these elements were not the subject of the modeling accuracy analysis. Within this research, the accuracy analysis was carried out exclusively on the elements of the analyzed object, that is, by comparing the geometry of the BIM model of the building with the corresponding parts of the cloud of points.

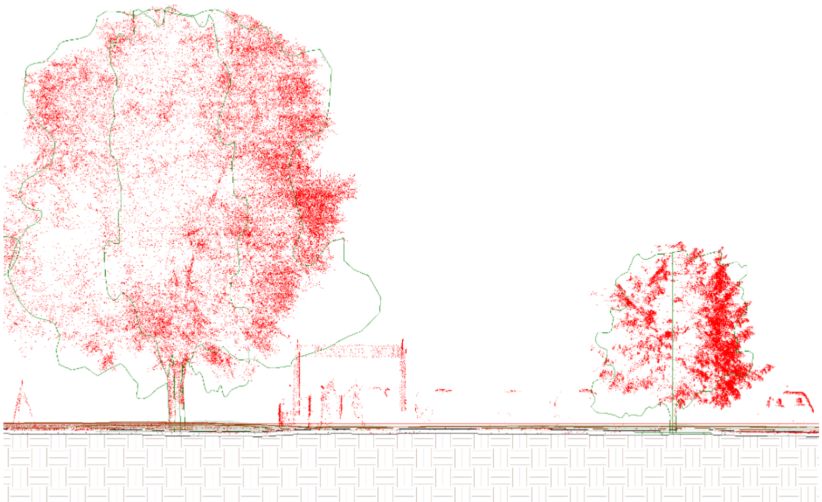


Figure 7. Modeling of the terrain and vegetation

After the completion of the modeling process, the final BIM model of the object was formed, which retained the georeferencing established during the registration of the point cloud. In order to verify the accuracy of the positioning of the model in space, it was overlapped with the available data of the land parcels. The results of this comparison show that the model is correctly positioned in relation to the boundaries of the plot and other spatial references, which confirms the correctness of the georeferencing procedure. Figure 8 shows the final model of the object overlaid with data on plots. It can be seen that the model is in the appropriate location and that its geometry matches the spatial position of the object in real space.

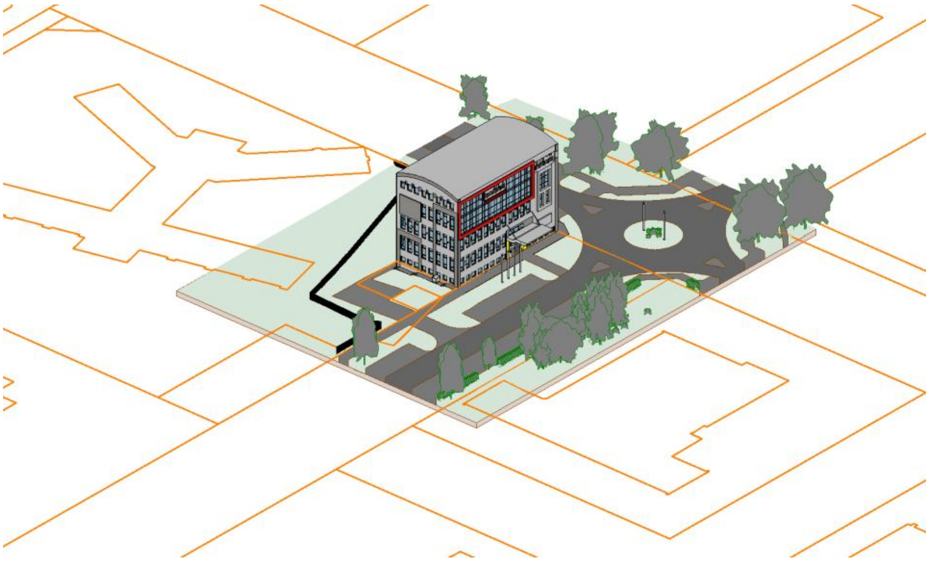


Figure 8. Overlap of the model and available plot data

One of the key advantages of BIM models compared to classic 3D models is the possibility of associating different attribute information to individual model elements [27], [28]. Each element in the BIM environment, in addition to geometry, also contains a set of parameters that describe its characteristics, such as dimensions, material, position in the object and other relevant information [21]. Figure 9 shows an example of part of the attribute data related to one wall element, which illustrates the informational component of the BIM model and the possibility of managing data about the object's elements.

