

AUTOMATING AS-BUILT-MODELLING BY USING DELIVERY DOCUMENTS

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Abstract

Building Information Modeling (BIM) promises advantages for Facility Management (FM) by integrating the lifecycle phases of a building. Especially the optimized start-up phase is mentioned as one key advantage of the BIM method. In order to implement a successful start-up, a holistic as-built model is necessary, in which all relevant information for FM is stored. Actually, for the generation of an as-built model a high manual effort is necessary. This paper aims to develop an automated as-built model by using delivery documents. Therefore, this paper presents a process using Optical Character Recognition and analyze the process in a proof-of-concept.

Introduction

Building Information Modeling (BIM) aims to integrate all stakeholders by using a digital building model throughout the lifecycle (Borrmann et al. 2021). The focus here is particularly on the consistent exchange of information using open data exchange formats (Baranova 2021). One important standard to exchange data throughout the lifecycle is the Standard of the Industry Foundation Classes (IFC) (ISO 16739-1). Especially IFC-based as-built models could support an efficient information exchange between BIM systems and FM systems, as Computer Aided Facility Management (Matarneh et al. 2019; Ensafi et al. 2022).

As-built models hereby describes the actual state of the building, as it is constructed and commissioned (Bartels 2020). It represents the update of the as-planned model, which describes the target status of the building and includes graphical and alphanumeric data (Pilling 2016). By integrating all FM-relevant data and the data of the service provisioning during the Operations & Maintenance (O&M) phase, an As-Operated model is generated (RealFM 2021). The maturity of the models is shown in Figure 1.

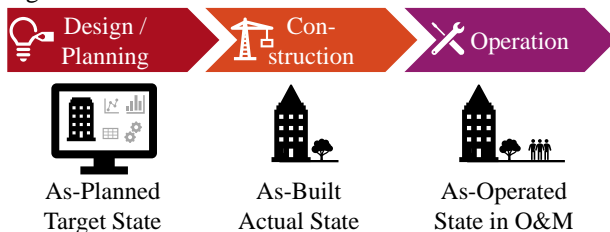


Figure 1: Maturity Levels of the BIM models throughout the lifecycle

While as-planned states the status of the design phase, the as-built modelling requires a finer level of detail, a more precise modelling as well as an accurate data import and

maintenance (Pătrăucean et al. 2015). But these data is often poorly collected, processed and revised in practice, what especially applies to asset-specific engineering data (Asmar et al. 2022; Hellenborn et al. 2023). This is especially due to the manual data entry during the construction and commissioning phase and the need for manual verification of Facility Managers (Klein et al. 2012).

1. In order to define the necessary data in the as-built model, it is necessary to unambiguously and clearly define the owner requirements, specially through exchange information requirements (EIR) and Asset Information Requirements (AIR). Research studies show, that the client's requirements are often not clear and specified (Hellenborn et al. 2023). Furthermore, the requirements change from client to client (Di Filippo et al. 2021).
2. In addition to that, especially for Construction Managers the usage of BIM software tools is often not common. Actually, the Construction Managers are using specific tools, such as MS Project or ERP to manage their processes as well as MS Office products, such as Word or Excel. This particularly applies to medium-sized companies (Lauer 2021).
3. The needed information is stored in documents, which are handed over in paper form or as a digital file. In particular, smaller craft businesses that work as subcontractors hand over their documents in paper form, which leads to a high documentation effort (Hausmann et al. 2022).

Actually, there is no connection between the delivery documents and the revision documents with the digital building model, although all needed information is stored in these two documents. Various studies focused on the processing of geometry to develop an as-built model (e.g. (Klein et al. 2012)) or on the documentation of construction specifics, such as timetables (e.g. (Park und Cai 2017)). The needed information for the asset owner and Facility Management are mostly not taken into account. Especially the information is not automatically read out of documents and assigned to objects in the model.

Therefore, it is necessary to implement an IFC-based interface, that enables the construction managers and their companies to automatically fill in all relevant data on the objects in the digital building model. By developing such an interface, the modelling of as-built models could be highly improved.

Based on this, the Facility Management is able to transfer and use all data in their Computer Aided Facility Management (CAFM) systems. This would lead to a better understanding of the building and improvements of efficiency

by the FM as well as an increase of user satisfaction (Bartels 2020).

Literature Review

Existing Solutions

In order to evaluate the state-of-the-art of as-built models, existing solutions for data acquisition, data integration, and data visualization need to be analyzed.

