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Requirements Analysis for BIM based Facility Management of Existing Buildings

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Abstract

The increasing needs and requirements for buildings from people present new challenges and expectations for the facility management (FM) industry. The development of BIM in the AEC industry gives the tools to cope with those challenges and promises many benefits including cost efficiency. Therefore, academia and industry are both motivated to research the possibilities of BIM integration in FM.

Existing practices in the field of facility management already show signs of the introduction of BIM. International standards such as COBie attempt to standardize the process of information handover at building commission. One of the central concepts of BIM is encompassing the entire lifecycle of a building, therefore BIM based FM is a natural progression of the technology. However, the industry still faces significant challenges especially in the field of existing buildings. Therefore, this paper investigates and attempts to define a requirements structure for the introduction of BIM based FM for existing buildings. It also makes an assessment of one of the most challenging steps, the Scan-to-BIM process, by undertaking a case study. It is demonstrated that despite fast technological advancement in the field of automation, the available tools still require large amount of manual input.

The field of BIM based FM for existing buildings presents challenging research opportunities which will enable its further implementation in the industry. This thesis finds three most significant topics of further research. These are (1) automation of Scan-to-BIM, (2) integration and interoperability improvement, and (3) requirements definition and system design process.

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List of Abbreviations

BIM	Building Information Modelling
FM	Facility Management
CAFM	Computer Aided Facility Management
CDE	Common Data Environment
CMMS	Computerized Maintenance Management System
IWMS	Integrated Workplace Management System
CAD	Computer-Aided Design
AEC	Architecture, engineering and construction
LoD	Level of Detail
LOD	Level of Development
LOIN	Level of Information Need
HVAC	Heating, ventilation, and air conditioning
MEP	Mechanical, electrical, plumbing
IFC	Industry Foundation Class
SLAM	Simultaneous Localization and Mapping

1 Introduction

The management of buildings, especially those of large proportions and of public service, is a critical activity which has a significant impact on life and requires sizeable manpower and financial load. Therefore, both professionals and academia who focus on facility management (FM) are always working on improvements which can make the process more efficient and can bring higher quality for the end users. Facility management is important both in terms of its impact on the life of people, as well as its economic significance. Design and construction require a large one time capital investment, but they are estimated to be only 15% of the total lifecycle cost of a building (E. Teicholz 2004), and other sources suggest this can be even less. Even though it is spread over time the cost of operating a building is far larger, therefore efficient facility management is important.

Being part of the wider AEC industry facility management is also impacted by the introduction of BIM and evidence suggests that the potential for improvement by its application is significant. Based on published UK commercial data, 'as measured' benefits of BIM are already evident, but a prediction is made that savings through the use of BIM in FM are likely to outweigh those in the rest of the building life stages ('A Report for the Government Construction Client Group. BIM Working Party Strategy Paper' 2011). The original concept of BIM involves its implementation in the entire lifecycle of a built asset. Therefore, the investigation of its application in facility management is a natural progression, as well as an interesting topic with promising future. This application is referred to as BIM based facility management.

The benefits from the application of BIM are already relatively well established, but it is often seen as a technology or method of work which is applied only in new build projects. This paper considers the large amount of existing buildings and attempts to demonstrate the technology, as well as the potential for application of BIM based facility management in them. Perhaps the most significant challenge specific to existing buildings is the creation and maintenance of a BIM model with little to no existing information. This topic is already researched in literature and there are three main challenges identified: (1) high modelling effort from captured building data into semantic BIM objects, (2) updating of information in BIM, and (3) handling of uncertain data, objects and relations in BIM occurring in existing buildings (Volk, Stengel, and Schultmann 2014). Both industry and academia have come up with technological solutions to these challenges which are discussed in this paper.

1.1 Motivation

The built environment is growing and is becoming more complex in its aim to meet the increasing needs of people, as well as their goal for more efficient operation. Therefore, the management of buildings faces higher expectations and stricter requirements. BIM is seen as a potential solution to these challenges, which can make the industry more efficient and can bring quality improvement.

The specific motivation of this thesis stems from the case of the TUM Department of Chemistry which resides in a building constructed more than 40 years ago. The administration is investigating the scenario of introducing a BIM based FM workflow and for this purpose also creating a BIM model of their assets. Currently the department is undertaking facility management based on historical arrangements and local knowledge. Their data management and processes are limited to basic information storage tools such as spreadsheet files and no dedicated FM system is being used. The decision to investigate BIM based FM is supported by existing challenges of the department. These include specific problems such as limited and outdated asset information and no transparency on work orders status, as well as system challenges such as efficiency increase in space management and maintenance of the assets.

