Enabling BIM for Property Management of Existing Buildings Based on Automated As-is Capturing

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Abstract –

Digitization and automation in construction are increasing particularly due to the establishment of Building Information Modelling (BIM). The models of BIM contain geometric as well as semantic information. The level of abstraction ranges from coarse models up to detailed modeled technical components of the buildings. So far, BIM has been developed and used for the planning and construction phase of the building's lifecycle. In order to fully use the benefits of BIM also for the operation and refurbishment phase, BIM models need to provide a reliable data basis of the as-built and respectively the as-is situation. However, up to now many properties have neither been planned nor constructed using BIM, at times not even digital planning information is available. Therefore, the digital model must be created from the real world.

The author's research proposes the development of an automated as-is capturing process of existing buildings as well as the data integration into BIM as a basis for property management. Suitable capturing techniques have been analyzed. Up to now, these techniques and the subsequent data transfer are still characterized by lots of manual work. Accelerating this process requires methods for the automation of data segmentation, classification and the modeling process. Conventional data capturing techniques such as laser scanning measure only visible surfaces. However, knowledge about inbuilt materials, constructional layers or thickness of e.g. walls is also important for optimized planning and utilization.

This paper summarizes the results of a joint research project in cooperation with a property management company.

Keywords –

Building Information Modeling, BIM, Automation and Robotics, Data Sensing, Computing

1 Introduction

For property management of buildings such as facility management (FM) a vast amount of data about functional, technical, descriptive as well as commercial aspects is needed. These are geometric data (e.g. for space management, the thickness of walls) or semantic data (e.g. fire ratings or the material of the walls). In many disciplines worldwide, digitization and automation are on the rise. In construction, a main aspect of digitization is the Building Information Modelling (BIM). During the past years BIM has been more and more introduced into the planning and construction phase of buildings. However, the planned situation usually differs to the built situation. Furthermore, BIM models of existing buildings often do not exist. In the following sections we discuss the requirements, techniques and steps for creating a suitable as-is model for the maintenance respectively operation phase of a building for the purposes of property management.

For development of such models, the following topics have been identified relevant: BIM systematics like as-is-terminology, level of development for BIM objects, computer aided facility management, data filtering and exchange. For each topic the paper gives a general overview based on state of the art literature and proposes additional systematics with focus on not yet met FM demands. Furthermore, capturing technologies and modeling systematics for the captured data are discussed. Here, experimental evaluation as well as concepts for a proposed modeling approach are added to a review of the current state of the art. Thereby, first results of the research project are described. Generally, the project is focused on two aspects – the integration of geometrical information as well as semantic information using available scanning techniques. The overall objective of the project is the development of an automated as-is capturing process for existing buildings as well as the data integration into BIM. The resulting BIM model shall be the foundation for the property management. This paper focuses on the aspect of the integration of geometrical information.

2 As-built vs. as-is BIM

BIM models should not only serve as a planning tool but also for managing tasks over the whole lifecycle of buildings. However, BIM is still an upcoming paradigm. Up to now, it is most frequently used in the earliest stage of the lifecycle, the planning phase [1]. Nevertheless, the operation phase is the longest lifecycle phase of a building. Consequently, extending BIM for use in this phase requires the introduction of additional BIM model specifications [2–4].

If BIM is also used for the facility operation it is crucial to keep the underlying model updated even after construction [5]. Currently, most existing buildings are not documented using BIM due to their planning and construction date before the rise of this method. The consequence is the necessity of creating digital models for existing building structures. In research journals, literature and professional's magazines these models, which represent the current geometric and semantic conditions, are called as-built or as-is models. Often the differentiation between as-built and as-is is not always clear. Therefore, we propose definitions to differentiate between these two terms.

[6] show in their literature review the different possibilities of creating as-built models with and without having an as-planned model. We hold the view that the existence of an as-planned BIM should be the fundamental characteristic for differentiation between an as-is and an as-built model. The as-built model arises during or after the construction phases by updating the as-planned model due to the observed accordances or differences between the actual as-built situation and the as-planned model. The as-is model in contrast represents a model which has been created from an existing in-use building, for which no reliable planning documents exist.