In recent years, various solutions for data acquisition for as-built models have been published. The earliest presented solutions are based on 3D laser scanning for building or geotechnical sites in order to generate geometric as-built models (Su et al. 2006; Deruyter et al.). Based on that research, further solutions for the acquisition of geometric data use advanced technologies, such as Autonomous Unmanned Aerial Vehicles, Imaging technologies or Augmented Reality were published (Omar und Nehdi 2016; Freimuth und König 2019). Not only geometrical but also alphanumeric data was integrated in as-built models, such as construction dates or production data (Son et al. 2017; Son et al. 2015). The analysis of these case studies shows, that the processes are regularly done manually. One presented solution for automated as-built models are sensors (Moselhi et al. 2020).

For data integration the solutions can be divided in solutions that (1) use proprietary exchange formats and (2) that use the open exchange format of the Industry Foundation Classes (IFC). Moretti et al 2020 use `IfcSharedFacilitiesElements` for the integration of as-built data (Moretti et al. 2020). Also solutions for as-built-schedules are presented by using an integrated entity information model based on ID of attributes (Fagiari et al. 2023).

For data visualization especially site photography is mentioned. Therefore, workflows were developed to efficient processing of unordered photos (Jadidi et al. 2015). This case study as well as the majority of the other case studies emphasizes that humans need to be trained and that humans are a central part for generating as-built models successfully. Furthermore, the analysis shows, that especially the geometric aspect is in the foreground.

Interoperability and Data Exchange standardization

This case study focusses on open exchange standards. Therefore, it is necessary to analyze the Model View Definitions (MVD) that are defined in the IFC standard. Furthermore, the state of the art of the Information Delivery Specifications (IDS) need to be analyzed.

The MVD is used to define a subset of the IFC data and defines exchange requirements (buildingSMART international 2024b). An IDS is a document, that can be interpreted by a computer and defines how information are delivered in a project. It hereby combines IFC and other extensions, such as company specific properties or properties of the buildingSMART Data Dictionary (buildingSMART international 2024a). While the concept of MVD deals with the content that is relevant for software manufacturers (e.g. mapping the class hierarchy and the transfer of geometry) and is the basis for use-case based Software Certification, the concept of IDS defines the al-

phanumeric information content of models and is therefore the more relevant concept for users and as-built models, because it describes all data that is needed.

One important definition for the handover to FM and therefore for as-built modeling are the FM-Handover-Aquarium and the FM Basic Handover, that is defined as MVD in IFC 2x3. The MVD aims to define the handover of information from Design and Construction Phase to FM software, such as CAFM and CMMS (buildingSMART international). The MVD are based on the entities and Property Sets (PSet) in IFC.

IFC is a central data format for IDS related to FM. Although there is currently no separate FM domain in IFC 4.3 (this still existed in IFC 2x3), the entities, such as

- Shared Facilities Elements – `IfcInventory`, `IfcFurniture`, `IfcAsset` and `IfcOccupant`
- Shared Management Elements – `IfcActionRequest`, `IfcOccupent`, `IfcOrderAction`, `IfcProjectOrder`, `IfcPermit`, `IfcCost`, `IfcCostSchedule`, `IfcWorkCalendar`, `IfcWorkPlan`, `IfcTask` and `IfcEvent`.

and Property Sets, such as, `PSet_ProjectOrderMaintenance-WorkOrder`, `PSet_Utility`, `PSet_Warranty` or `PSet_ActionRequest` are integrated for FM in IFC. There are also other class-specific PSets, quantity sets and other attributes relevant to FM. The classes defined in IFC are particularly suitable for describing as-built data. These can be used to fundamentally describe the building and the associated technical systems. There are also individual classes that can map FM process data (Bartels 2020; Bartels und Wimmer 2024).

Methodology

In order to implement an interface that allows an automated filling of the missing attributes from the as-planned state to the as-built state by taking IFC and IDS into account, four steps were taken. These steps are shown in Figure 2.

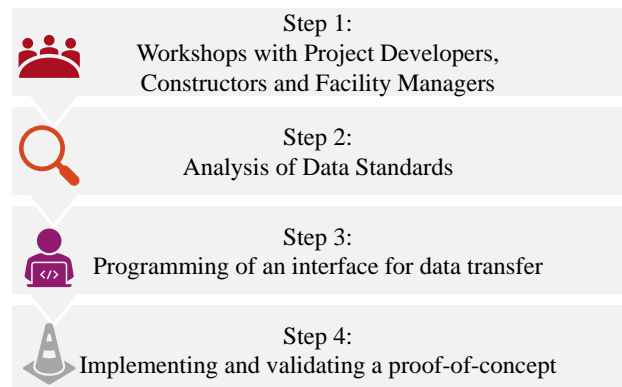


Figure 2: Methodology of this paper

First, workshops were conducted with Developers, Constructors, Planners and Facility Managers in order to get to know the needed attributes and the state-of-the-art. Secondly, data standards were analyzed to develop data specifications, with whom it is possible to filter the needed data out of documents and to transfer the needed data into an IFC-file by applying IDS. Thirdly, an interface was programmed and implemented to transfer the files.