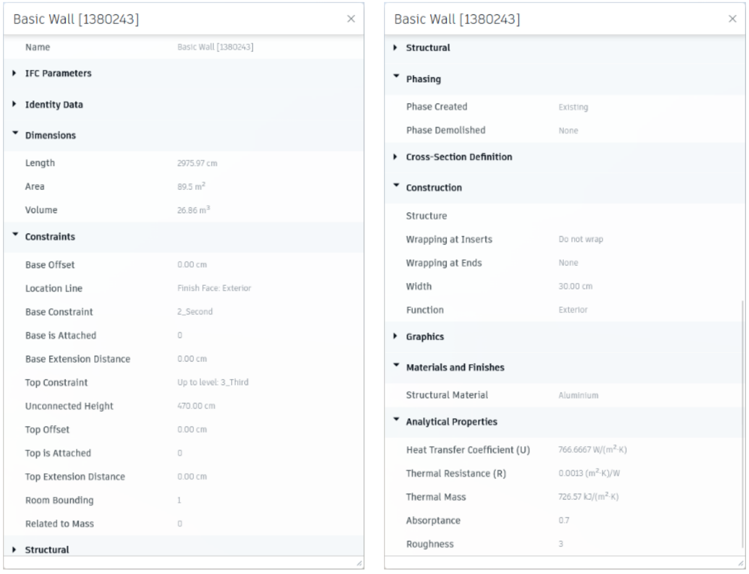
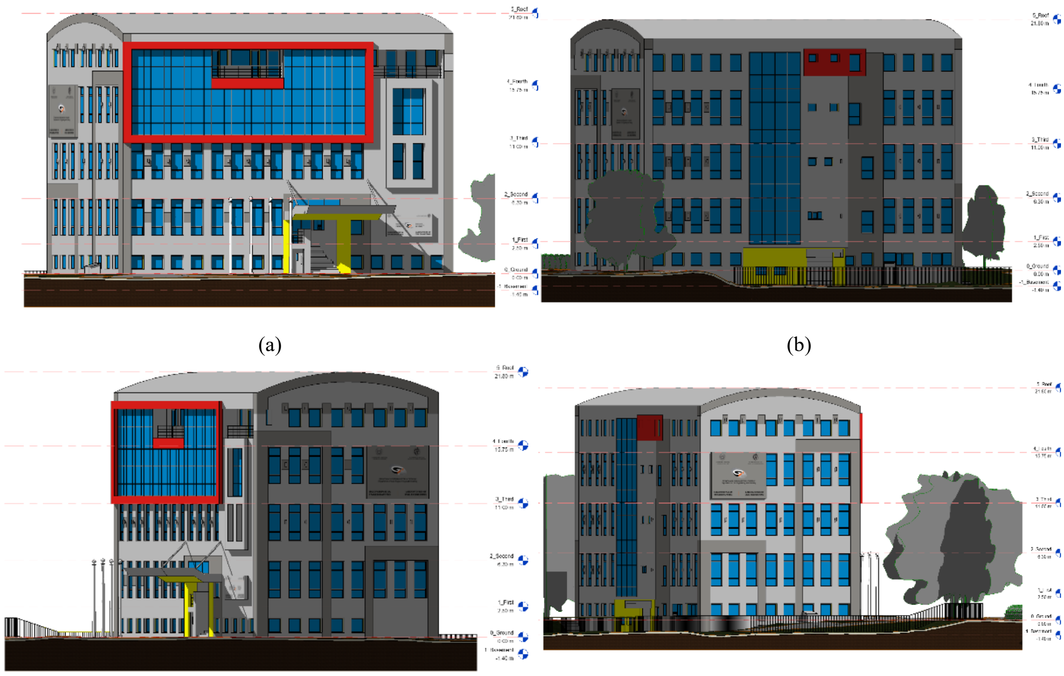