This thesis takes on the task of answering the questions which these challenges pose. This is namely the analysis of the requirements for creating and operating a BIM based FM system that meets the needs of an institution such as the Department of Chemistry at TUM. This analysis involves answering the questions of how a 3D BIM model for an existing building is created and what its technical requirements are. Also, what the requirements for BIM based FM as a system are and what the process of defining them is. Answering these questions is the main motivation of this thesis, however, in the process it also deals with others which are necessary prerequisites.

1.2 Approach

In order to tackle the topic proposed in the previous chapter this thesis takes on a structured approach, which deals with the complexity of the topic by separating it in manageable pieces and finally coming to a holistic answer.

The thesis first focuses on the background required to work on the topic of BIM based FM through an extensive literature review which is found below in chapter 2. This includes the nature of facility management including capabilities of existing solutions, as well as state of the art technology. Furthermore, the paper examines the existing implementation of BIM in facility management, as well as current research found in literature.

After an understanding is formed of facility management, BIM and the integration of both, the thesis deals with the topic of BIM models for existing buildings found in chapter 3. In this chapter the current process and methods for creating models are critically reviewed, as well as the most promising modern technologies.

In chapter 4 the thesis investigates the requirements for the BIM based FM of an existing building. This includes concise literature review and definition process, as well as the proposal of a requirements structure. It is suggested that model and system requirements are defined in terms of maturity levels and a matrix.

Finally, in chapter 5 the thesis presents a case study for the creation of a BIM model for the purposes of facility management. The test subject is a university building, in specific part of the interior space of one floor. The case study analyses the entire process from data capture to model and system implementation.

In the conclusion in chapter 6 the thesis makes a summary of the findings on the topic of BIM based FM. It also makes recommendations for further research on the topic.

2 Background

To discuss the role of BIM in facility management this paper goes through a series of steps to gradually build up the required background knowledge. It starts with the definition, nature and need for facility management. Then it deals with different tools and methods employed in the field. Finally, it delves into the actual topic of BIM based FM. This is done through a methodical literature review presented in the following chapters.

2.1 Facility Management

The definition of Facility Management (FM) according to ISO 41001:2018 is:

"[An] organizational function which integrates people, place and process within the built environment, with the purpose of improving the quality of life of people and the productivity of the core business."

From this definition and others found in literature (Roper and Payant 2014) it is evident that facility management is not one activity, but rather a wide range of activities. There are no items that are strictly defined because it is a function that is tailored to the needs of the specific organization. This means that in facility management a one-size-fits-all solution does not exist. This is evident in the list of common functions in this industry. It is seen below in Table 2.1 that according to different sources these lists can contain anywhere between 4 and 15 items (Barrett and Baldry 2003; Becerik-Gerber et al. 2012; Roper and Payant 2014).

Table 2.1 Common FM functions as listed in different sources

(Barrett and Baldry 2003)	(Becerik-Gerber et al. 2012)	(Roper and Payant 2014)
4 functions	6 functions	15 functions
Real estate and building Facility planning Building operations General/office services	Real estate management Energy management Noncapital construction Maintenance and repair Quality assurance and control Commissioning and close out	Management of the organization Facility planning and forecasting Lease administration Space planning, allocation, and management Workplace planning, allocation, and management Budgeting, accounting and economic justification Real estate acquisition and disposal Sustainability Architectural/engineering planning and design Construction project management Operations, maintenance and repair Technology management Facility emergency management Security and life-safety management General administrative services

Several important topics emerge from these lists. To begin with facility management is responsible for the real estate owned by an organization. This can encompass activities such as leasing, acquisition, and disposal. The facility managers should also plan and forecast the use of its assets, as well as manage general office and administrative services. However, arbitrarily the most essential function of FM is to operate the buildings, for which it is responsible. This can be described simply by building operations

(Barrett and Baldry 2003) or broken down into a more detailed list including maintenance and repair, energy management, noncapital construction and more (Becerik-Gerber et al. 2012). These are the activities that are a prerequisite for the successful operation of a building, and they are part of the life of any built asset independent of the complexity of the facility management process. In this paper these essential functions will be discussed in more detail.