Fourth, the programming and the process was implemented in a proof-of-concept to validate the programming, its acceptance and to analyze the results.

Data Analysis

Evaluation of the basis for information exchange

To implement an interface for transferring data and information from delivery and revisional documents to the digital building model by using IFC, the Exchange Information Requirements and Asset Information Requirements were evaluated with workshops.

Therefore, all in all 9 workshops were conducted, respectively 3 workshops with project developers and owners, 3 workshops with construction companies and 3 workshops with FM companies. The workshops took place from June 2023 to September 2023 and were conducted in person as well as online.

The workshops showed, that as-built models are more and more requested in building projects. In most of the cases, IFC is asked as exchange format for as-built models. But also proprietary formats (especially Revit) are requested. Furthermore, the workshops showed, that there is a need for the automated reading and transferring of information out of delivery and revisional documents to the digital building model. Especially the project developers stated, that this would improve the information exchange across the whole lifecycle and would perfectly fit to their aim of having as-built data for all developed building. For the Construction companies, the linking of documents and the digital building model also offers opportunities and is viewed positively; in addition, the aspect of a possible tracking of deliveries and thus a should-is comparison is emphasized as an advantage.

Lastly, the workshops aimed to evaluate the needed information of the stakeholders. The project developers stated, that the EIR and AIR are still not finalized and change slightly in the projects. The same effects are stated by the construction and FM companies. This often causes incomplete or wrong information in the as-built models due to missing definitions of the EIR and AIR in contracts. Therefore, some of the construction and FM companies developed their own AIR and EIR. Although the AIR and EIR vary slightly, the experts stated, that the information requirements are usually based on the Construction-Operations Building information exchange (COBie) or the German standard CAFM-Connect (CC). Especially CC is used in most of the projects as basis for the Information Requirements. An analysis of these exchange formats is shown in the next section.

Relevant Exchange formats

Due to its complexity, IFC is not specific and fully suitable transferring and storing FM data throughout the lifecycle of a building (Yalcinkaya und Singh 2019). Therefore, formats have been developed to transfer FM data properly and to get as-built models. As shown in the next section, the IFC-based exchange formats CAFM-Connect and COBie are the most mentioned formats for the delivery of as-built models. The workshops showed, that the EIR and

AIR are based on the attributes mentioned in these two standards.

COBie was developed in 2007 by Bill East from the United States Army Corps of Engineers (Lavy et al. 2019). The format uses spreadsheets to transfer BIM information from the Design and Construction process to FM (FM Handover). COBie defines three types of information delivery, one for information, that is created by designers, one that is created by contractors and one that is created by both of them. Hereby COBie defines information requirements for spatial and equipment assets (East 2013).

CAFM Connect is a German IFC-based initiative of various CAFM vendors. CC aims to capture the data collected in the Design and Planning phase and transfer it in a usable way into CAFM systems (Verband für die Digitalisierung im Immobilienbetrieb, CAFM RING e. V. 2019). Therefore, various lists were developed, to define all relevant data for the building objects, e. g. based on the German standard DIN 276 (Otto und Bartels 2018).

In the following, a door will be used as example for the requested data in CC. IFC defines a door with the entity IfcDoor, a subtype of IfcProduct. Various Property Sets assign to the entity IfcDoor, such as PSet_IfcDoorCommon, PSet_DoorLiningProperty. But also FM-data could be assigned by using PSet_Warranty, PSet_Manufacturer or PSet_MaintenanceStrategy (buildingSMART international 2022). These attributes are the basis for CAFM Connect and further defined in the lists. An example for the standardized attributes of a door (IfcElement IfcDoor) is shown in Table 1.

Table 1: Example of CAFM-Connect Attributes (ifcDoor)

IfcElement	DIN 276	Attribute	Type
IfcDoor	334.10	Door Stop	IfcText
IfcDoor	334.10	Number of wings	IfcText
IfcDoor	334.10	Automatic drive	Ifc Boolean
IfcDoor	334.10	Year of manufacture	IfcReal
IfcDoor	334.10	Description	IfcText
IfcDoor	334.10	DiBT approval number	IfcReal
IfcDoor	334.10	Hold-open system	IfcText
IfcDoor	334.10	Fire resistance class	IfcText
IfcDoor	334.10	Escape door	Ifc Boolean
IfcDoor	334.10	Manufacturer	IfcText
IfcDoor	334.10	Emergency exit lock	Ifc Boolean
IfcDoor	334.10	Overhead door closer	Ifc Boolean
IfcDoor	334.10	Opening type	IfcText
IfcDoor	334.10	Protection requirement	IfcText

Furthermore, CAFM Connect developed so called BIM profiles, in which relevant attribute for FM services are defined (Verband für die Digitalisierung im Immobilienbetrieb, CAFM RING e. V. 2023).