Figure 9. Attributes within the model

For a clearer view of the geometry of the building and the relationship between individual structural elements, elevations of the facades were created. The characteristic levels of the building are defined in the view, which enable precise determination of the height relationships between floors and individual architectural elements. Figure 10 shows four elevations of the object, which represent views from all four sides of the world. This kind of display enables a more detailed analysis of the object's geometry and the mutual relationship of the elements on the different sides of the building. The inclusion of shadows in the display additionally contributes to a better visual interpretation of the shape of the facade and the spatial arrangement of elements, which facilitates the analysis of the geometry of the modeled object.



(a) (b) (c) (d)

Figure 10. East (a), West (b), North (c) and South(d) view of the object

After the completion of the modeling process, realistic renderings of the object were created (Figure 11), which enable a visual presentation of the final BIM model. Appropriate materials and textures have been applied in the renders in order to faithfully depict the appearance of the facade. This type of display allows easier viewing of modeling results and provides a clearer idea of the final appearance of the model in relation to the real object.

Figure 11. Realistic renders of the object and its surroundings

4. RESULTS

4.1. CLOUD TO MODEL DISTANCE ANALYSIS

In order to assess the accuracy of the created BIM model, an analysis of deviations between the geometry of the model and the registered cloud of points was carried out. For this purpose, the Cloud to Model method implemented in the CloudCompare software was used, which enables the determination of the signed distances between the cloud points and the nearest model surfaces, whereby the distances, in addition to the size, also contain a (+/-) sign, which makes it possible to distinguish between positive and negative deviations and provides a quantitative assessment of the model's geometric compliance with the real state of the object. This method makes it possible to determine the distance between cloud points and the nearest surfaces of the model, thus obtaining a quantitative assessment of the geometric deviation between the model and the actual state of the object. The analysis was carried out exclusively on the elements of the analyzed object, while the elements of the environment that were modeled for the sake of visual context, as already mentioned, were not included in the accuracy assessment. In this way, it is ensured that the results of the analysis directly reflect the accuracy of the modeling of the object itself.

In order to gain insight into the distribution of deviations between the cloud of points and the BIM model, a histogram of C2M distances was created (Figure 12). The histogram shows the frequency of occurrence of deviations between cloud points and the nearest model surfaces. A total of 12 974 857 points were used in the analysis, with deviations ranging from −0.2853 m to 0.5066 m recorded. The mean value of the deviation is 0.0026 m, while the standard deviation is 0.0117 m, which indicates that most of the deviations are in a relatively narrow range. The histogram shows a concentration of the largest number of points near zero deviation, indicating a good fit between the geometry of the BIM model and the point cloud.

