Towards Digitalization of Building Operations with BIM

Markus Krämer and Zsuzsa Besenyői
Hochschule für Technik und Wirtschaft Berlin
E-mail: Markus.kraemer@htw-berlin.de Zsuzsa.Besenyoei@htw-berlin.de

Abstract. Building Information Modeling (BIM) is today one of the most promising approaches to achieve digitalization in the construction industry over the whole building life cycle. Meanwhile most of the projects in research, industry or public authorities focus on the planning or construction phase, the practical usage of BIM in operational phase within Facility Management (FM) is still rare. Despite of the well agreed benefits of using BIM in the operations to improve maintenance planning and control, ensure speed up of FM hand over from construction or improve start-up management of building operations to name three of them, serious obstacles for practical use of BIM in FM must be considered. Just to mention two of them, today accepted standards helping FM organization to setup their BIM requirements according to different BIM uses are missing or As-Built information of existing buildings to setup digital building model needed for BIM are not available.

The lack of exiting (3D) digital building models in FM will not change quickly; far more the 90 % of the buildings to be operated and maintained in FM business are existing buildings. The acquisition of As-Built information may be simplified by digital surveying methods (e.g. 3D Laser Scanning, Aerial photo capturing by Surveying Drone), but there is still an enormous amount of effort for parametric modelling needed to setup digital building models for FM, which cannot be achieved by typical FM organizations today.

This paper extents first results of the research project BIM-FM presented on INservFM in 2017 comparing different digital surveying technologies used in field tests and to optimize workflow to make digital building models of existing buildings available for FM purposes. In order to give FM organization access to BIM data over a long period of building operation, new concepts of data management based on semantic web technologies to link BIM data to existing alphanumeric information located in Computer Aided Facility Management (CAFM) systems be discussed.

1. Building Information Modelling within Operational Phase of Building Life Cycle

Building Information Modeling (BIM) is today one of the most promising approaches to achieve digitalization in the construction industry over the whole building life cycle. This statement is proven by the numerous amount of national and international initiatives conducted by industry and public associations in Construction and Facility Management sector to implement this new planning method in practice¹. In BIM method a digital representation of the real building (a digital twin) is used throughout the whole building lifecycle from planning over construction to the operation of the building in order to establish an optimized collaboration and information exchange between all participants and disciplines in building industry. In this article this digital representation of the

¹ for German public initiatives see BMVI (2015) „Stufenplan Digitales Planen und Bauen“
building containing (3D) geometry, topology and linked alphanumeric building data is referred to as building model or (virtual) digital building model. 

But most of the projects in research, industry or of public authorities focus on the planning or construction phase. Although the benefits of using BIM in the operational phase of a building is commonly agreed [1], the practical usage of BIM in Facility Management (FM) is still rare. One reason for this is the lack of already finished construction projects especially in Germany which can be handed over as a digital building model to Operation and FM. Even in current construction projects in which the BIM method is in use, there are lots of uncertainties, how a final “As-Built” building model for FM purposes should look like and which information have to be included. Upcoming standards from BuildingSMART, GEFMA, VDI and others will help to define those requirements from FM perspective in near future. Finally, it is a trivial insight, that a digital building model can only match facility data information needs if they are anticipated before in the planning and construction project. Hence, knowing which usage scenarios of BIM are most important in FM business is essential. An overview of recent investigations showing goals and benefits of BIM in FM is given in [3]. Among others, enhancing the quality of building documentation or enhancing visualization and understandability of design concept are of most importance to owners and FM. Furthermore and efficient FM hand over from construction projects and a seamlessly management startup of building operations is required from BIM uses. But at the end it has to be considered, that there are only few practical experiences of using BIM in day-by-day FM business yet.

The lack of exiting (3D) digital building models in FM will not change so quickly, since even if all new construction projects would have been conducted by using BIM methods, far more the 90 % of the buildings to be operated and maintained in FM business are existing buildings. Another obstacle of implementing BIM in FM business in near future is the enormous effort of capturing exiting buildings and creating appropriate As-Built digital building-models for FM from scratch. In consequence, setting up digital building models for existing buildings with less effort becomes most important for applying BIM in FM practice. Even then, this model(s) has to be maintained by the FM organization during a long period of operating, some times more than 50 years. Keeping this As-Built building model(s) up-to-date will be a big challenge for FM also. Updating the building model will usually require additional updates in other common information sources of FM, e.g. data bases of Computer Aided Facility Management (CAFm) systems - and even keeping CAFM data bases up-to-date is today a big challenge in practice.