In particular, this means that an as-built modelling process takes place during or immediately after the BIM-supported construction phase. In between construction steps, it is also possible to get information about hidden building elements, such as the arrangement of concrete reinforcement layers. In contrast, the as-is modelling process describes the goal of creating the model of an existing in-use building. This scenario limits the possibilities of capturing information especially about hidden building elements. The fact that the building is in use and equipped with multiple (mobile) assets leads to more difficult conditions for data capturing.

3 Level of development (LOD)

With their Building Information Modeling Protocol Exhibit in 2008 the American Institute of Architects (AIA) established the levels of development (LOD) for describing the level of completeness to which a model element is developed [7]. In the updated document "Project Building Information Modeling Protocol Form" the AIA defines the LOD 500: "The Model Element is a field verified representation in terms of size, shape, location, quantity and orientation. Non-graphic information may also be attached to the Model Elements." [8]. BIMforum, the American chapter of buildingSMART, used these LODs to develop the Level of Development Specification Guide [9]. In general, this specification framework supports the design process by providing tools for a collaborative work environment. This guide serves as a communication tool for the standardized definition of the contents required in the design phase, in order to make them available to all project participants in a standardized way.

Within the LOD level system, LOD 500 can be considered as the as-built LOD. Figure 1 and 2 are depicting LODs and associated BIM lifecycle phases: planning LODs in green and as-built LOD in yellow.

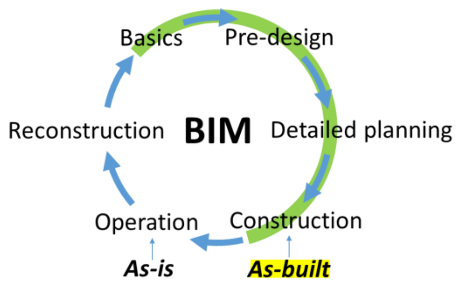

Figure 1. As-is and as-built BIM in lifecycle

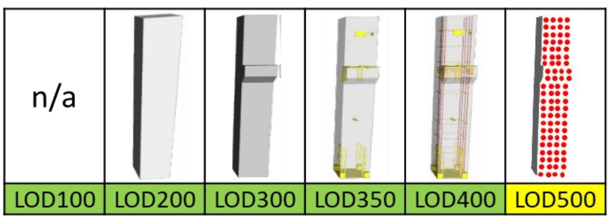

Figure 2. The different LODs of a precast structural column out of the LOD Spec. Guide, extended by a self-made illustration of LOD500.

LOD500 should represent the geometric verification e.g. by a laser scan. [9]

LOD 500 marks the conclusion of the planning and construction phases by representing in general the geometric update of the as-planned model after the building's construction.

In our research, we develop a specification framework for existing buildings without existing planning and construction models. There is no need to define stepwise requirements for building elements as during the planning phase. Rather, the challenge is to filter the relevant data out of an existing building. Therefore, we developed the level of as-is documentation (LOAD), which is described in the next section.

4 Level of as-is-documentation (LOAD)

Before making use of the benefits of BIM in operation, the data required for the BIM applications has to be defined. BIMForum developed a framework (Level of development specification guide [9]) for specifying BIM model contents with standardized specifications for planning and construction. Due to the fact that it is hardly possible to use these frameworks for an as-is documentation (see section 2) we present the level of as-is documentation (LOAD).

The LOAD is divided into three parts. The first part is the level of as-is geometry (LOAG) representing the specification for geometric requirements. The level of as-is information (LOAI) defines requirements for semantic data, which focus on the attribution of model elements. The last part is the level of accuracy (LOA), which has been contributed by the U.S. Institute of Building Documentation and defines the tolerance for the geometric deviation between reality and BIM model [10].