The role of facility management is further emphasized by its economic significance. There are different estimates of the cost of facility management compared to other parts of the building lifecycle such as construction or demolition. However, all of them agree that the better part of these costs occur in operation and maintenance and some even suggest they are several times greater. Teicholz suggests that design and construction are often less than 15% of the total lifecycle cost of a building (E. Teicholz 2004). Another source suggests that lifecycle costs of a building can be 5 – 7 times higher than initial investment costs (S. K. Lee, An, and Yu 2012). The UK government also recognizes that “maintenance and operational costs of a facility far outweigh the original capital cost of construction”(Philp, Churcher, and Davidson 2019). Whole lifecycle cost theory goes even further to suggest that for every £1 spent on capital, £50 is spent on maintenance, and £200 on operational costs (Boussabaine and Kirkham 2008). Facility management is the discipline responsible for the management of these costs, therefore this serves as further motivation to dig deeper into the possibilities for its improvement. Going back to the definition of this discipline it is now known that FM is of great significance to the quality of life of people and the success of business, as well as their economic performance.

2.1.1 CAFM

In order to understand facility management, it is necessary to know the tools used by the industry. These tools range from paper-based systems to the most sophisticated digital solutions which exist today. This report will focus on the higher end of this spectrum since the goal is to understand the benefits of digitalization and later on BIM. Computer-Aided Facility Management (CAFM) is among the most prevalent terms found in the field. CAFM provides the administrative tools and ability to manage facilities operations. CAFM includes the creation and utilization of IT based systems in the built environment. A typical CAFM system can be described as a combination of CAD and relational database software with specific abilities for facility management (Watson and Watson 2016).

According to the German Facility Management Association (GEFMA), CAFM software are the tools used to implement and support facility management with the help of modern information technology over the entire lifecycle of the asset (GEFMA 2022a). Some of the core applications from GEFMA 400 standard include (GEFMA 2021):

- Space management
- Maintenance management
- Inventory management
- Cleaning management
- Room and asset booking
- Security management
- Relocation management
- Rental management
- Energy controlling
- Safety and occupational safety management
- Environmental protection management
- Help and service desk
- Budget management and cost tracking
- BIM data processing
- Contract management
- Workplace management
- Utility bills

This list is comprehensive since it is provided by a regulating body, however, it does not mean that a CAFM system necessarily offers all of this functionality. Practical implementations of CAFM are more likely to only provide parts of these applications which are found to be necessary by the individual organization using it. Nevertheless, it shows that CAFM can have a wide range of capabilities.

2.1.2 CMMS

Computerized maintenance management system (CMMS) is another tool frequently found in the facility management industry. According to IBM CMMS is “a software that centralizes maintenance information and facilitates the process of maintenance operations." The core capabilities include:

- Resource and labor management
- Asset registry
- Work order management
- Preventive maintenance
- Materials and inventory management
- Reporting, analysis and auditing

These systems emerge from large technological enterprises maintaining physical equipment and today it is also employed by different industries including facility management (IBM 2022).

CMMS tends to be geared towards the technical side of facility management rather than organizational activities. It is a system that will be more suited for equipment servicing and maintenance, including the management and tracking of work orders. Therefore, this might be a preferred choice for organizations such as production facilities and probably less preferred for office spaces or other human oriented spaces.

2.1.3 IWMS

Finally comes the most recently emerged term, Integrated workplace management system (IWMS). GEFMA defines IWMS as "an IT system which integrates functionalities of room and area management, real estate management, maintenance and repairs including building maintenance, project management, as well as energy and sustainability management on a unified web-based platform." It goes on to say that in Europe the term can often be equated with CAFM (GEFMA 2022b).

However, IWMS can also be described as a software system that integrates the space tracking capabilities of CAFM and the maintenance tracking capabilities of a traditional CMMS (Accruent 2022). It is also pointed out that Integrated Workplace Management System came up as a term in 2004 by Gartner, the leading technology research institute that evaluates and reports on software and technology markets. Gartner defines IWMS as an "enterprise-class software platform that integrates key components in five functional domains, operated from a single technology platform and database repository" (Planon 2022). These domains are:

- Real Estate and Lease Management
- Facilities and Space Management
- Asset & Maintenance Management
- Project Management
- Environmental Sustainability

It is perhaps best said that IWMS is a term which describes the most comprehensive technological solution that facility management can employ to its use. It brings all necessary functionalities under one roof and aims to satisfy all requirements of the facility manager as well as the enterprise.