This article extents first results presented on INservFM in 2017 in Frankfurt [4] using different digital surveying technologies in field tests within the scope of the research project BIM-FM in order capture existing buildings and make them available to be used for FM purposes. It will also explain new research concepts for data management based on semantic web technologies to retrieve information of multiple building models virtual linked to alphanumeric data located in standard CAFM database management systems.

2. Approach in Research Project BIM-FM

In early summer 2016 a joined research project of HTW Berlin and Beuth Hochschule Berlin has started to address these challenges. The project aims to investigate which existing technologies and procedures can help to generate As-Built virtual building models of existing buildings for FM purposes more easily and how major aspects of a Common Data Environment (CDE) as described in PAS 1192 (NN 2013, page 25) would look like from FM perspective. Especially, if they make use of multiple linked building models during the operational phase of the building life cycle. The project is funded by Institut für angewandte Forschung Berlin (IfaF). The main focus of the project is to develop concepts close to practical usage and to evaluate the implementation during the project. Therefore two application partners (Gegenbauer Facility Management, Alexander Agamus GmbH) and one technology partner (Ambrosia FM Consulting & Services GmbH) from industry participate.

Since in FM business information management is different depending whether to operate a building from the perspective of a FM service provider based on contracts or from perspective of the building
owner, the authors believe that in consequence BIM management has to be handled differently as well. To cope with this, two prototypes of building models of different existing buildings will be developed within the project (see Figure 1.).

![Figure 1. Pictures of Use Cases in the BIM-FM Project (St. Hedwig Hospital and Verbändehaus Berlin)](image)

The first Use Case is a fairly new office building (construction year 2000) comprising multiple owners (Verbändehaus am Weidendamm, Berlin Mitte), which is managed by Gegenbauer Facility Management. The facade design and the whole architecture is quite regular with constant repetitions of elements. Important technical equipment’s of the HVAC systems is placed on the roof, moreover a huge atrium covered with glass are in focus point in terms of existing data capturing (see Figure 5.). BIM requirements for this Use Case focus on the perspective of FM service providers, which have to deal with all aspects being part of their contract for a certain contract duration.

The second Use Case is St. Hedwig-Hospital Berlin (Berlin Mitte), which is managed by Alexianer Agamus GmbH reflecting the owner’s perspective. In contrast to Verbändehaus this Use Case is an old building, which is in parts protected as a historic monument (see Figure 3). Furthermore, special requirements coming from medical technology of a hospital (e.g. in surgery or radiological rooms) and due to the old building some really small and contorted rooms for building equipment has to be considered.

### 3. Workflow-Analysis of As-Built Digital Data Capturing

#### 3.1. Capturing methodologies of point cloud data

There are numerous amount of technologies to capture the existing conditions of the buildings. Meanwhile usually the classical and semi-automatic measurement methodologies are time and effort consuming, the nowadays most popular capturing methodologies are the terrestrial 3D Laser Scanning and Drone Surveying.

Terrestrial 3D Laser Scanning not only provides fast and accurate point measurement but also enables the surveyors to gain measurement data up to one-two kilometers depending on the type of the equipment (short, moderate or long range scanner). The final result of the 3D Laser Scanning is an accurate and dense set of points which is called point cloud. In the point cloud each individual points possess x,y,z coordinates which has been measured according to the travel distance of the laser beam emitted by the laser scanner.

Collecting existing building related information by Surveying Drones can be based on three different capturing methodology, namely LIDAR-, video- or photo-based inspection. Meanwhile each
capturing techniques have their own advantages and drawbacks, all of them directly or indirectly could provide point cloud measurements as well. During the presented research only the photo-related capturing procedure has been in focus, where the Drone (or in other name, flying platform) is assessed with a high-end camera, taking aerial photos about the selected building part. These aerial photos are transformed by photogrammetry into point cloud data, which accuracy and density is more humble compared to the result of terrestrial 3D Laser Scanning.

At the present study, a mobile phone assessed with Google Tango technology has been also tested, which application enables the equipment to directly capture point cloud data. Considering the density and accuracy of the captured points, the overall results are promiscuous, however this technology only can be utilized within the range of 4m.