4.1 Level of as-is geometry (LOAG)

The LOAG is structured into four increments of ten beginning with LOAG10 and extending to LOAG40. The LOAG10 represents the simplest version of a building element, usually a one or two-dimensional one. The LOAG20 serves for describing the optimized bounding box (OBB) of a building element. For many applications, only the OBB of building elements is needed, e.g. for the management of available spaces. The LOAG30 and LOAG40 are geometric representations of higher detail, where the step from LOAG30 to LOAG40 requires a higher modelling effort. In figure 3 the LOAGs of columns are shown. The LOAG30 is modelled with an idealized constant profile, whereas the LOAG40 represents the highest geometric depth of detail, most closely to a true-to-deformation model.

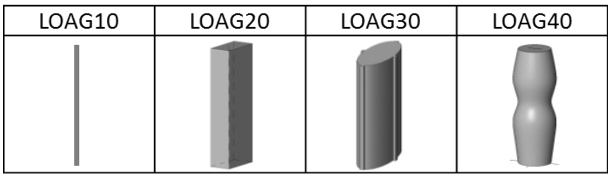

Figure 3. The four LOAGs of a column.

4.2 Level of as-is information (LOAI)

In contrast to the LOAG structure, the LOAI is non-hierarchical and represents semantic requirements related to attribute sets. These attributes refer to the different applications of the BIM model. The actual selection of required semantic attributes depends on the specific use case. When transferring data, proprietary formats do not cover all data interfaces. In such cases, the open standard format Industry Foundation Classes (IFC) [11] has been identified as best practice. The IFC documentation already provides a minimum quantity of different attributes, which can be attached to building elements in a standardized way. These attributes are organized in different property sets. For example, walls have the property set Pset_WallCommon, with the attributes of this property set being "Reference, Status, Acoustic Rating, Fire Rating, Combustible, Surface Spread Of Flame, Thermal Transmittance, Is External, Extended To Structure, Load Bearing and Compartmentation". For adding new attributes from the IFC documentation, so-called custom property sets can be created. Such custom property sets allow for the description of any arbitrary information, though their non-standardized way may limit their interpretation.

4.3 Level of Accuracy (LOA)

The U.S. Institute of Building Documentation provides the LOA in the USIBD Level of Accuracy (LOA) Specification Guide [10]. The LOA is structured into five levels, LOA10 to LOA50, with accuracy requirements increasing at each level.

Table 1. Levels of Accuracy defined by USIB

Level	Upper Range	Lower Range
LOA10	User defined	5cm *
LOA20	5cm *	15mm *
LOA30	15mm *	5mm *
LOA40	5mm *	1mm *
LOA50	1mm *	0 *

*specified at the 95 percent confidence level.

It is important to understand that the LOA Spec. Guide differentiates between different types of accuracy.

- *Measured Accuracy:* Standard deviation range that is required from the final measurement.
- *Represented Accuracy:* Standard deviation range that is required once the measurements are processed into a model.
- *Absolute Accuracy:* Standard deviation related to a given reference frame (e.g. whole building, floor or object)
- *Relative Accuracy:* Standard deviation related not to a fixed superior datum, but within an object´s region.

Consequently, it becomes possible to choose different LOAs for specific object types or regions. The following example shows how to use the different accuracies. For a Computer Aided FM (CAFM) project, a model with low accuracy for the global position of a building asset is sufficient, but the asset itself should be captured and stored with a high accuracy. It means that the absolute accuracy requirements for an asset are low (e.g. LOA10), but for the relative accuracy are much higher (e.g. LOA30). Thus, a suitable measurement technique has to be chosen due to the needed LOA. E.g., mobile laser scanning reaches only minor absolute accuracies (up to multiple decimeters) but – with some systems – relative accuracies within one centimeter can be achieved.

5 BIM for Property Management

In comparison to design and construction, the operation phase is the longest phase in a buildings' lifecycle. The pre-operation phases design, detailed planning and construction take about 2-5 years. In contrast to this, a building is in operation for a minimum of 20 years [12]. The main task during the operation phase is the FM , as it ensures the maintenance and value preservation of the building. CAFM systems store FM-related building data and allow for a methodized access to this data. Hence, it can be used for management of inventory documentation, spaces, contracts, energy, sustainability and other tasks that require assessing, controlling and maintaining building data [13].