Together with CAFM and CMMS, these are the tools that stand out in facility management literature. While they are identified as stand-alone terms, there appears to be a lot of overlap. The critical functionalities required by the industry are found in the definition of each of these systems. Perhaps facility management solutions are better characterized by the specific capabilities that are offered, rather than the terminology.

Figure 2.1 The three FM Tools which stand out in literature

2.2 BIM based FM

A concise summary of traditional facility management and its tools is given above. With this background knowledge in this chapter the paper discusses the concept of BIM based FM. This can initially be described as the use of BIM tools to facilitate more efficient and effective facility management process. To provide motivation for the implementation of BIM in FM, Figure 2.2 illustrates how information is lost between the different stages of a project and gives an estimate of a $15.8 Billion loss due to this information mismanagement. This loss of information is preventable and the answer to this may be the implementation of BIM throughout the entire lifecycle of a building.

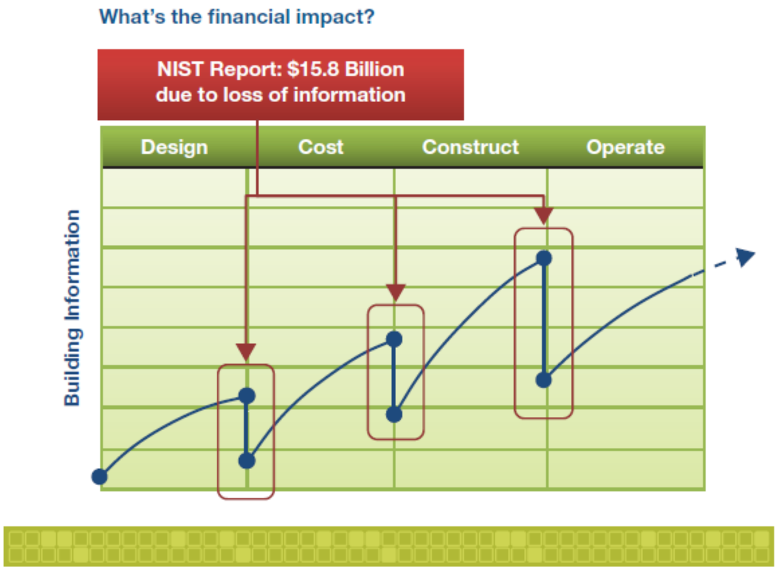


Figure 2.2 Loss of value as information is lost (E. Teicholz 2004)

2.2.1 Introduction to BIM and FM

It is assumed that the reader is well acquainted with the building information modelling (BIM) theory, hence it is not described in such detail. However, as a short reminder and to set the right tone, this is the BIM definition according to the Road Map for Digital Design and Construction of the Federal Ministry of Transport and Digital Infrastructure:

"Building Information Modelling means a collaborative work method that creates and uses digital models of an asset as a basis for the consistent generation and management of information and data relevant to the asset's lifecycle as well as for the sharing or passing on of such information and data between the participants for further processing by way of transparent communication." (Bramann and May 2015)

The main idea of the BIM process is the efficient use of information for all needs related to the lifecycle of an asset. The integration of BIM is most notable and advanced at the planning and construction stages of a project. In many countries it is already mandated that the BIM method should be used, and this trend is likely to continue. While the method is already applied in the industry for planning and construction, it remains mostly at research level for the rest of the asset's lifecycle stages. However, the underlying concept of BIM is that it is utilized for the whole duration of the life of a building, as seen in the definition above and in Figure 2.3 below. Therefore, the natural progression of its development is to encompass the operation stage, or facility management.

Figure 2.3 BIM reference process (Bramann and May 2015)

Another concept relative to the development of BIM is the addition of dimensions. Historically all building drawings were only in 2D and new technology allowed for the construction of 3D models. This concept in modeling was taken further by introducing a 4^{th} dimension, which is time. From there stems the theory of nD modeling. It builds upon the 4D modelling theory and further integrates an n^{th} number of design dimensions into a holistic model. This enables users to work through the whole lifecycle of an asset in one place. (A. Lee et al. 2005)

The 4^{th} dimension is generally established to be time or scheduling and the 5^{th} – cost (Volk, Stengel, and Schultmann 2014). However, the continuing list of dimensions can also include maintainability, sustainability and accessibility among other topics. This concept demonstrates the expanding use and the potential of BIM.