3.2. Data collection and data processing of point cloud data

Independently from the selected capturing methodology, the main milestones of the overall workflow of As-Built Digital Data Capturing are identical. Its detailed sub-processes, their relevant time consumptions as well as critical factors can be seen in Figure 2., where the stages of point cloud utilization scenarios (see Chapter 3.3.) are also indicated.

**Figure 2.** Overall workflow of As-Built Digital Data Capturing and the Stages of Point Cloud Utilization Scenarios
3.2.1. Initial Data Capturing
Considering only the first stage, the most crucial point is the correct positioning of the inspection equipment. Therefore the planning of it is inevitable, even though the actual time consumption of it is small amount. This determination assures that, the collected initial data (raw data) will possess at least a lower level of overlapping (around 25-30%) within each other, ensuring the success of the raw data processing later on. Consequently at the case of the 3D Laser Scanner it is crucial to position the instrument between every door openings, hence providing the connection between different building areas. Accordingly at the case of the Surveying Drone, the actual taken aerial photos must contain partly identical building spots too. Although the actual data capturing has a middle-level time consumption within the whole workflow, the critical factor is in a low level as a result of a proper equipment position planning.

3.2.2. Raw Data Processing
Within the second stage, the raw data are joint together according to the overlapped regions, providing one single registered point cloud data. During this procedure it is also possible to join raw data originating from different capturing methodologies as well (see Figure 3. and Figure 4).

This registration process can occur either automatically or manually (or at special cases according to targets/tie points). Meanwhile the automatic-based registration consumes less amount of labor time than its manual match, but it also requires higher identity level (overlapping above 55-60%) from the registered-to-be raw data pairs. Accordingly manual registration is required at the case of lower level overlapping, as well as at the case of very identical building parts (e.g. different levels of a staircase) or at the case of raw data originating from different capturing methods. Thus the whole success of the workflow (i.e. the creation of point cloud) heavily depends on this procedure, the critical factor is in a very high level. Depending on the number of raw data and the level of overlapped regions, the actual time consumption can range between low till a high level.

![Figure 3. Integration of point cloud data originating from different surveying technologies at the case of the St. Hedwig Hospital (left side: 3D Laser Scanning; right side: 3D Laser Scanning and Google Tango technology)](image_url)
Figure 4. Integration of point cloud data originating from different surveying technologies at the case of a pilot test on the HTW Campus, Wilhelminenhof (left side: 3D Laser Scanning; right side: 3D Laser Scanning and Drone Surveying).

3.2.3. Data Post-processing

At the case of the third stage, the unnecessary points (noises) must be removed from the point cloud data and individual smaller segments must be created from the remaining data set as well (see Figure 5, left side). This stage also can be performed automatically and manually. Despite of the low labor force demand at the case of automatic cleaning and segmentation, the result of it is still not satisfactory. Although most of the unwanted points are removed during the automatic cleaning process, unwanted points, like people silhouettes are still remained. Furthermore despite the fact, the whole point cloud is automatically segmented according to different building ensembles, poles, vegetation, and ground, but building parts which are actually relevant are not identified as individual building segments (Figure 5, middle). In order to achieve the required results (Figure 5, right side), vast amount of manual labor force is necessary in a form of manual cleaning and segmentation.

The execution of this stage is essential in order to enhance the visibility of the desired geometric information, meanwhile to reduce the power demand for further processing unnecessarily large data. Considering the success of the overall workflow, the manual cleaning and segmentation is the most critical sub-step within this stage. Firstly this one ensures to avoid processing large amount of point cloud at once during the building modeling phase. Secondly by naming different segments according to their name in the existing CAFM system, highly could aid the work of Facility Managers (see Chapter 3.3.2.). On the other hand, mark ups could be also added to these segments, in order to indicate the smaller segment parts according to the existing naming scheme in the ‘CAFM system’ (see Chapter 3.3.3.).

Figure 5. Data post-processing of point cloud data at the case of Verbändehaus (left side: unprocessed data; middle: automatically processed data; right side: manually processed data)
3.2.4. Building Modeling

Within the last stage, the digital building model will be created according to the established point cloud data. This generation can be executed also in a semi-automatic or in a traditional, manual way. Within the first option, the building modeling can be significantly enhanced, by a semi-automatic modeling system, which is able to transform the overall point cloud data into parametric building objects (native Revit Family objects).