For setting up these CAFM systems, BIM is capable of providing the database, since a building information model is in particular a unified information base and a location-aware model of building assets attached with information [14]. Furthermore, the data of a BIM model can be transferred to the CAFM application, such that time-consuming and error-prone efforts on manual data input can be bypassed, ultimately improving the final data's quality[15]. The automatic transfer mechanism data updates, e.g. in the case of reconstruction or renovation [16]. For these purposes, Gnanarednam et al. [17] present suitable data exchange formats such as the IFC and the Construction-Operations Building information exchange (COBie).

Apart from the synergies between BIM and CAFM, there are advantages to creating BIM models of existing structures, such as the reduction of errors to minimize risks for reconstruction [2] or the use of BIM models for building performance simulations [18]. In principle, this framework is a synthesis of encountered challenges and lessons learned from the presented case study. The framework proposes questions for identifying important data and ensuring interoperability between the different interfaces.

The mentioned literature in context of BIM and FM focus on setting up BIM models for aspects of FM during the planning phase [5,12,16,17]. They show significant benefits of the data exchange from BIM to a FM system. However, research on setting up BIM models in the later lifecycle phase is scarce and does not highlight the workflows of capturing and organizing on-site data for the BIM model [19]. Instead they propose the use of floor plans [15], which are often not representative of the actual state of the property situation.

For FM software applications several exchange formats haven been developed. COBie [20] was developed by the buildingSMART alliance and focuses on providing information about type and location of assets. For identifying and maintaining the asset, it defines requirements for identification tags and typecasting as well as for needed information about e.g. installation date, warranty and scheduled maintenance. COBie attributes can be added to model elements in BIM software. The associated standard exchange format is a spreadsheet application file with data organized in different sheets. Another standard for defining attributes for the use of CAFM are BIM profiles of CAFM-Connect [21]. The aim of CAFM-Connect is to grant interoperability between different software which are in use throughout the whole lifecycle management of buildings. The recently released BIM profile is CAFM-Connect 3.0, which delivers a framework for classifying documents, space usage and building components. This framework uses IFC as a programming platform for documenting FM relevant data. The attributes of the IFC entities are filtered and extended with additional attributes in the BIM profiles. Research already observed that there might be a lack of utilities in COBie to satisfy CAFM information requirements. Progress can be made by utilizing IFC for that purposes [17].

5.1 Data filtering and exchange

For proper usability of CAFM systems, great amounts of as-is information with high LOAD content not only need to be stored with the help of BIM but also have to be filtered to allow for a user-friendly FM operation or for sufficient exchange with other stakeholders. Thereby FM can make use of general BIM concepts for restricting models into partial-, aspect- or submodels such as the Information Delivery Manual (IDM) methodology developed by buildingSMART [22,23]. The IDM defines standardized exchange of information in several steps by participants and the coordinator in form of a handbook. The purpose of the IDM process is to filter the essential information for a partial model to generate the Model View Definition (MVD) and to establish an exchange requirement (ER). Thereby all participants of the different sectors agree on a certain communication. Based on the ER, automatic data management can be developed which will positively affect the interoperability of any collaboration [23].

One of the key components of the IDM process is the capturing of workflows with the participants. BuildingSMART refers to the method of Business Process Model and Notation (BPMN) as a guideline for the design of graphical Process Map documentation. The BPMN uses a flowchart and a column division to describe the overall process with the tasks of the various participants, as well as when and which data needs to be exchanged [22,24].