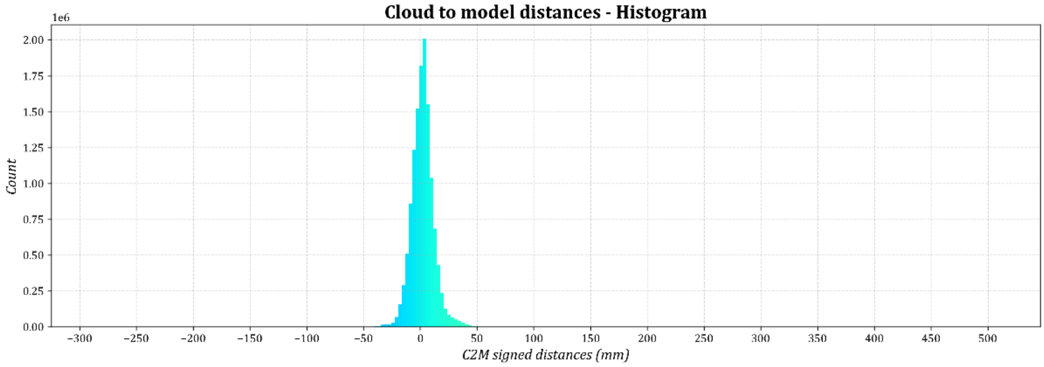


Figure 12. Histogram of C2M distances

A more detailed analysis of the points with the largest deviations revealed that these values do not represent errors created during the modeling process, but are mainly the result of noise in the data, reflections or specific situations during the recording of the object. The largest recorded deviation is approximately 50 cm, and occurs in the area of the window opening (Figure 13). In the specific case, during the laser scanning the window was open, while in the BIM model it was modeled in a closed position, which led to a significant deviation between the cloud points and the model surface. Such deviations cannot be considered a modeling error, but are a consequence of the difference between the current state of the object at the time of recording and the way the element is represented in the BIM model. This example illustrates that extreme deviation values in C2M analysis do not necessarily indicate model deficiencies, but may be the result of various factors affecting the quality and interpretation of point clouds.

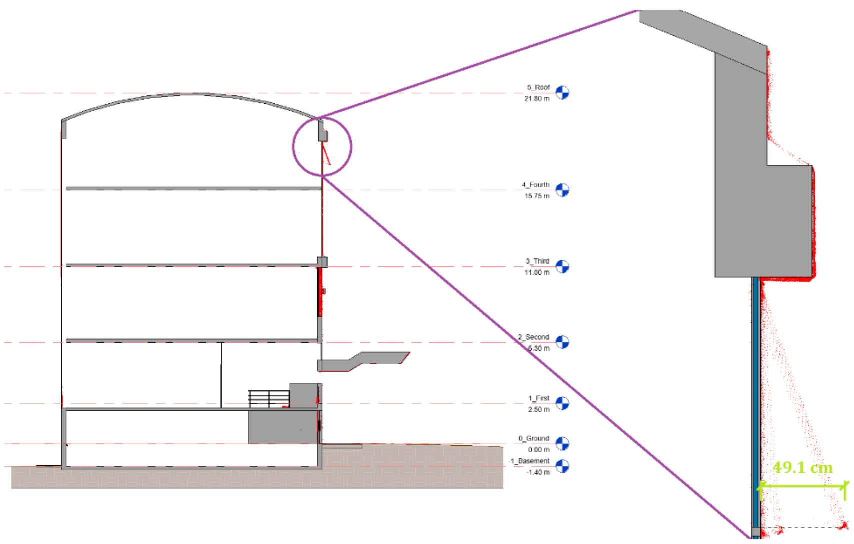


Figure 13. Deviation of the model caused by the opened window

In addition to the previously mentioned example, cases were also identified in which deviations are a consequence of the limitations of parametric BIM elements. One such example is shown in Figure 14, where a discrepancy between the geometry of the modeled elevator door and the point cloud can be noticed. Cross-sectional analysis revealed that the elevator doors in the model are positioned approximately 9 cm further than their actual position registered in the point cloud. This deviation is not due to an error in the interpretation of the cloud of points, but to the limitations of the door family used, whose parametric structure does not allow completely identical modeling of the real geometry of the element. Such situations represent a typical challenge in the Scan to BIM process, where standardized BIM families can lead to local deviations between the model and the real geometry of the object.