By the usage of this tool the walls, openings, beams and columns, furthermore any MEP pipe system can be automatically recognized (see Figure 6. left side). After this digital observation, some further manual work is necessary in a form of ‘allowing’ the existence of the recognized elements (at the case of false recognition) or connecting individual elements which were maliciously recognized separately. Through the application of this tool the labor demand of the manual building model creation can be reduced significantly, meanwhile this sub-process only demands a modest amount of labor force. Consequently the critical factor of this sub-process is on a middle level, hence it does not affect the success of the overall workflow but dramatically improves its global time consumption.

Since via the semi-automatic modelling stage a low-detailed digital building model is created, only it’s further manual development is necessary. Throughout this last step each individual building object ought to be modelled, which takes a vast amount of labor hours. The critical factor of the last step is also on a really high level, but only if the main aim of the model development is to reach the highest detail of information (see Figure 6. right side).

![Figure 6. Building Modeling at the case of Verbändehaus](image)

(left side: automatic building modeling; right side: manual building modeling)

3.3. Approaches of Using Captured As-Built Data in FM

3.3.1. Scan2BIM

The utilization of the point cloud at the case of the Scan-to-BIM scenario occurs in a ‘classical way’. During this approach the objects of the building model are defined by the help of the point cloud segments and (in addition) existing plans. After having done so, the point cloud data (and plan data) is not necessary anymore.

At a first glance the most favorable option would be to model the building including all the tiniest building elements with the highest detail of information (Besenyői, Zs. p. 47). Hence, the building model contains all the relevant geometry and non-geometric information out of the original source of data, meaning the point cloud data set is fully exploited. Therefore, it can be discarded right after the model creation.
However, this option holds a lot of drawbacks. At one hand this development is still incredibly time and effort consuming. On the other hand, even if the development of the building model is satisfactory, the maintenance of it still holds serious issues. Furthermore, if the building model holds too many information, the performance of the building model will slow down dramatically.

3.3.2. Scan2DataSet

Since one of the main goals of the project is to reduce efforts for digital building model creation, it is undoubtedly necessary to limit the details of BIM object to a satisfactory level. Consequently another option is needed to utilize the point cloud in a more versatile way. Therefore, the point cloud has to be accessible to the FM later as well. This process could be referred as Scan-to-Dataset.

The original set of information (point cloud) is presented beside the building model, however not in the form of a parametric building element. In this way the Scan-to-Dataset scenario could enable the building model to include less details from the beginning. The digital representation of the building could be developed only till a certain level, where the parametric objects are only represented in a schematic way (“light weight” BIM objects).

Since the point cloud is represented in order to refill the missing information in the building model, only the question of ‘how to utilize it in the FM context’ remains. To use the point cloud data for visualization of missing or incomplete building elements of the building model, the elements within the point cloud has to be identified, segments have to be more defined and named, as well as markups have to be created.

At one hand by representing the point cloud data in the above mentioned way, it would allow the FM to look for information regarding the missing/incomplete building details. In this way the time and effort of creating an As-Built building model could be reduced, resulting time and effort saving, meanwhile less hardware performance is needed. On the other hand, the building model and the point cloud data set together could be handed-over for further self-customized building model development, refining the modelling on demand.

3.3.3. Scan2CAFM

In order to absolutely dispose the effort of building model creation and to eliminate the additional work of the point cloud data set, the direct information retrieving from the original source of information could be a further (third) option. At the case of this scenario no digital building model would be created meanwhile all the relevant FM information should be retrieved from the point cloud data set and transferred to the data base of a CAFM system directly.

The point cloud data contains not only information for visualization, but also enables numerical measurement, additional markups and picture linkage to every single captured point in the original set of information. So, why not retrieving information from the point cloud to avoid traditional site surveying work.

Unfortunately, in this way items like equipment plates cannot be analyzed due to quality restrictions (scan resolutions are too bad to read text elements on the plates). But inventory items (tables, chairs,) or some MEP equipment (pumps, motors) can be identified very well in the scan data. This information and further measurements (e.g. distances between walls and equipment location, built-in spaces,) can be used to setup CAFM database entries. Field tests in the project have shown, that using the point cloud data this way is somehow promising, since this additional data source for FM surveyors can reduce the amount of a second or third visit on site.