Development of an attribute list and process

Based on these data exchange formats, a consolidated list of attributes for building objects has been developed. The following Figure 3 shows the attributes of a door, all based on the global unique identifier (GUID), as example and in which phase data is actually included in the model. It furthermore shows, that various stakeholders need to enter data throughout the lifecycle. At the beginning of the project, the planners (e.g., Architects) enter various planning data. These data are needed for tendering and awarding.

Maturity Level	Source of Information	Attributes / Information
As-Planned	Digital Building Model / Door List (BIM-Software) Planner (here: Architect)	GUID Name Description Emergency Exit lock Protection Requirements Number of wings Opening Type Overhead door closer Fire resistance class Emergency Exit Fire Protection Door Stop Hold-open system
	Delivery Note Construction Manager	Manufacturer Year of Construction Serial number Automatic drive DiBT approval number
As-Built	Revision Documents Construction Manager / Commissioning Manager	Inspection intervall Maintenance intervall Commissioning date Qualification of the examiner
	Contract Facility Manager	Contractor Fault Priority
As-Operated	Service Provisioning Documentation (CAFM) Facility Manager	Inspection Report Result Description Responsible Person Date of Maintenance Next Maintenance Result plus Building Automation System and IoT-Data

Figure 3: Data entry throughout the lifecycle

Based on that data, the Constructor execute his services. Due to the incomplete data and changes in the construction phase, it is necessary to enter further data. During the

construction phase, the Construction Manager need to enter various data to achieve an as-built model. Especially data about the manufacturer and the year of Construction as well as serial numbers need to be entered in the digital building model. Beside that data also data of the commissioning is needed to receive an as-built model. Therefore, after the Commissioning additional data need to be entered in the digital building model. These data are especially Commissioning Dates and data about the service provisioning for Facility Management.

The remaining data is entered during the O&M phase of the building by the Facility Management and includes data about the service provisioning. These data could be transferred out of the CAFM system by using IFC.

Especially the data, that need to be entered by the Constructors is a key success criterion. On the other hand, that data is often not fully entered in the digital building model. The workshops with the constructors showed, that the Construction Manager is not capable to enter all relevant data due to

1. a lack of knowledge regarding BIM, especially in entering data
2. an insufficient hard- and software equipment on the construction site,
3. especially a lack of time due to the task on the construction site
4. belayed information of the sub-contractors due to missing documents.

The numbers 1-3 could be solved by the suggested approach of this paper. Furthermore, number 4 could also be solved, if the delivery of the documents is ruled in the contracts and the delivery of documents could even better be controlled.

Development of an automated document-based as-built model

Based on the data standards and processes, an automated exchange process to receive an as-built model has been developed.

Extraction of information on delivery documents

Currently the technical capabilities of material suppliers vary substantially. Around 1 percent of suppliers can share delivery bills via an API with defined End Points that can be accessed from external parties. Approximately 5 percent of material suppliers offer customer portals, where they upload electronically generated PDFs . The majority of suppliers, around 74%, are able to send scans or electronically generated PDFs of the delivery bills to an agreed upon mailing address. Only 20% of suppliers are not able to electronically transfer the delivery receipt. The only way for them to transmit the information is to bring the physical document to the construction site or send it via post. To mitigate this problem and enable all delivery receipts to be pushed into the digital workflow a scanning application on the construction site is unavoidable.

After each document is at least available as a digital picture the next step is to retrieve the information of the

scanned documents. This can already be done with common OCR applications (to transform the scan into a machine-readable string. (Memon et al. 2020; Chaudhuri et al. 2017) After all documents are in machine-readable format the varying formats need to be mapped on one central standard. To guarantee a very high data quality this mapping is currently still done manually but large language models already show to be a great way to automate this task. An extract of a delivery bill of the example project is shown in Figure 4.

Transporteur Transport AG		Fahrzeug Art Norm Kontrollschild Fahrer	
Lieferdatum	22.02.2023	Ankunft Baustelle	
Beladezeit	15:32 Uhr	Beginn Ablad	
Lieferzeit	15:15 Uhr	Ende Ablad	
Grund der Wartezeiten			
Zusatzmittel		Zusatzstoff	
Sorten-Nr.	Artikel-Nr.	Menge	
A110	525 M	8.0 m3	
	Product Name	Quantity	Unit
Stand Lieferung			