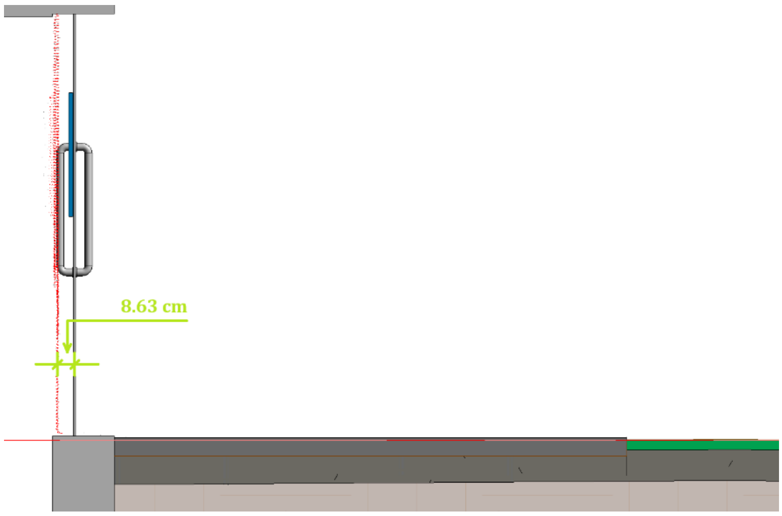


Figure 14. The error of modeling the elevator door

4.2. MEDIAN ABSOLUTE DEVIATION (MAD) FILTERING

In order to ensure a more reliable analysis of modeling accuracy, extreme deviation values were filtered using the Median Absolute Deviation (MAD) method. This method represents a robust statistical technique for identifying and removing extreme values (outliers) from a data set [29]. Unlike the standard deviation, which can be significantly affected by extreme values, the MAD is based on the median and absolute deviations of individual values from the median, thus providing a more stable estimate of the data distribution [30].

The MAD filtering procedure begins by determining the median of the set of deviations between the point cloud and the model. After that, the median of the absolute deviations of all values (x_i) from the obtained median is calculated [31].

$$MAD = \text{median}(|x_i - \text{median}(x_i)|) \quad (1)$$

Based on this value, a robust estimate of the standard deviation is determined that is not affected by extreme values, denoted as σ_r, which is used to define the limits of acceptable deviations [31].

$$\sigma_r = 1.4826 \cdot MAD \quad (2)$$

The factor 1.4826 is used to scale the MAD to the level of the standard deviation for a normal distribution [32], thus obtaining a robust estimate of the dispersion σ_r that allows the application of the $\pm 3\sigma$ criterion to identify extreme values, but without the sensitivity to outliers characteristic for the classical standard deviation. Points whose deviations exceed a predefined threshold (most often $\pm 3\sigma_r$) are considered extreme values and are removed from further analyses to provide a more reliable assessment of modeling accuracy [31].

$$\text{median}(x_i) - 3\sigma_r \leq x_i \leq \text{median}(x_i) + 3\sigma_r \quad (3)$$

Within this study, the median deviation is 2.291 mm, while the MAD value is 5.711 mm, which gives a robust estimate of the standard deviation σ_r of 8.467 mm. Based on this criterion, the range of acceptable deviations from −23.110 mm to 27.692 mm, ie $\pm 3\sigma_r$ around the median, is defined. The application of the MAD filter was performed on the initial set of 12 974 857 points from the point cloud, whereby after filtering, 12 652 561 points were retained, while 322 296 points were removed from further analyses. This represents approximately 2.48% of the total number of points, which indicates a relatively small share of extreme values in the analyzed data set.

Figure 15 shows a histogram of the C2M deviation distribution after applying MAD filtering. It can be seen that the largest number of points is concentrated near zero deviation, which indicates a good match between the geometry of the BIM model and the point cloud. After removing extreme values, the distribution of deviations takes on a more compact form and clearly shows that most of the deviations are located within a relatively narrow interval around the mean value.

