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Approach for an Update Method for Digital Factory Models

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Abstract

The requirements of factory planning and the building concerned have changed in the last years. Factory planning has the task of designing products, plants, processes and the building of a factory. Although the building has an indirect influence on manufacturing systems, a quick conversion of the building is crucial in the event of changes in production technology. A current digital building model of the factory enables to carry out conversion processes quickly. The approach develops a method to update a digital building model of a factory during operation. Photogrammetry is used to update point clouds and derive BIM models.

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1. Introduction

Factory planning describes the systematic process for planning factories in structured and successive phases. This process includes the design of products, plants, processes and the building of a factory. Tools and methods are applied in factory planning to support the complex planning process. The planning of the factory building can be derived from the production task. The demands placed on factory planning and the building in question have changed in recent years. Restructuring is becoming increasingly important [1–3]. As a reaction to the dynamic and unpredictable changing corporate environments and the associated need for regular adaptation, factories have been planned for several years to be more adaptable [4]. But conversion in factories is a complex and resource-intensive process. Digital building models can be employed to support conversion measures in factories. There are different levels of digital building models regarding the information they contain. In general, a distinction can be made between point clouds and building information models (BIM) [5]. In factories point clouds are used during planning, construction and operation phase [6]. Point clouds are particularly common in applications for monitoring construction progress [7], [8] and as a data basis for conversions [9]. In a BIM model, all relevant building data are digitally modelled, combined and collected. In order to have a sufficient database for conversions within a factory, digital building models such as point clouds and BIM models must be kept up-to-date. Only an up-to-date database can be used for reconstruction [10].

2. Related work and its shortcomings

The related work can be categorized in approaches for updating laser scans of (a) outdoor areas, (b) indoor areas as well as updating (c) BIM models.

Approaches to update laser scans and the resulting point clouds first appeared in cartography. Inglot et al. use low-level aerial photogrammetry and terrestrial laser scanning to densify and filling point clouds [11]. The focus here was on gathering

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spatial information about the terrain. Areas not or poorly detected by airborne laser scanning (ALS) were subsequently added by terrestrial laser scanning and photogrammetry. The approach and referenced literature [12] shows that the integration of laser scan data and photogrammetry data is possible. However, the experiments are only done in the outdoor area and a continuous updating of the point cloud is not discussed. Aijazi et al. also apply their approach to urban cartography and use incremental scanning to update hidden areas and to detect and analyze changes [13]. The developed algorithm inserts objects, which are repeated in the scans, into the 3D cartography or deletes them, if the objects occur only sporadically. The approach is based on repetitive scans, created by mobile terrestrial data acquisition techniques. Therefore, the approach is not suitable for cost-effective selective updates within a building. Photogrammetric integrations are not considered. In the work of Beutel et al. reference is also made to the repetition of LiDAR (light detection and ranging) scans to record topographic changes and thus to update the database [14]. The focus is on developing an efficient and scalable algorithm using a graphics processing unit (GPU) to perform natural neighbor interpolation over a 3D volumetric grid. The approach thus deals with large-scale updates and changes in the landscape. Small-scale changes and the integration of photogrammetric data are not considered. Caroti et al. are presenting an UAV-Borne (unmanned aerial vehicles) photogrammetric low cost 3D surveying methodology for cartographic update [15]. The focus is specifically placed on a cost-effective update of cartographic maps. The need for up-to-date data is recognized and highlighted. Surveying with different technologies such as terrestrial laser scanning and photogrammetry are also considered. The application, however, refers to the exterior and not to surveys inside the building for small scale updates.

The approach of Gao et al. refers to the updating of BIM models from the planning phase using point clouds [16]. The aim is to close the gap between as-designed BIM and as-built BIM. As with some of the previously mentioned approaches, repeated scans are used during the construction phase to document the progress of the construction. However, the approach does not consider the operational phase of a building or factory. Also, only laser scanners are used to document construction progress. The approach of Braun et al. also aims at progress monitoring of construction work on site [7]. The actual state of the construction site here is detected by photogrammetric surveys. The focus is on as-built and as-planned comparison. The approach is limited to the planning and construction phase of a building. The operating phase and the updating of the digital building model during this phase is not considered. Shellshear et al. provides a first approach to incrementally update point clouds of a factory [9]. The necessity of having an up-to-date digital building twin for conversions in order to avoid delays in the planning process is identified and confirmed. In the approach, the incremental new recording by laser scanners is applied. Although the sectional updating of building areas is also addressed, the approach is not cost effective, as a laser scanner must be available for each new recording. In addition, laser scans must be carried out from many different positions in order to record all areas of the factory in appropriate quality. This is a time-consuming process. The approach is limited to laser scanning, which causes difficulties with very small and partial recordings. Other recording technologies are not considered. A number of studies also exist which only relate to the detection of changes but not to the resulting updating of the databases [17], [18].

