Turning a point cloud into a Building Information Model (BIM): Defining and validating the accuracy requirements for existing buildings

Katja ŽAGAR, Slovenian National Building and Civil Engineering Institute, Slovenia
Laurens OOSTWEGEL, Slovenian National Building and Civil Engineering Institute, Slovenia
dr. Katja MALOVRH REBEC, Slovenian National Building and Civil Engineering Institute, Slovenia

Keywords: *digitalization of existing buildings — point cloud — Building Information Model (BIM) — accuracy.*

CHNT Reference: Žagar, K., Oostwegel, L. and Malovrh Rebec, K. (2021). 'Turning a point cloud into a Building Information Model (BIM): Defining and validating the accuracy requirements for existing buildings', in CHNT – ICOMOS Editorial board. *Proceedings of the 26th International Conference on Cultural Heritage and New Technologies.* Vienna

The digitalization of existing buildings, including those protected as cultural heritage, is one of the main future goals to streamline the planning and funding of buildings' revitalization as well as to convert them into healthy and resilient living and working environments. Furthermore, one of the usual renovation goals is to make them more energy efficient. Considering all the building phases, the management-and-operation phase represents 60% of all the costs. In order to make this phase more efficient, we need accurate as-built information, which could be a part of the Building information modeling (BIM) communication process. A digital representation of the building's creation usually starts with capturing the spatial data (point cloud), which is then used to prepare a semantically enriched model with a specific geometrical accuracy (BIM). Most of the existing buildings do not have a BIM and creating one can be a complex, multiple-step process. Different tools and standards concerning different aspects of the BIM for existing buildings are available; however, determining the requirements for turning point clouds into models of different accuracies remain undefined. Thus, the aim of our research was to develop a methodology for the definition and validation of the geometric accuracy of the model compared to the captured point cloud. The methodology relies on previous studies and is presented with a case study.

In order to determine the methodology, it is important to understand the complete process of implementing the BIM for existing buildings, as each of the steps in the process affects the end result. Based on existing literature (e.g., Biagini et al., 2020) the schema containing the five main steps, being planning, reality capture, data processing, modeling and inclusion of the model into the common data environment, was outlined. For each of those steps, the decisions needed to be made at the beginning, the process and the quality-control methods were identified.

In the planning phase, the potential use of the BIM as well as the requirements enabling it need to be determined. Reality capture consists of an appropriate surveying method and the gathering of additional information related to the building, ensuring the requirements from the first phase are met. Laser scanning and photogrammetry are two techniques currently being used to capture point clouds. Since point clouds are unstructured and the point cloud's processing also requires large computing power, they are usually preprocessed and manipulated (cropped, aligned, scaled, triangulated into meshes, turned into planes etc). That leads to a modeling phase where some of the unnecessary geometrical details are lost. Depending on the purpose of the project, different levels of accuracy need to be maintained for different building elements. The modeling phase of the project can require lots of effort and knowledge. Achieving the required result demands a skillful modeler, able to correctly interpret the different parts of the cloud and convert them into the correct BIM objects, containing the right semantics and geometrical accuracy.

In our study the proposed methodology was tested and applied to the point cloud of an existing building located in Germany. The building "Halle 6" was built 50 years ago and was used as an industrial plant. It is a part of a larger complex of buildings. The point cloud of the building was prepared by terrestrial laser scanner. To ensure the quality of the point cloud, reference and control points were determined, measured by the terrestrial geodetic method with a relative accuracy of 3 mm, which is used in the process of registration of 3D LIDAR images.

One of the building facades, containing different building elements, was chosen as the focus of the research. Based on the chosen facade, the accuracy requirements were determined. The USIBD Level of Accuracy (LOA) specification guide (2019) was used as the basis. This guideline defines five LOAs with specific tolerance ranges (LOA50: 0 mm to 1 mm, LOA40: 1 mm to 5 mm, LOA30: 5 mm to 15 mm, LOA20: 15 mm to 5 cm and LOA10: 5 cm to 15 cm) and suggests different LOAs for specific building elements with different Uniformat levels (e.g., shell, exterior vertical enclosures, exterior walls). On the other hand, the applied standard states that the required accuracy for the elements of the building should be individually determined, based on the specific purpose of the project. The same claim can also be found in other documents (e.g., Common BIM Requirements Finland – Series 2: Modeling of the starting situation). For that reason, experts were consulted for setting the requirements for the BIM model of a façade that was planned to be renovated. A checklist containing a list of all the facade elements with the accuracy requirements, as well as the information about the planned intervention, was created in order to help the modeler with the modeling process. The importance of understanding relative and absolute accuracy – the latter one representing the accuracy of true element dimension instead of the accuracy of the location of the object in a coordinate system – was recognized and was also considered in the planning phase.

Based on the point cloud and the checklist of requirements, a BIM model of the facade was made in Revit. Since the model was based on the point cloud, the coordinate reference system of the model and the point cloud was the same and there are no errors from geo-referencing. First, the model was assembled out of basic elements from the Revit library, then some of the elements were replaced by uniquely modeled entities to match the existing structures as closely as possible. Since the façade consisted of some of the repeating elements (shelves, columns), those were manually modeled with greater detail, using family templates in Revit. In our case, the repeating elements were all modeled as the same BIM object, which might not be a correct approach in every case. Depending on the importance or the function of each of those elements, it is necessary to determine whether those elements should be modeled individually or not in order to meet the required threshold of geometrical accuracy. Another challenge was determining the correct size of the windows and doors, as their edges were clearly covered with different layers of plaster. The same challenge later arises in the evaluation phase.