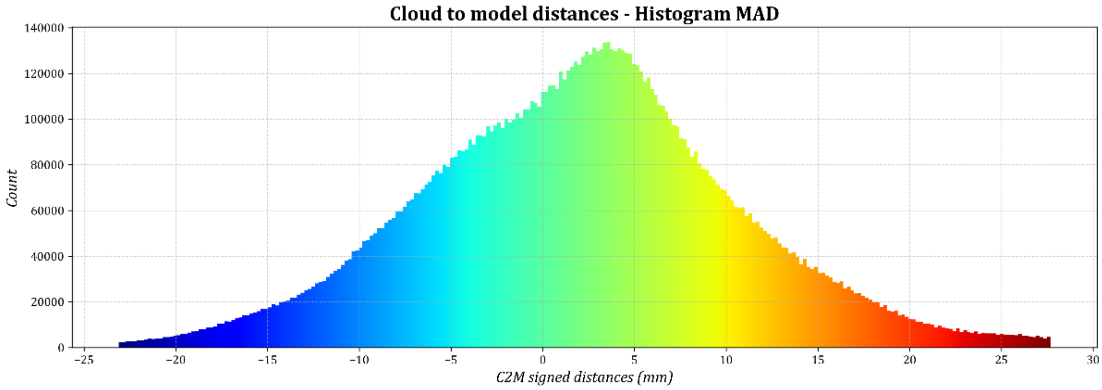


Figure 15. Histogram of C2M distances after MAD filtering

Table 1 shows the basic statistical parameters of the deviation between the point cloud and the model, calculated for the initial data set and for the data set after applying MAD filtering. Observing the results for the initial set of points, one can observe the presence of extremely large values, where the maximum deviation reaches 506.58 mm, which significantly affects statistical parameters such as standard deviation and Root Mean Square Error (RMSE). After applying the MAD filter, extreme values were removed, which significantly reduced the range of deviations, where the maximum deviation in the filtered set is 27.7 mm, while the minimum deviation is −23.1 mm.

Table 1. Statistical parameters of C2M deviations

	All points	**Filtered points**
Min	-2.85 mm	-2.31 mm
Max	506.58 mm	2.77 mm
Mean	2.56 mm	1.99 mm
Median	2.29 mm	2.16 mm
Standard deviation	11.69 mm	8.57 mm
RMSE	11.97 mm	8.79 mm

A particularly important indicator of accuracy is RMSE, which represents the square root of the mean of the squared differences and gives a measure of the typical deviation between the model and the cloud of points, with the method of its calculation emphasizing larger deviations compared to smaller ones. Therefore, this parameter is particularly sensitive to the presence of extreme values in the data set. In the initial data set, the RMSE is 11.97 mm, which is a direct consequence of the presence of large deviations in the data distribution. After removing the extreme values by applying MAD filtering, the RMSE value is reduced to 8.79 mm, which represents a significant reduction in the total estimated model error. This reduction clearly demonstrates the impact of extreme values on squared statistical measures, as well as the importance of applying robust filtering methods in modeling accuracy analysis.

Figure 16 shows the spatial representation of the deviation between the cloud of points and the BIM model obtained by applying Cloud to Model analysis. Deviations are represented by a color scale, with blue shades indicating negative deviations, green values close to zero deviation, while yellow and red shades represent positive deviations of greater intensity. Such a visual display of deviations enables quick identification of the parts of the model where the largest deviations occur. Most of the object's surfaces are shown in green tones, which indicates that the largest number of points are located in the immediate vicinity of the modeled surfaces and confirms the good agreement between the BIM model and the point cloud, which is in accordance with the results of the statistical analysis presented in the previous chapters. Local deviations can be observed on certain elements such as the edges of the facade, window openings and parts of the structure where there are changes in geometry or where the modeling was performed using parametric BIM families that do not fully reproduce the real geometry of the object. Also, larger deviations may be due to the lack of points in certain parts of the cloud due to occlusions or reflections during laser scanning.