Because of the above-mentioned shortcomings of current developments and literature, the core focus of this paper deals with the updating of factory building models. In order to record small changes that occur, for example, during maintenance work, a photogrammetric recording is selected. This procedure ensures that the digital building twin is kept up-to-date even during operation in case of minor changes to the factory building. It thus provides a basis for conversion planning at any time. A clearly defined method to update the geometry of point clouds and BIM models will overcome the shortcomings of current approaches.

3. Approach for an update method

In this chapter a novel updating approach is presented, which aims at closing the gap to selectively update digital building models of production facilities in form of point clouds and BIM models. In order to update the digital building model, it is assumed that an initial 'basic model' is first recorded resp. modelled. It is intended to keep this basic model up-to-date during operation. To introduce the following update method, the steps change detection, update process point cloud and update process BIM model are discussed.

3.1. Change detection

For the detection of external changes on buildings, the literature mainly mentions methods using large-area data acquisition measures such as airborne laser scanning (ALS) [19]. Change detection in the outdoor area is also based on comparison of multi-temporal lidar data [20], [21]. Widely used approaches for indoor change detection in buildings are also those based on cloud-to-cloud comparison of LiDAR data [22].

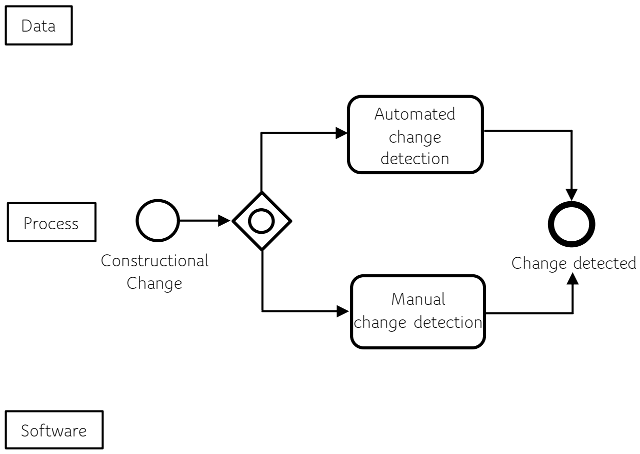

Fig. 1. Variants of change detection

In order not to be dependent on time-consuming and costly multi-temporal lidar data for change detection in this method, either advanced low-cost fully (a) automated change detection methods or (b) manual change detection is to be used (cf. figure 1). As the first step in the method, a structural change to the factory building must be identified. In order to realize advanced and cost-effective possibilities of automated change detection within buildings, the method relies on change detection by image recognition. Different frameworks can be used for object detection managing to automatically detect changes of the built environment. Examples are TensorFlow Object Detection API, Google Cloud Vision API, clarifai and IBM Watson Visual Recognition. This list is not exhaustive. The automated change detection notifies that a structural change has been made. The digital building model can then be updated at the position where the change was detected. This system requires video surveillance of all areas of the object, e.g. by webcams. Drones equipped with cameras are also conceivable. The manual change detection can be achieved by regular inspections of the building. During these tours, planning documents are compared with reality by the inspector. Structural changes are then marked in the planning documents or the digital building model.

3.2. Update process point cloud

To record the as-is state of a building, point clouds produced by laser scanners are common practice [23]. The initial recording of the building by creating the point cloud is referred to in the following as the 'basic model'. The goal is to partially update this once created basic model in case of small changes. In the case of extensive building changes, a new recording with the help of a laser scanner is recommended. This new recording will not be considered in the following. In the present method small-scale changes of the built environment are focused. These small-scale building modifications occur significantly more frequently. Due to unsuitable procedures, building operators were faced with problems when updating point clouds. Planning data in the form of point clouds was therefore outdated very quickly.