Other authors describe the evolution of BIM in a different manner. For instance, this could be through the identification of different types of BIM models. These include:

- BIM design model
- BIM construction model
- BIM as-built model
- BIM FM model

According to this theory one of the biggest challenges ahead of facility managers is the flow of information between these models. (Schley et al. 2016) In all theories it is clear that the aim should be a seamless integration of BIM throughout the whole lifecycle and encompassing all aspects of a built asset.

Finally, to realize this integration it is also necessary to use fully open process and data integration by ‘web services’. This is described at the highest level of the UK BIM maturity model and it is also referred to as iBIM. (‘A Report for the Government Construction Client Group. BIM Working Party Strategy Paper’ 2011) More modern theory refers to this technology as cloud computing, cloud-based BIM or simply cloud-BIM and the basic concept is illustrated in Figure 2.4. It enables higher level of cooperation and collaboration and provides a real-time communication platform. As portrayed the system is centralized by the cloud where computation, storage and processes occur while devices such as laptops, tablets or mobiles are used only for communication. (Wong et al. 2014)

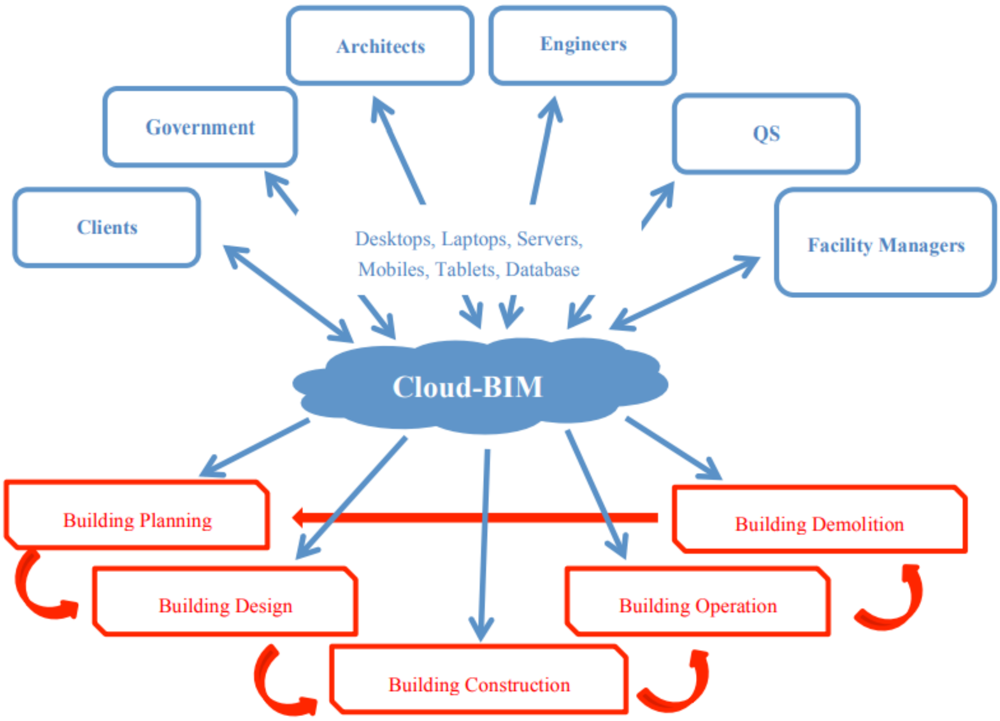


Figure 2.4 Cloud-BIM concept (Wong et al. 2014)

2.2.2 BIM uses for FM

Based on published UK commercial data, 'as measured' benefits of BIM are evident and reflect the current usage of BIM, which is mostly in the design/pre-construction stages. Moreover, a prediction is made that savings through the use of BIM in FM are likely to be significantly greater than for the rest of the stages ('A Report for the Government Construction Client Group. BIM Working Party Strategy Paper' 2011). This is illustrated in Figure 2.5 below where the red line demonstrates benefit which is already measured, and the green line demonstrates upside potential. Another study shows the amount of money which is wasted while looking for, validating, and/or recreating facility information that should be readily available in the U.S. Capital Facilities Industry was estimated at $15.8 billion in 2002 (GSA 2011). BIM can be employed to prevent this waste and achieve those potentials, therefore further research in BIM uses for FM is worthwhile. In this chapter the paper aims to describe the main BIM applications in FM found in literature, including existing practices and potential developments.