Figure 4: Extract of the exemplary delivery bill

IFC integration – Developing a process of automated as-built-documentation

The process of automatic as-built documentation on the IFC model is represented by a two-track, interlinked workflow between the construction site ("on-site") and the material dispatcher ("off-site") and is shown in Figure 5. As in the conventional workflow, the construction site is the starting point: The site manager or foreman determines the time of a material delivery. For this purpose, a task is created in a model-based construction management software, which consists of the following information: (1) time of delivery (date and time), (2) location of delivery (linked components or GUIDs), (3) product specifications (e.g., compressive strength of the concrete), and the (4)

order quantity (e.g., m³ of the delivery). While information (1) and (2) is entered individually by the ordering party, (3) can be read from the stored IFC file and thus pre-filled for the order. The construction site management would then only have to send the order information in the next step after checking the order. The order information, including the linked GUID(s), is then automatically sent via an interface (API) to the ERP system of the dispatcher, who checks the incoming order electronically and releases and picks the goods accordingly. After the final check, the physical delivery process can be started while the information flows back into the construction site management software via the updated delivery information in the ERP system. This means that the status of the delivery is visible at all times, as well as the expected time of arrival (ETA) and the underlying material information. When the delivery finally arrives and all materials have been delivered as ordered, the delivered and thus installed material information must be integrated back into the building model. There are two possible ways of doing this: using ML, as described in the section before, or sending delivery bills electronically. If the information contained in the delivery bill cannot be transferred from the dispatcher's ERP system to the construction site management software via the interface, the delivery bill would have to be scanned manually on site. The use of ML allows the automatic capture and evaluation of the information depicted on the delivery bill and thus the transfer into a digital format. By matching the previously placed digital order and uploading the delivery bill, the delivery bill can be subsequently linked to the order and thus to the underlying GUIDs. Ideally, however, the use of a paper-based delivery bill should be avoided anyway.

In this case, the delivery bill would be sent digitally via API when the physical materials are dispatched. The previously placed order is linked to the components, making it easy for the construction site team to compare them when goods are received for verification purposes. Once the information on the delivery bills has been successfully processed electronically, the semantic interoperability of the collected information is permanently guaranteed. This is due to the storage of the information in a model-based and document-oriented NoSQL database management system. Although this database system is initially independent of the IFC standard, the export of the data from the software allows it to be converted into a wide variety of formats. Both API requests and the export as an IFC file itself access the database and convert it into the desired format with respective PSets.

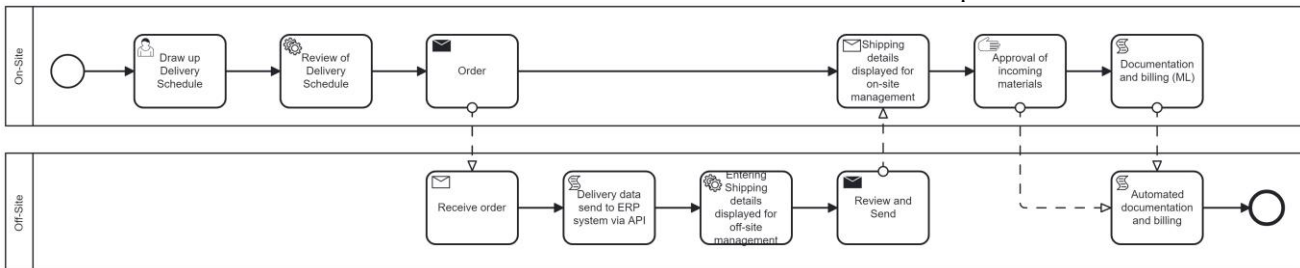


Figure 5: Process of integrating information in BIM

Critical reflection on surplus value

The process of automatic as-built documentation on the basis of model-based deliveries provides great added value, particularly for users on the construction site, but also for all other project stakeholders. The results show, that a majority of the demanded information (see previous chapters) could be filled in automatically by using OCR in combination with BIM.

The proof-of-concept also shows, that the added value arises primarily in the following four areas for the construction site: (1) order information, (2) communication, (3) documentation and (4) archiving.

Firstly, material information already contained in the model does not have to be entered again when filling in the order information. Instead, the quality and quantity can be pre-filled and only needs to be checked before the order is placed. In shell construction in particular, where measurements are still taken using analog, laborious and error-prone processes based on 2D plans, time savings of over 60% (equivalent to around 2 minutes per order) can be achieved for a typical order. Whereas previously, for example, the length, width and height of foundations were multiplied and then added together by number, the site team now obtains this information by simply clicking on the components.

Secondly, the information can subsequently be transmitted electronically via an interface to the dispatcher's ERP system. This process eliminates the need to prepare the order information again (e.g., as a PDF for sending by e-mail) or to call the material supplier. As a result, time savings of around 80% (equivalent to around 1 minutes per order) can be observed.