6 Data capturing techniques

For getting information about the actual geometric state of buildings, one common method today is the use of terrestrial laser scanning for data capturing. Different studies identified terrestrial laser scanning as a valid and popular method [2,25]. Multiple scan positions are registered to each other and the point cloud of the captured area will be processed. Another scan method is mobile laser scanning. Mobile laser scanning uses the simultaneous localization and mapping (SLAM) algorithm for continuous scanning [26]. This leads to enormous time saving during on-site capturing. The downside is a decreased accuracy. In this project, one goal was to find easy-to-use scanners, which provide fast data capturing. They should guarantee a sufficiently high accuracy while at the same time being rather affordable. Thus, we evaluated BLK360 from Leica [27], an easy to use low cost terrestrial laser scanner and mobile laser scanner ZEB-Revo RT from Geoslam [28].

First part of the evaluation of the two scanners was an accuracy check. In case of BLK360 we compared a single as well as a multiple scan setup. The reference laser scanning instrument for this evaluation was VZ-400 from RIEGL [29], a high accuracy surveying instrument. We calculated cloud-to-cloud distances, the minimized sum of distances between points of two point clouds, using the software CloudCompare [30]. The distances distribution classified in LOAs is shown in table 2.

Table 2. Relative distribution of cloud-to-cloud distances in single scan and multi scan scenario

Level of Accuracy	Single Scan	Multi Scan
LOA50 (0-1mm)	19.39%	15.83%
LOA40 (1mm-5mm)	54.23%	44.18%
LOA30 (5mm-15mm)	22.13%	33.29%
LOA20 (15mm-5cm)	4.25%	7.71%

The results show that 94.75% (single scan position) and 92.29% (multi scan position) of the distances achieve the requirements of LOA30 (or better), while only 4.25% and 7.71%, respectively, do not. Hence, we decided that the BLK360 could fulfil the accuracy requirements of LOA30. For the Zeb Revo we present initial investigations. For a simple visual analysis, we superimposed two point clouds, one captured with BLK360 and one captured with Zeb Revo (Figure 4).

Figure 4. Point to point distances. Colored – Zeb Revo. Black (underlaid) – BLK360.

The colored points (enlarged for presentation) represent the point cloud surveyed with Zeb Revo. The colorization depends on the deviations to the point cloud captured with BLK360. Deviations here represent to the absolute accuracy. Apart from the highlighted corridor the deviations were almost everywhere below 1 cm. The scan of the corridor was drifting (absolute accuracy here appx. 10 cm). Nevertheless, we found out that there was overall a relative accuracy according to LOA30 (5-15mm).

We validated BLK360 to be accurate enough for retrofits requiring a LOA30 (absolute and relative accuracy). The ZEB-Revo RT shows a good relative accuracy but in a given reference frame the absolute accuracy is up to multiple decimetres. Therefore, we decided to use this technique when a fast but not too accurate survey is needed.

7 Automation in modelling

The captured laser point clouds generated by the equipment described in the section before are then used as the basis for the modeling process. Common suitable building information modeling software accompanies much manual work. However, with manual modeling being a time-consuming and costly process, automation in modeling would save much time and money.

Automation takes different forms which can roughly be divided into modeling aids and partial or even full reconstruction methods. Modeling aids are mostly concerned with solving specific tasks without necessarily reconstructing geometry. Such methods could include techniques for point cloud alignment, filtering or the extraction of features. These can ease both, manual and automated modeling processes. Despite contributing to the modeling process, the aforementioned methods have in common that they are neither meant for nor capable of fully reconstructing building geometry. Fully automated methods aim to fill this gap requiring at most only minimal user input. In fact, a detailed review of the various steps required for automated modelling has been outlined in [31,32].

In context of the project's tasks, we investigated various strategies used during the automated reconstruction process, which can be categorized into preprocessing and segmentation methods.