The accuracy quality assessment of our demo-case BIM model was made based on another checklist, containing the requirement categories. Although the semantics represent an important part of the BIM model, in our case, only the geometrical accuracy was evaluated. The focus of the study was on determining the accuracy of the BIM model through a comparison of two data sets (the model and the point cloud). The point cloud was considered to represent the ground-truth dimensions. Although the measuring instrument can have an important impact on the end result, the intrinsic error of the point cloud was not taken into account in the represented study case.

The accuracy-evaluation method that was used relies on the analysis of absolute accuracy (true location of a point in a coordinate system). The methodology described by Boundel et al. (2017) was used in order to detect the non-modeled elements, large deviations and modeling errors (easily recognized deviations, e.g., elements placed at wrong locations) as well as the classification of the points into the USIBD LOA range categories. The point cloud, made out of the visible surfaces from the Revit model, was compared to the original (source) point cloud in an open-source software tool called Cloud Compare. Points with large deviations and parts of the cloud with occluded zones were excluded from the deviation analysis. The results were represented in the form of a color map on the model point cloud. The points were then classified into USIBD LOA ranges and the percentage of points falling into a certain LOA category was determined. A color map of the accuracy results from Cloud Compare, representing the different LOA ranges, can be found in Figure 1. The deviation analysis was also made with another software tool, working as a Revit plugin. The second tool was used in order to compare the results and the process needed to obtain them.

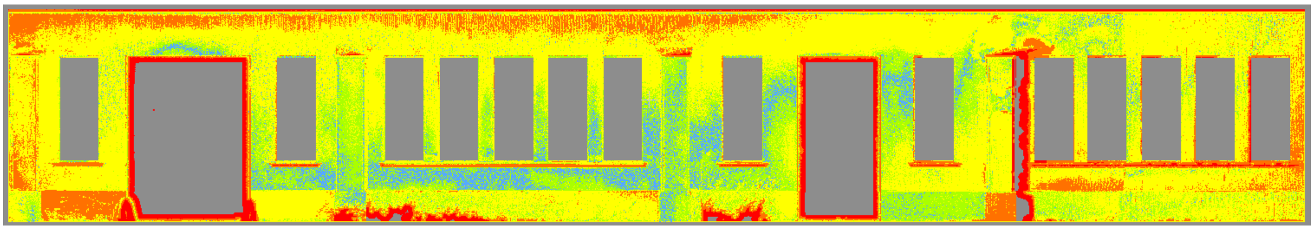

Fig. 1. Color map of the façade, representing different LOA ranges (red - LOA 10, orange - LOA20, yellow - LOA30, green - LOA40, blue - LOA50)

Besides the absolute accuracy analysis, the important dimensions of some of the façade elements (e.g., height and width of the window) were also evaluated based on the comparison of the dimensions from the point cloud and the ones of the modeled elements. The dimensions of the point cloud elements were determined by using the Random sampling consensus (RANSAC) algorithm to create planes, fitting the point cloud and measuring the dimensions of the edges created at plane intersections. The method was previously described by Tan et. al. (2020). Since, the façade consisted out of different repeating element, the ones, represented with the fewest missing points and the best RANSAC results, were chosen for the analysis. The completeness of the point cloud was recognized as an important aspect of the process.

By identifying the challenges arising in the modeling phase and with the help of already-existing literature the methods and guidelines for the process of turning a point cloud into a BIM were developed. The accuracy requirements and their evaluation were defined in a consistent way that can be used by subsequent researchers and other BIM users. The results were presented for the case of a façade that needs to be renovated, but can also be used for other implementations, such as building a digital twin to be used as a virtual museum or creating data storage for historical objects of high value.

Funding

The contribution is financially supported by the Slovenian Research Agency, project number 0726/20J. Research team thanks Ingenieurbüro Metrika360 for point cloud.

Conflict of Interests Disclosure

There is no conflict of interest.

Author Contributions

Conceptualization: Katja Malovrh Rebec, Katja Žagar
Data curation: Katja Žagar
Formal Analysis: Katja Žagar, Katja Malovrh Rebec
Funding acquisition: Katja Malovrh Rebec
Investigation: Katja Žagar
Methodology: Katja Žagar, Katja Malovrh Rebec, Laurens Oostwegel
Project Administration: Katja Malovrh Rebec
Resources: /
Software: Autodesk Revit, Autodesk ReCap, CloudCompare, Undet, Autodesk Point Layout
Supervision: Katja Malovrh Rebec
Validation: Katja Žagar, Laurens Oostwegel
Visualization: Katja Žagar
Writing – original draft: Katja Žagar
Writing – review & editing: Katja Žagar

References

Biagini, C., Ottobri, P., Banti, N. and Bongini, A. (2020). 'Validation processes of H-BIM models: a case study', *IOP Conference Series: Materials Science and Engineering*, 949. DOI: 10.1088/1757-899X/949/1/012115

Bonduel, M., Bassier, M., Vergauwen, M., Pauwels, P. and Klein, R. (2017). 'Scan-to-BIM output validation: Towards a standardized geometric quality assessment of building information models based on point clouds'. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W8, pp. 45–52. DOI: 10.5194/isprs-archives-XLII-2-W8-45-2017

Tan, Y., Li, S. and Wang, Q. (2020) 'Automated geometric quality inspection of prefabricated housing units using BIM and LiDAR', *Remote Sensing*, 12(15). DOI: 10.3390/rs12152492

The Building Information Foundation RTS (2012). *Common BIM Requirements Finland – Series 2: Modeling of the starting situation.* Available at: *https://buildingsmart.fi/wp-content/uploads/2016/11/cobim_2_inventory_bim_v1.pdf*. (Accessed: 20 August 2021).

U.S. Institute of Building Documentation (2019). *USIBD Level of Accuracy (LOA) Specification Guide*. Available at: https://usibd.org/product/level-of-accuracy-loa-specification-version-3-0/. (Accessed: 20 August 2021).