However, the greatest added value for the construction site comes from automated documentation. Today, manual diaries ("delivery lists"), for example in the form of an Excel spreadsheet, are created at great expense, particularly for concrete but also steel deliveries. Almost all the information typically contained there, such as the installation date, the delivery bill number, the quantity, the component or the location, could be automated using the process outlined above. What would currently require time-consuming updating could be generated and pre-filled at the touch of a button, leaving just one verification process. Time savings of over 90% (equivalent to approx. 3 minutes per order) seem plausible.

Finally, the filing of delivery bills in physical orders or the filing of scanned or digitally transmitted delivery bills in digital folders is also overdue. Delivery bills would be automatically linked to the IFC model and made available to everyone at any time via an interface to Common Data Environments or billing software, without the need for manual intervention. Time savings of almost 100% (equivalent to approx. 1 minutes per order) can therefore be realized.

For the construction site team alone, this results in a time saving of 7 minutes per order and documentation process. For a medium-sized construction project (roughly 5 Mio EUR construction volume) with approx. 300 delivery bills per months, resulting in roughly 10,000 orders, this would

mean 1,170 hours in total. Additional time and cost savings can be expected from the reduction in human error when planning and rescheduling orders, as well as from automatic version management and the resulting traceability of changes. Finally, there are possibilities for data analysis and evaluation, e.g., with regard to target/actual materials or CO₂ values, which were previously unheard of or only possible with great effort, if a material database is connected accordingly.

Conclusion

This paper presented an automated approach to generate as-built models by using the BIM method in combination with OCR. It hereby combines an IFC-based model with information out of delivery documents. A process has been developed and implemented in a proof-of-concept. By doing so, the efficiency of the information exchange and maintenance has been increased in the proof-of-concept. Furthermore, the automated exchange of information – based on IFC – lead to a more precise delivery of the information, that were evaluated in the workshops with project developers and facility managers.

This paper is a first approach for automated as-built models, that was evaluated in practice. the PoC shows that the process outlined in this paper can be used to automate data enrichment from BIM models to as-built models, further research is needed. The PoC shows in particular, that not all relevant information for FM could be extracted of the delivery documents. That means, that further documents – especially the revisional documents – need to be integrated in the process. In addition to that, the workshops with the experts showed, that not all companies are using digital delivery documents, but some still have delivery bills in paper form. This makes it necessary to scan or photograph the delivery documents. One solution is to use other internal systems (such as ERP).

All in all, this paper shows, that the manual integration of information could be reduced to a minimum by using OCR or related systems. Furthermore, it shows, that all relevant software systems, such as ERP-systems, need to be connected to the digital building model in order to fill in information automatically. Furthermore, PSets for IFC should be developed to generate as-built models out of delivery bills.

References

- Asmar, Daniel; Daher, Rema; Hawari, Yasmine; Khoury, Hiam; Elhajj, Imad H. (2022): Automated building and evaluation of 2D as-built floor plans. In: *Machine Vision and Applications* 33 (3). DOI: 10.1007/s00138-022-01289-8.
- Baranova, Olga (2021): Open data formats in building information modeling. In: *E3S Web Conf.* 263, S. 4062. DOI: 10.1051/e3sconf/202126304062.
- Bartels, Niels (2020): *Strukturmodell zum Datenaustausch im Facility Management*. Wiesbaden: Springer Fachmedien.