Meanwhile there will be a significiation reduction of work, only limited amount of details can be automatically or even manually retrieved yet and the quantity of useable information is limited.
4. BIM-FM Linked Building Data Platform and Next Steps

In Figure 7, the concept of integration of existing information sources can be seen, namely the BIM-FM Linked Building Data Platform (BIM-FM LBDP) is explained. BIM-FM LBDP is acting as a middleware software layer, which can be used by the Facility Manager either to retrieve information on demand (ad hoc queries) or based on predefined rules. In the first step this can be done using a simple web browser.

The basic idea of BIM-FM LBDP is that, all connected information sources (left side of the picture) are simultaneously queried, so that the user only has to ‘ask’ once to get ‘answers’ from multiple data sources. This concept allows information query (for example: retrieving information about a certain fire extinguisher) where the BIM-FM LBDP collectively recalls answers from the CAFM database (containing maintenance data like last inspection dates) and the connected building models. In this way the so found items in the building model can be represented as parametric building objects, e.g. with their position in the building and with their geometric information. Therefore, according CAFM entries can be limits to a minimum.

To make use of the Scan Scenario Scan-to-Dataset (see Chapter 3.3.2. ) all segments of the point cloud will be also connected as an information source. Since a set of markups can be attached to the point cloud segments and then stored, users may find visualization information of certain areas in the point cloud including the searched items. In this case exact measurements can be executed in the point cloud as well, without any further setup within the building models. This step would be another attempt to reduce the effort of creating As-Built building models, since only “light-weight” BIM object with less details are needed.

![Figure 7: BIM-FM Linked Building Data Platform](image)

The above mentioned multi-source approach requires that common catalogue-definitions and ontologies are applied to setup link data on a semantic level. Within the project scope several techniques will be evaluated to export connected data sources to semantic web endpoints. First attempts to export building models based on IFC standard to semantic triple stores are promising.

5. Conclusion

According to the approach used in BIM-FM research project two prototype digital building models are created for existing buildings in Berlin. One of them was designed from FM service providers perspective (Verbändehaus in Berlin Mitte), one of them is design from FM and owners perspective (St. Hedwig-Hospital also in Berlin, Mitte). Additional field tests has been carried out on HTW Berlin, Campus Wilhelminenhof using terrestrial 3D Laser Scanning, Surveying Drones assessed by
photogrammetric applications and a smartphone based on Google Tango technology. The gathered
data has been post-processed with off-the-shelf applications in terms of registration, cleaning,
segmentation and semantic parametric modelling. Finally, all information was uploaded to a common
data environment implemented with open source data base applications, where data was linked to
commercial CAFM systems.

Based on the findings of the field tests and with input of the FM organizations, a common
workflow have been designed, which offers three different approaches to make use of captured data:
Scan2BIM, Scan2CAFM and Scan2Dataset. The combination of those approaches enables on-demand
modelling over the operational life span of the building, increasing the initial efforts to setup a digital
building model significantly.

In the end, results of the field tests with three different digital capturing technologies are promising.
Considering only the 3D Laser Scanning it is highly suitable to capture large ‘visible’ areas and
surfaces in a short amount of time. Since the integration of point cloud data is possible within different
capturing methodologies, it is advisable to combine the technology of Drone Surveying with 3D Laser
Scanning. This methodology combination would provide point cloud data about outdoors areas as
well, which are not visible by 3D Laser Scanning (non-walkable roof structures or very detailed, high
façade elements, see Figure 4.). For elements, which detailedness is exceptionally important (i.e:
architecturally protected elements) and cannot be properly reached neither by 3D Laser Scanning nor
by Drone Surveying (i.e: indoor areas) the usage Figure 3. Integration of point cloud data originating from
different surveying technologies at the case of the St. Hedwig Hospital (left side: 3D Laser Scanning; right side:
3D Laser Scanning and Google Tango technology) Google Tango technology should be considered (see
Figure 3).

Considering the raw data processing, off-the-shelf software can automate labour-intensive
activities up to a certain scale. But still remaining manual tasks in modelling and post processing of
scanned data make it seem unrealistic, that all As-Built data need for FM from existing buildings can
be transformed to digital building models in a first step. Therefore, future common data environments
have to manage parametric IFC models, point cloud data enriched with mark-ups and alphanumeric
CAFM data. Accessing those heterogeneous data with powerful semantic query engines will be key to
successfully integrate BIM method in todays FM business.

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