The update process of the point cloud starts with 'Planning of the photography scheme' (see figure 2). It is planned how the changed object to be captured can be photographed from different perspectives. This is necessary to gain photos usable for the later photogrammetry process [24]. In general, SLR cameras or smartphone cameras can be used for the recording process. Until now, mainly SLR cameras have been used for photogrammetry. But due to the rapid development of smartphone cameras, smartphones can also be used for photogrammetry. In the later evaluation different devices will be used for the recording process and their results will be compared. Regardless of the recording device, the resulting photos are then used in photogrammetric post-processing. Most of the software runs these steps: Align images, calculate model and texturing [25] and so does the developed process (cf. figure 2). After the partial photogrammetry model is created it is registered with the point cloud (see figure 2). The basic model is downloaded from the data repository, usually as an .E57 file format developed by ASTM International for storing point clouds. Control points are used to insert the photogrammetry model in the correct orientation and scaling into the point cloud of the laser scanner. The updated point cloud is thus stored again in the data repository as a new basic model. The partial update of the point cloud is now complete.

3.3. Update process BIM model

The point cloud can then be used to assist in updating the BIM model [26]. This is still a manual process. Although there are first approaches to automatically generate BIM models from point clouds to make time-consuming manual modeling obsolete, these have not yet reached a stage where they can be used in practice without loss of quality and without extensive rework [26], [27]. Figure 3 shows the BIM update process using the point cloud from the data repository.

Beginning with the change detection via the update of the point cloud of a building up to the update of the BIM model, the entire process chain for updating the digital building model was presented (see figure 1-3). An evaluation of the method follows.

4. Results from the implementation of the update method

To apply the method described above, first the basic model is created. This is done by creating a point cloud and a BIM model of the test environment. The test environment is a technical room. The point cloud is created with a FARO