- Bartels, Niels; Wimmer, Reinhard (2024): BIM von A bis Z etablieren, inklusive „Tuning“-Maßnahmen. Teil 4: Schnittstelle zum Facility Management (4), S. 36–39.
- Borrmann, André; König, Markus; Koch, Christian; Beetz, Jakob (2021): Building Information Modeling. Wiesbaden: Springer Fachmedien Wiesbaden. buildingSMART international (Hg.): Basic FM Handover View. Online verfügbar unter <https://technical.buildingsmart.org/wp-content/uploads/2021/01/GSC-001%20Basic%20HandOver%20to%20Facility%20Management.zip>, zuletzt geprüft am 01.04.2024.
- buildingSMART international (Hg.) (2022): IfcDoor. Online verfügbar unter <https://ifc43-docs.standards.buildingsmart.org/IFC/RELEASE/IFC4x3/HTML/lexical/IfcDoor.htm>, zuletzt geprüft am 11.10.2023.
- buildingSMART international (Hg.) (2024a): Information Delivery Specification IDS. Online verfügbar unter <https://technical.buildingsmart.org/projects/information-delivery-specification-ids/>, zuletzt geprüft am 01.04.2024.
- buildingSMART international (Hg.) (2024b): Model View Definition (MVD) - An Introduction. Online verfügbar unter <https://technical.buildingsmart.org/standards/ifc/mvd/>, zuletzt geprüft am 01.04.2024.
- Chaudhuri, Arindam; Mandaviya, Krupa; Badelia, Pratixa; Ghosh, Soumya K. (2017): Optical Character Recognition Systems. In: Arindam Chaudhuri, Krupa Mandaviya, Pratixa Badelia und Soumya K Ghosh (Hg.): Optical Character Recognition Systems for Different Languages with Soft Computing, Bd. 352. Cham: Springer International Publishing (Studies in Fuzziness and Soft Computing), S. 9–41.
- Davenport, Thomas (1998): Putting the Enterprise into the Enterprise System. Analytics And Data Science. Hg. v. Harvard Business Review. Online verfügbar unter <https://hbr.org/1998/07/putting-the-enterprise-into-the-enterprise-system>, zuletzt geprüft am 27.11.2023.
- Deruyter, Greta; Hennau, Marc; De Wolf, Vicky; Dewulf, Niek: Approach for comparing design and as build models based on data acquisition using a 3D terrestrial laser scanner, a case study. In: Proceedings of the 4th International Workshop on 3D Geo-Information, Ghent University, 4-5 November, 2009, Ghent, S. 2–14.
- Di Filippo, Andrea; Cotella, Victoria Andrea; Guida, Caterina Gabriella; Molina, Victoria; Centarti, Lorena (2021): BIM Interoperability and Data Exchange Support for As-Built Facility Management. In: Osvaldo Gervasi, Beniamino Murgante, Sanjay Misra, Chiara Garau, Ivan Blečić, David Taniar et al. (Hg.): Computational Science and Its Applications – ICCSA 2021, Bd. 12950. Cham: Springer International Publishing (Lecture Notes in Computer Science), S. 702–711.
- East, Bill (2013): Using COBie. In: Paul Teicholz (Hg.): BIM for Facility Managers: Wiley, S. 107–143.
- Ensafi, Mahnaz; Harode, Ashit; Thabet, Walid (2022): Developing systems-centric as-built BIMs to support facility emergency management: A case study approach. In: *Automation in Construction* 133, S. 104003. DOI: 10.1016/j.autcon.2021.104003.
- Fagiar, Muaz; Mohamed, Yasser; AbouRizk, Simaan (2023): Simulation-Assisted Project Data Integration for Development and Analysis of As-Built Schedules. In: *Buildings* 13 (4), S. 974. DOI: 10.3390/buildings13040974.
- Freimuth, Henk; König, Markus (2019): A toolchain for automated acquisition and processing of as-built data with autonomous UAVs. In: Proceedings of the 2019 European Conference on Computing in Construction. 2019 European Conference on Computing in Construction, Jul. 10, 2019: University College Dublin (Computing in Construction), S. 9–18.
- Hausmann, Maik; Lücke, Michael; Lechtenberg, Simon; Guhlemann, Kerstin; Best, Christina (2022): Entwicklung eines Geschäfts- und Betreibermodells für digitale Plattformen im Handwerk am Beispiel von Athene. In: Andreas Ehlert und Hans Jörg Hennecke (Hg.): Personenzentrierte Digitalisierung zur Zukunftssicherung des Handwerks. Ergebnisse des Forschungsprojekts „Athene 4.0“. Düsseldorf: Handwerk NRW w.V., S. 26–34.
- Hellenborn, Benjamin; Eliasson, Oscar; Yitmen, Ibrahim; Sadri, Habib (2023): Asset information requirements for blockchain-based digital twins: a data-driven predictive analytics perspective. In: *SASBE*. DOI: 10.1108/SASBE-08-2022-0183.
- ISO 16739-1, 2018: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.
- Jadidi, Hossein; Ravanshadnia, Mehdi; Hosseinalipour, Mujtaba; Rahmani, Fatemeh (2015): A step-by-step construction site photography procedure to enhance the efficiency of as-built data visualization: a case study. In: *Vis. in Eng.* 3 (1). DOI: 10.1186/s40327-014-0016-9.
- Khan, M. Arsalan (2023): Integrating BIM with ERP Systems Towards an Integrated Multi-user Interactive Database: Reverse-BIM Approach. In: M. S. Ranadive, Bibhuti Bhusan Das, Yusuf A. Mehta und Rishi Gupta (Hg.): Recent Trends in Construction Technology and Management, Bd. 260. Singapore: Springer Nature Singapore (Lecture Notes in Civil Engineering), S. 209–220.
- Klein, Laura; Li, Nan; Becerik-Gerber, Burcin (2012): Imaged-based verification of as-built documentation of operational buildings. In: *Automation in Construction* 21, S. 161–171. DOI: 10.1016/j.autcon.2011.05.023.
- Lauer, Thomas (2021): Wandel als Folge von Digitalisierung. In: Thomas Lauer (Hg.): Quick Guide Change Management für alle Fälle. Berlin, Heidelberg: Springer Berlin Heidelberg (Quick Guide), S. 105–123.