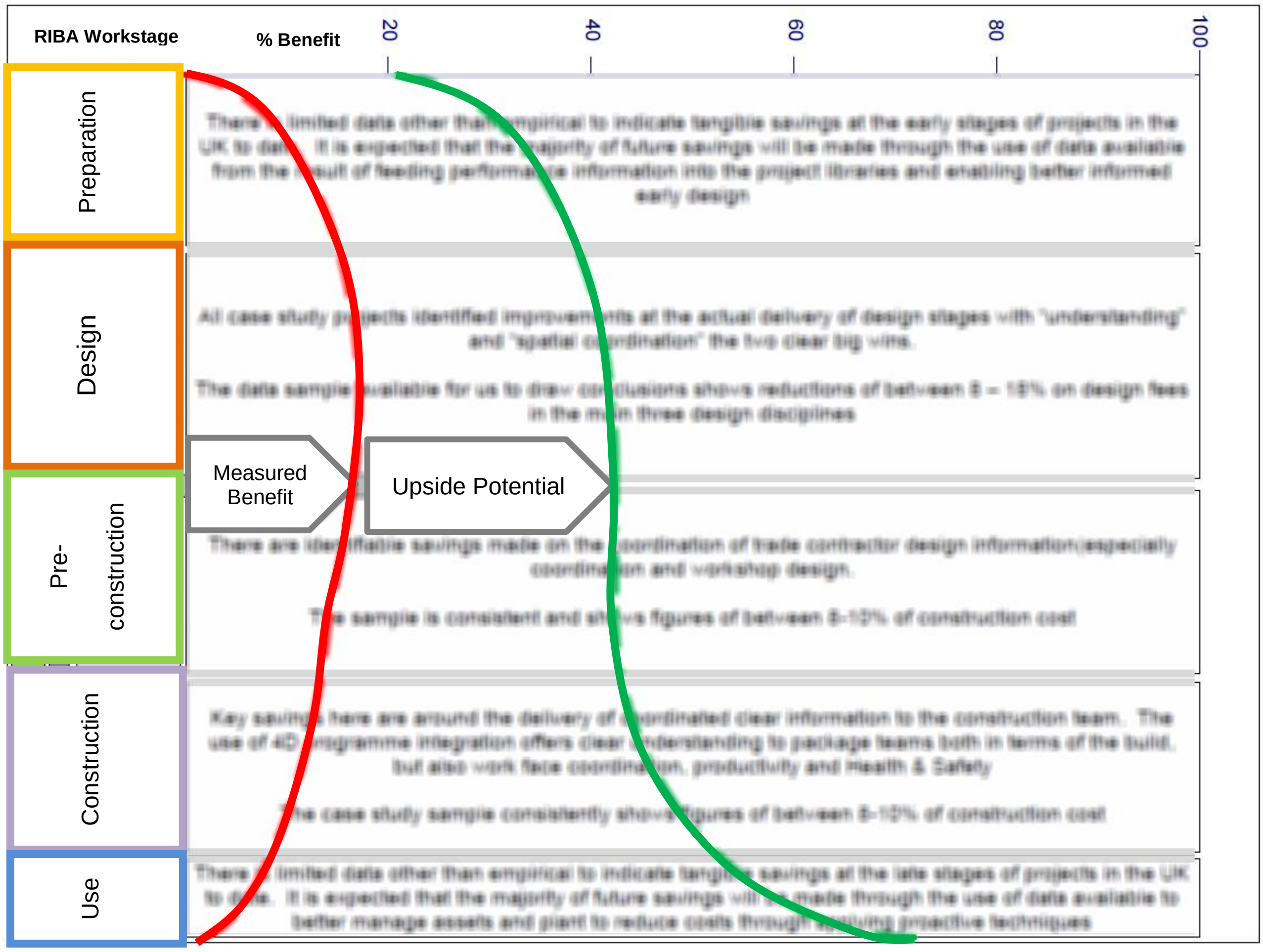


Figure 2.5 Measure and potential benefits of BIM graphical representation ('A Report for the Government Construction Client Group. BIM Working Party Strategy Paper' 2011)

There is already extensive literature on the use of BIM in FM. Becerik-Gerber identifies potential FM application areas that BIM can be used for through an expert survey (Becerik-Gerber et al. 2012). The list of potential BIM applications is seen in column one of Table 2.2. Some of those areas include locating building components and facilitating real-time data access, which seem to be trivial tasks in maintenance. However, this highlights the fact that even simple operational activities have potential for improvement which can be realized with the aid of BIM. Furthermore, the list mentions more comprehensive activities such as space management, emergency management, energy management and others. These are areas where a more complex solution might be necessary, but again the survey responders identify the serious potential for BIM application. In column two of Table 2.2 there is a list which attempts to summarize the general FM areas of value for BIM application. These are system level improvements rather than individual applications.