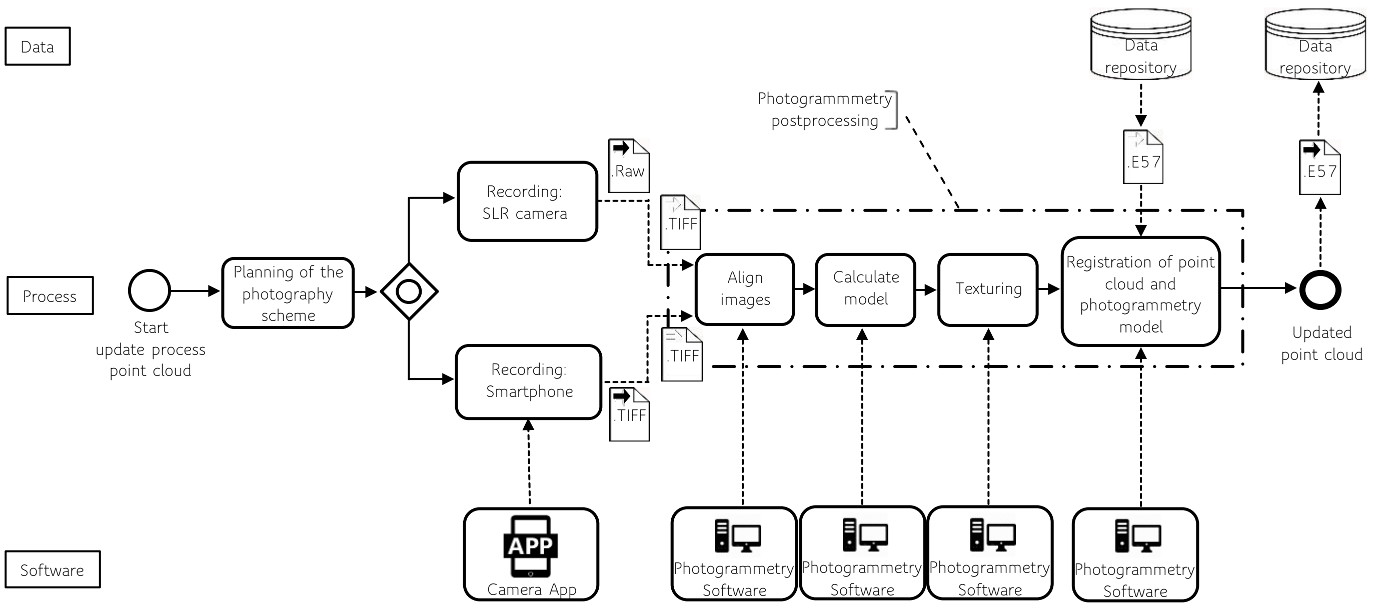

Fig. 2. Update process point cloud

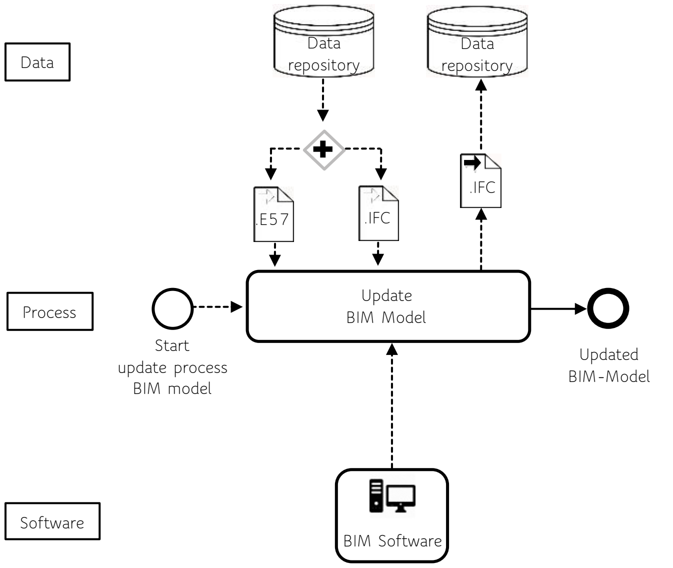

Fig. 3. Update process for BIM Model

FOCUS S 350 laser scanner. The BIM model is created with the Autodesk Revit software. The two digital models represent the basic model on which the change detection, the update of the point cloud by photogrammetry and the update of the BIM model with the updated point cloud are evaluated. A change is made in the plant room by installing a filter on a supply air duct. All process steps of the method are run through for evaluation. The focus, however, is on the creation of the photogrammetry model and integration into the point cloud of the laser scanner. For this purpose, different camera devices are used for the recording and their results are compared in time and quality after the photogrammetry postprocessing. The photogrammetry postprocessing of the commercial software RealityCapture and the open source application Meshroom are compared.

4.1. Change detection

For the change detection an automated change detection was applied. For this the TensorFlow Object Detection API version r1.12 is used. A GoPro HERO8 camera is selected to monitor the room. The recording of the camera is the basis for change detection. On the left of Figure 4, the original condition of the room and the technical equipment can be seen. On the right the installation of the filter is shown. The filter is detected by the object detector with a probability of 100% and is labeled as a changed object. In this case the video surveillance of a room was easy to realize. In the case of larger and winding rooms or entire buildings, video surveillance is much more complex. We will not discuss change detection any further at this point.

4.2. Update process point cloud

To update the initial laser scan point cloud of the plant room, a photogrammetric model of the filter must first be created. In preliminary tests it could be determined that in poorly illuminated areas a significant improvement of photogrammetry results could be achieved by additional illumination spots. Since the technical room used for the experiment was very poorly lit, construction spotlights were