- Lavy, Sarel; Saxena, Nishaant; Dixit, Manish (2019): Effects of BIM and COBie Database Facility Management on Work Order Processing Times: Case Study. In: *J. Perform. Constr. Facil.* 33 (6), Artikel 04019069. DOI: 10.1061/(ASCE)CF.1943-5509.0001333.
- Matarneh, Sandra T.; Danso-Amoako, Mark; Al-Bizri, Salam; Gaterell, Mark; Matarneh, Rana T. (2019): BIM for FM. In: *F* 38 (5/6), S. 378–394. DOI: 10.1108/F-07-2018-0084.
- Memon, Jamshed; Sami, Maira; Khan, Rizwan Ahmed; Uddin, Mueen (2020): Handwritten Optical Character Recognition (OCR): A Comprehensive Systematic Literature Review (SLR). In: *IEEE Access* 8, S. 142642–142668. DOI: 10.1109/ACCESS.2020.3012542.
- Moretti, Nicola; Xie, Xiang; Merino, Jorge; Brazauskas, Justas; Parlikad, Ajith Kumar (2020): An openBIM Approach to IoT Integration with Incomplete As-Built Data. In: *Applied Sciences* 10 (22), S. 8287. DOI: 10.3390/app10228287.
- Moselhi, Osama; Bardareh, Hassan; Zhu, Zhenhua (2020): Automated Data Acquisition in Construction with Remote Sensing Technologies. In: *Applied Sciences* 10 (8), S. 2846. DOI: 10.3390/app10082846.
- Omar, Tarek; Nehdi, Moncef L. (2016): Data acquisition technologies for construction progress tracking. In: *Automation in Construction* 70, S. 143–155. DOI: 10.1016/j.autcon.2016.06.016.
- Otto, Jens; Bartels, Niels (2018): Integration von FM-Prozessdaten in ein digitales Gebäudemodell. In: *Bau-technik* 95 (12), S. 823–831. DOI: 10.1002/bate.201800044.
- Park, Jaehyun; Cai, Hubo (2017): WBS-based dynamic multi-dimensional BIM database for total construction as-built documentation. In: *Automation in Construction* 77, S. 15–23. DOI: 10.1016/j.autcon.2017.01.021.
- Pătrăucean, Viorica; Armeni, Iro; Nahangi, Mohammad; Yeung, Jamie; Brilakis, Ioannis; Haas, Carl (2015): State of research in automatic as-built modelling. In: *Advanced Engineering Informatics* 29 (2), S. 162–171. DOI: 10.1016/j.aei.2015.01.001.
- Pilling, André (2016): BIM - Das digitale Miteinander. 1. Auflage. Berlin, Wien, Zürich: Beuth Verlag GmbH (DIN).
- RealFM (2021): BIM2FM - Leitfaden zur Anwendung der BIM-Methodik in der Betriebs- und Nutzungsphase. Mit Handlungsempfehlungen für Betreiber und Nutzer zum Informationsfluss in allen Lebenszyklusphasen von Bauwerken. 1. Auflage. Berlin: RealFM.
- Son, Hyojoo; Bosché, Frédéric; Kim, Changwan (2015): As-built data acquisition and its use in production monitoring and automated layout of civil infrastructure: A survey. In: *Advanced Engineering Informatics* 29 (2), S. 172–183. DOI: 10.1016/j.aei.2015.01.009.
- Son, Hyojoo; Kim, Changwan; Kwon Cho, Yong (2017): Automated Schedule Updates Using As-Built Data and a 4D Building Information Model. In: *J. Manage. Eng.* 33 (4), Artikel 04017012. DOI: 10.1061/(ASCE)ME.1943-5479.0000528.
- Su, Y. Y.; Hashash, Y. M. A.; Liu, L. Y. (2006): Integration of Construction As-Built Data Via Laser Scanning with Geotechnical Monitoring of Urban Excavation. In: *J. Constr. Eng. Manage.* 132 (12), S. 1234–1241. DOI: 10.1061/(ASCE)0733-9364(2006)132:12(1234).
- Verband für die Digitalisierung im Immobilienbetrieb, CAFM RING e. V. (Hg.) (2019): CAFM Connect. Nahtloser Übergang der Gebäudedaten von Planung und Bau in den Betrieb. Online verfügbar unter <https://caf-m-connect.org/>, zuletzt geprüft am 09.10.2023.
- Verband für die Digitalisierung im Immobilienbetrieb, CAFM RING e. V. (Hg.) (2023): BIM-Profile. Online verfügbar unter <http://caf-m-connect.org/bim-profile/>, zuletzt geprüft am 09.10.2023.
- Yalcinkaya, Mehmet; Singh, Vishal (2019): VisualCOBie for facilities management. In: *F* 37 (7/8), S. 502–524. DOI: 10.1108/F-01-2018-0011.