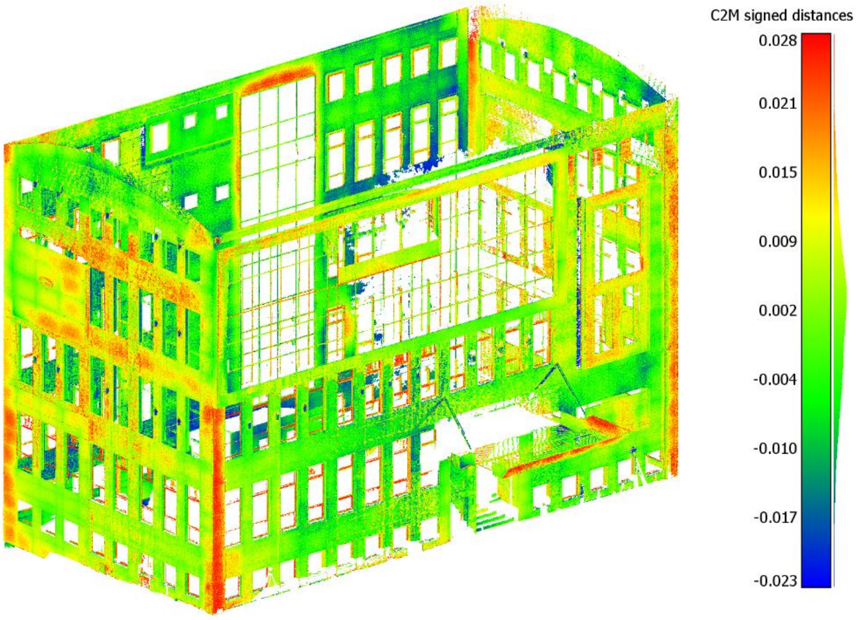


Figure 16. Point cloud styled by the value of parameter describing the distance between points and the model

Additional confirmation of the quality of the modeling is provided by the analysis of the percentage distribution of deviations. The results show that 17.22% of the points are within the ±2 mm interval, while 43.02% of the points are within ±5 mm. 73.46% of all points are in the ±10 mm interval, while 88.43% of the points deviate by less than ±15 mm. If a wider interval is observed, as many as 94.93% of the points are within ±20 mm, while 97.11% of the points have a deviation of less than ±25 mm. Finally, 98.23% of the points are within ±30 mm, while only 229 971 points from the initial set are outside this interval.

Figure 17 shows the Cumulative Distribution Function (CDF) of the absolute deviations between the point cloud and the BIM model. This function displays the percentage of points whose deviation is less than or equal to a certain error value, thus providing a clearer view of the distribution of deviations in the entire data set. The steep rise of the curve in the initial part of the graph indicates that a large number of points are located in a relatively small error interval. Based on the graph shown, it can be seen that most of the points have deviations smaller than approximately 10 mm, while almost the entire set of points is within an interval of about 30 mm. This shape of the curve indicates that most of the deviations are concentrated in small error values, while larger deviations occur only at a smaller number of points. The CDF analysis thus confirms the results obtained by the statistical analysis and additionally indicates the good geometric conformity of the BIM model with the cloud of points.