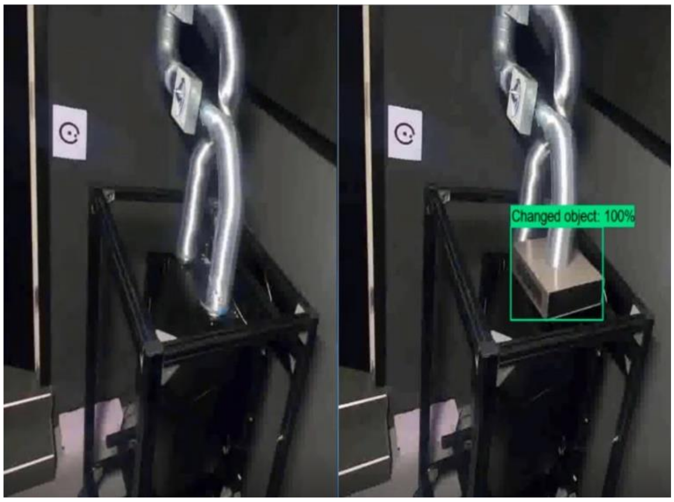

Fig. 4. Change detection

used in the case study. No additional lighting is required in normally lit rooms. In order to record the subsequently installed filter (see Figure 4) with cameras, arc-shaped images were taken at different heights around the technical plant. As in table 1 presented, three devices are used for recording. A Nikon D810 SLR camera with a SIGMA Art 24mm F1.4 DG HSM lens and two smartphones: iPhone XS and iPhone 6. The Nikon D810 has 36.3 megapixels, the iPhone XS 12 megapixels and the iPhone 6 8 megapixels. For the recording of the structural change 08:30 minutes were recorded three times (D1-D3) with each device. This results in a different number of photos depending on the shooting speed and subsequent loading time (cf. Table 1). The 08:30 minutes for recording with all devices was chosen in order to establish comparability and to achieve a fast recording process on site. Thus, after the calculation of the photogrammetry model, conclusions can be drawn which device provides the best results and whether adequate results can already be achieved with smartphones.

Table 1. Data sets of recording with camera settings.

Device and Data set	ISO	F Stop	Shutterspeed	Number of photos
Nikon D810 D1	800	5,6	1/125 sec	224
Nikon D810 D2	800	5,6	1/125 sec	237
Nikon D810 D3	800	5,6	1/125 sec	209
iPhone 6 D1	250	2,2	1/125 sec	297
iPhone 6 D2	250	2,2	1/125 sec	339
iPhone 6 D3	250	2,2	1/125 sec	330
iPhone XS D1	250	1,8	1/125 sec	369
iPhone XS D2	250	1,8	1/125 sec	353
iPhone XS D3	250	1,8	1/125 sec	344

This is particularly relevant as technical service personnel often have smartphones available on site. These could be used for the recording of the conversion. The iPhone 6 was deliberately used for the recording in order to test whether older smartphone versions provide usable results by photogrammetry applications. We carry out all postprocessing experiments on a computer with an Intel Core i7-6700 CPU with 4 cores @ 3.40 GHz, 32 GB RAM, a NVIDIA GeForce GTX980 Ti and

Windows 10 as operating system. The data sets are calculated with the software RealityCapture BETA 1.0 and the open source photogrammetry software Meshroom 2019 2.0. The goal is to identify the differences in quality and to compare the calculation times of the different data sets. The steps align images, calculate model and texturing were performed successively using RealityCapture and Meshroom. With RealityCapture it is possible to add photos, which were not recognized during first alignment manually using control points. The number of recognized images and thus the quality of the calculated model can be improved. However, there have also been cases where the data set has been damaged and considerable errors occurred. This happened in 2 of the 9 data sets by setting control points. In the following only the results without control points are described to be able compare them with Meshroom.

The fastest calculated data sets in RealityCapture were those of the iPhone 6 (see Figure 5). The average size of an iPhone 6 image is 10.03 Mb. The images were created on both smartphones with the App 645 PRO Mk III and the settings shown in table 1. The calculation of the iPhone XS images took considerably longer (see Figure 5). Here, the average image size of 19.32 Mb was almost twice as high as that of the iPhone 6. The calculation of the photos of the Nikon D810 3D geometry took the longest. The data set D810 D2 had a calculation time of 02:00:25 h (see Figure 5). The result of all data sets was the 3D model of the technical system with

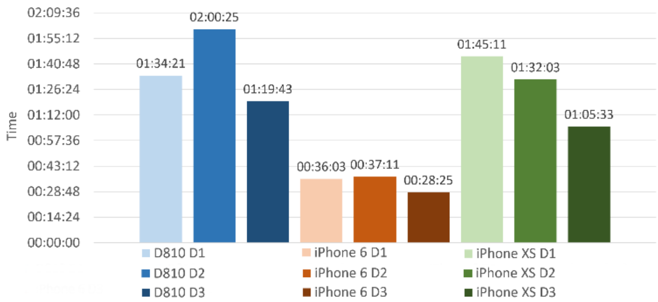

Fig. 5. Total processing time RealityCapture first alignment data set

subsequently installed filter. To compare the quality of the results of the different data sets, a rendering of each data set was created. It is noticeable that the results of the D810 perform best overall. There are hardly any misalignments. Only one data set was damaged using control points. On the other hand, with the iPhone 6 data sets, misalignments can be observed throughout. A further use of the calculated 3D models is not recommended. The results of the iPhone XS are reusable in 2 of 3 data sets. One dataset (iPhone XS D2) has too large misalignments. A comparison of the results of RealityCapture can be seen in Figure 6. On the left side the calculated 3D model of the data set iPhone 6 D2 is shown. The misalignments are clearly visible. On the right side of Figure 6 the data set Nikon D810 D2 is shown. The dataset was calculated in detail and shows hardly any misalignments. The calculated 3D model of the data set Nikon D810 D2 is best for integrating it into the original laser scan.