Potential FM applications and improvement areas for BIM	**FM areas of value for BIM application**
(Becerik-Gerber et al. 2012)	(Schley et al. 2016)
Locating building components	
Facilitating real-time data access	
Visualization and marketing	
Checking maintainability	Improved space management
Creating digital assets	Streamlined maintenance
Space management	Efficient use of energy
Planning and feasibility studies for noncapital construction	Economical retrofits and renovations
Emergency management	Enhanced lifecycle management
Controlling and monitoring energy	
Personnel training and development	

Table 2.2 Potential BIM applications in FM

Furthermore, Kassem formulates differently the main advantages of applying BIM in facility management. These include:

- Improvement to current manual processes of information handover
- Improvement to the accuracy of FM data
- Improvement to the accessibility of FM data and efficiency increase in work order exchange
- Increase of efficiency for creating bespoke plans, elevations and visual renders all from the same model
- The ability to attach legislative/statutory compliance data, which can be reported and scheduled out of the one model
- The potential for room finding and accurate fault reporting through the interrogation of the model
- The ability to scenario plan refurbishment projects in a 3D environment.

This list is task oriented rather than system. For instance, the current process of information handover from end of construction phase to operation phase may include inefficient recreation of information in large scale. This can be represented by data regarding materials, finishes or equipment which is known, but because it is not transferred properly, is lost and has to be collected again. An efficient handover of this information can provide good data quality within an easy to orientate 3D environment, which can in turn lead to increased operation efficiency. (Kassem et al. 2015)

In a case study of the Sydney Opera House the key generic features of BIM required for the support of asset and facility management are identified as follows.

- Robust geometry
- Comprehensive and extensible object properties
- Semantic richness
- Integrated information
- Lifecycle support

Here by semantic richness is understood that the model provides object relationships which can be useful for analysis and simulation. Integrated information means the use of single repository with data organized in a consistent, accurate and accessible way. Finally, it is highlighted that the purpose of BIM is not only during design and construction, but through the whole lifecycle of a building (Morris et al. 2006).

Furthermore, BIM in facility management can be used to commission a building more efficiently, quickly populate a facility management database, manage facility assets with BIM asset management tools or to rapidly evaluate the impact of retrofit or maintenance work on the facility. An example scenario is when the facility manager can use a 4D model to monitor the condition of an asset and based on that have more accurate financial planning (Eastman 2011).

A case study from New Zealand directly demonstrates the potential in energy management. After the introduction of a modern FM system, they were able to use timetabling to regulate heating, ventilation and air-conditioning in teaching spaces. This led to a significant reduction in electricity consumption. (‘Casestudy: UNITEC’s Integrated Information System’ 2019) This effect may only be partially attributed to BIM, however it demonstrates the potential of having a central information repository which is accessible by the correct person. In other words, this is the ability of the system to provide the right information where it is needed, and this is a central concept in BIM based FM.

This is also recognized by the Institute of Workplace and Facilities Management, who highlight the need of facility managers for easy access to data and information in order to optimize the operation of built assets. This includes good quality, well structure information which can be measured and analyzed. (IWFM 2020)

As seen so far, there are multiple application areas for BIM in FM. Some sources demonstrate individual tasks or give lists of multiple applications. Other sources aim to define processes which have influence on system level. Finally, there are those who aim to define the areas of FM which are improved by BIM. In order to make it more understandable and interpretable, this knowledge is structured in a summary of the findings.

2.2.3 Summary of BIM uses for FM

There are different ways to demonstrate the effect of BIM on FM, however, these can be generally divided in two categories. The first category includes specific use cases such as tasks or projects. The second one contains applications of BIM which lead to improvement in processes or methods of work. A structured summary of these findings is provided below in Figure 2.6. It is not an exhaustive list, however, it highlights recurring themes found in literature. Under 'Tasks' are summarized specific BIM applications leading to the improvement of a concrete task. Some of them are already demonstrated in industry such as the more efficient management of HVAC systems ('Casestudy: UNITEC's Integrated Information System' 2019). Tasks are useful to demonstrate benefits of BIM in a direct and measurable fashion. However, the execution of tasks is enabled by the underlying processes. These processes, as well as system capabilities, are summarized in the first column of the figure. They include improvements which are mostly related to the management and structure of information. This includes elements such as central repository, accessibility, semantic richness of the model, as well as information structure. These characteristics of the improved system can then enable improved efficiency and effectiveness in task or project executions. Finally, the tasks can be attributed to different areas of facility management, therefore identifying where improvements are to be expected. Although most FM areas are impacted there are a few which stand out, namely space management, maintenance, energy management and information management. Together these can have a profound effect on the entire facility management process and can therefore lead to an enhanced lifecycle management of the building asset.