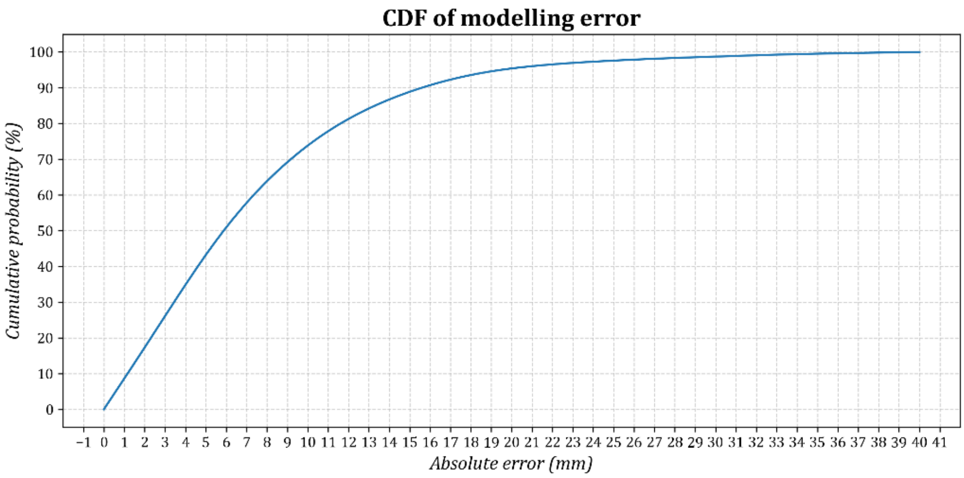


Figure 17. Cumulative Distribution Function

5. CONCLUSION

This paper presents the process of creating a Scan to BIM model of the building of the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, based on data collected by terrestrial laser scanning. After collecting and processing the point cloud, the object was modeled in the BIM environment, while the accuracy of the model was assessed using Cloud to Model (C2M) analysis. The resulting deviations were analyzed using statistical methods, including robust data filtering using the Median Absolute Deviation (MAD) filter.

The results of the statistical analysis show that most of the cloud points have relatively small deviations compared to the modeled surfaces. The dominance of values near zero deviation, as well as the distribution of deviations shown by histogram and CDF analysis, indicate a high degree of agreement between the BIM model and the real geometry of the object. The obtained values of RMSE and standard deviation after filtering additionally confirm that most of the deviations are in a relatively narrow interval, which indicates good geometric accuracy of the created model.

The obtained RMSE value of approximately 8.79 mm indicates a high level of geometric accuracy of the model, bearing in mind that it is a modeling of an existing object based on terrestrial laser scanning. In the context of the Scan to BIM process, this level of accuracy is considered satisfactory for the needs of existing condition documentation, facility management, etc. However, for applications that require a higher level of precision, such as prefabrication or deformation analysis, further improvement of models and data processing methods may be necessary.

Visual analysis of the distribution of deviations additionally enables the identification of specific parts of the model where larger deviations occur. In Figure 17, it can be seen that in the zone around the window, more pronounced positive deviation values appear, represented by red shades. These deviations arise as a consequence of the limitations of parametric BIM families, which do not always allow a completely faithful reproduction of the real geometry of the elements. On the other hand, negative deviations represented by blue shades can be observed in the part of the facade that was covered by vegetation during the recording, which is a consequence of the lack of points in the cloud due to the occlusion caused by the presence of a tree.

It is important to note that during this research the roof of the building was not covered by scanning, because terrestrial laser scanning does not allow adequate data collection of surfaces that are not visible from ground level. For a complete geometric reconstruction of the object, it is necessary to integrate the data collected by other recording methods, primarily by using unmanned aerial vehicles (UAVs) equipped with photogrammetric [33] or LiDAR sensors [34]. The integration of data collected from the air and data from a terrestrial laser scanner would allow obtaining a complete point cloud of the object, including the roof surfaces.

The obtained results confirm that the Scan to BIM approach enables the creation of geometrically reliable BIM models of existing buildings based on data collected by laser scanning. Although certain local deviations of the model from the cloud may appear, most often due to limitations of BIM families or lack of data in the point cloud, the results of statistical and visual analysis confirm that the created model is a faithful geometric representation of the real object. Therefore, based on everything stated, it can be concluded that the geometry of the modeled object within the Scan to BIM process was modeled with a high degree of accuracy and that the created BIM model faithfully reproduces the actual state of the object registered by laser scanning.

This research is limited to the analysis of the exterior of the object, while the interior spaces are not covered by scanning and modeling. The accuracy of interior modeling can vary significantly due to the greater complexity of the geometry, the presence of equipment and the limited space for positioning the scanner. Future research should also include interior spaces in order to obtain a comprehensive assessment of the accuracy of the Scan to BIM process at the level of the entire facility. Also, further research in this area can be directed towards the improvement of parameter families in order to better correspond to the real geometry of objects, as well as the integration of data collected by different recording methods. A special direction of research is the application of artificial intelligence and machine learning methods in order to automate the process of recognizing and modeling architectural elements within the Scan to BIM process.

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