In Meshroom, the overall calculation times (in total: Align images, calculate model and texturing) are significantly higher. The calculation time for the images of data set D810 D2 was longest with 10:19:23 h. Also, for the iPhone 6 D1 dataset the calculation time in Meshroom is with 02:54:22 h more than four times as long as in RealityCapture. Misalignments also

Fig. 6. Comparison of an iPhone 6 (left) and a Nikon D810 (right) model

occur more frequently in the quality of all data sets. Surprisingly, the alignment rate in Meshroom is better. Especially in the iPhone 6 data sets, the alignment rate is on average twice as high.

Fig. 7. Integration result of Photogrammetry model (Nikon D810 D2) and point cloud of laserscanner

To integrate the photogrammetry model into the point cloud of the laser scan, control points are used in RealityCapture. This enabled the photogrammetry model to be placed at the correct position in the point cloud of the laser scanner and automatically scaled correctly (cf. Figure 7). The density of the point cloud of the photogrammetry model is higher than the density of the original laser scanner point cloud (see Figure 7).

The update process shown represents an installation of an object that did not exist before. It would also be possible to change or omit an object. If an object disappears, the point cloud of the laser scanner would only have to be edited to remove the object. If the object is changed, the point cloud of the laser scanner would first have to be edited and then a photogrammetric recording would have to take place, which is then integrated into the basic model using the process described above. The results show an integration of a photogrammetry model into the point cloud of a laser scanner to update a digital factory model in the form of a point cloud is possible.

4.3. Update process BIM model

The updated point cloud is then used to support manual updating of the BIM model [28]. In the present evaluation, the point cloud (.E57 file) was converted into the point cloud format .RCP (Autodesk RECAP) readable by Autodesk Revit and imported into Revit. Now the point cloud can be used as a supporting element in the BIM modeling software Revit. This ensures the filter is reliably modelled in the correct position, at the correct height and orientation. The IFC exchange format is designed to document BIM models and was used in the present case study to store the updated BIM model (see Figure 3).

5. Conclusion and future work

The proposed method for updating the geometry of a digital factory model was evaluated in a case study in which a component is subsequently added in a technical room. Metadata associated with the geometry was not considered in the work but needs to be included in future research. The result is that smartphones are also suitable for the photogrammetric update process of a point cloud. This means that the recordings can be carried out by the service personnel of the technical facility management in a factory after a modification with low cost devices. Overall, the quality of the SLR models were the best. Surprisingly the photos of the iPhone XS performed even better than the SLR photos at the alignment rate (without control points in RealityCapture). From the iPhone 6, however, only about 46.5% of the images of all three data sets could be used by the photogrammetry software RealityCapture. The calculated 3D models of the iPhone 6 were hardly reusable because of misalignments. For photogrammetry only current smartphone models are recommended. The use of control points in RealityCapture is only worthwhile if the alignment rate is very poor (under 50 %). Otherwise the results showed the risk of causing misalignments is too high. When calculating the 3D model, the process of meshing is the most time-consuming process for all data sets. This is followed by texturing for all data sets. During the tests it turned out that the time of meshing and texturing depends strongly on the image size. For further investigations, it would be advisable to include reconstruction measures in which objects in the building change or are removed. This would simplify the presented process or extend it by an editing step of the point cloud. In this paper only the addition of an object was considered as an update example. The frequency of the changes to be updated depends strongly on the conversion activities and cannot be generalised. Applications in the field will show in the future whether the method is scalable in terms of the calculation time required and whether it can be used for large factory buildings. However, the update method is also applicable to any type of building. In the present work no compressed versions of the images of the DSLR were used. Therefore, the use of compressed images in the photogrammetry software is a possible extension of the case study with respect to the quality of the results. A further investigation in the sense of the authors is to find out up to which extent a building must change in order that using a laser scanner achieves a time saving to perform an update.

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