Preprocessing is generally used as an optional step and aims to simplify and ease subsequent steps. Point cloud denoising, axis-alignmend and downsampling in particular are most illustrative of this issue, as each of these methods addresses common problems present in raw point cloud data. Denoising is usually performed through use of filters which are already known from image analysis like the bilateral filter [33] and are meant to mitigate the effect of outliers in the point cloud. Usually, this effect helps segmentation algorithms to extract sharper point clouds segments, however in case of low-quality data denoising can be absolutely mandatory. Not only does denoising help to improve the data's visual quality, it also eases the software supported manual modeling process. Point cloud axis alignment addresses the problem of incorrectly aligned point clouds and is best applied to man-made structure with dominant rectangular geometry. Similar to denoising, alignment methods simplify manual modeling, reorienting point clouds in a way that their major walls are oriented along the global coordinate system axes. Despite this benefit appearing to be marginal from a user perspective, it offers a significant benefit to automated methods. Voxel-, supervoxel- and octree-based data structures [34,35] which are being used for downsampling or fast neighborhood lookups are themselves axis-aligned. They are thus more compact and offer better performance for axis-aligned point clouds.

With the former steps offering ways of cleaning up point clouds, they generally fall into the category of modeling aids, but as mentioned earlier, they also have a notable impact on segmentation algorithms. Segmentation and feature extraction methods in particular stand in close relation with them, as both usually involves octrees or voxelgrids for neighborhood lookups and deliver more precise results for denoised point clouds. Commonly extracted features include structure indicators such as linearity, planarity and scatter values and surface normals. Structure indicators are particularly useful for extracting features such as edges. Figure 4 illustrates the results of feature line segmentation. Such methods lend themselves to the category of semi-automated modeling aids, as they create geometry meant for guiding manual modeling.

Figure 4. Top: Laser scan (ceiling removed for visibility). Bottom: Simplified model based on extracted feature lines.

In terms of plane segmentation, in other contributions [36,37] normal estimations and the RANSAC paradigm has been applied. Both help estimate local planes oriented along surface in point clouds. The extracted planes can directly be used to extract wall and floor segments, thus letting these methods fall into the category of fully automated reconstruction methods.

Figure 5. Point cloud segmentation for planar segments. Left: Input point cloud. Center:

Outlines of detected plane surfaces. Right: Exploded view, the single points being mapped to their respective plane

Figure 5 shows, how a successful plane extraction can lay out the foundation for this step. Other creative methods involve the removal of extracted planes as a preliminary step to detecting and reconstructing pipes [38].

8 Conclusions and Outlook

Within this paper we presented first results of our research concerning the needed requirements, techniques and steps for creating a suitable as-is BIM model for the maintenance respectively operation phase. Future work will now focus on detailing and optimizing the capabilities of the presented techniques and workflows. For data capturing e.g. in-depth investigation in the field of mobile laser scanning and the reachable accuracies are intended. Furthermore it should be researched in how far a point to point distance calculation is representative to verify accuracy in a real survey scenario where multiple scans get registered.

Automated modelling methods still offer much potential not only for reconstructing geometry, but also deriving semantic information. Future work with previously described techniques will involve a combined approach which will most certainly lead to a more robust segmentation with less outliers and improved performance. With the current approaches being capable of e.g. associating point cloud regions to detected planes, going beyond geometry-based point cloud analysis becomes an intriguing possibility. Traditional texture analysis techniques employed in the field of image analysis are well-established and, in combination with machine learning, have led to solid results in the fields of object recognition and classification [39]. Applying these techniques with respect to point cloud colour information for identifying, segmenting and classifying surfaces to derive additional semantic information, seems quite intriguing.

Another perspective would be a survey on how automated methods are capable of dealing with input data of varying quality. Further investigations with mobile scanning devices would prove interesting, especially when it comes to techniques for denoising the data and comparing automatically reconstructed models of capturing devices with varying accuracies.

Either way, with capturing techniques becoming more accurate and inexpensive and automated methods becoming less reliant on user interaction while at the same time providing more detailed and semantically rich results, the BIM process for capturing the as-is state of existing buildings will grow more attractive and more popular in the future. Furthermore, the described strategies for the implementation of as-is geometry information into the BIM context will now be used for implementing semantic as-is information alike. Both aspects will then be combined to allow efficient property management of existing buildings based on a reliable geometric and semantic data basis.

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