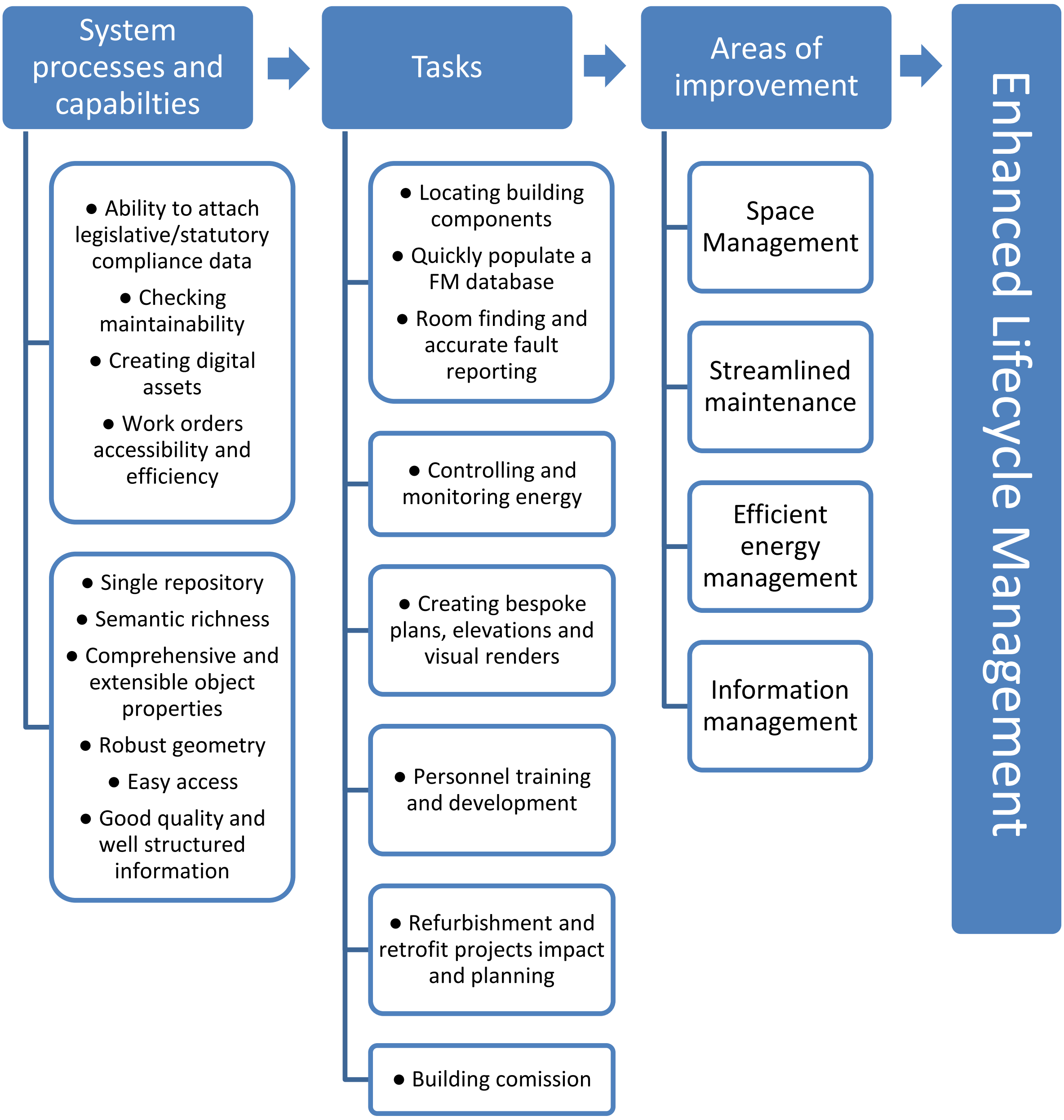


Figure 2.6 Summary of BIM based FM system processes and capabilities which facilitate enhanced lifecycle management

However, the implementation of BIM in facility management is not without challenges. Some of these include the lack of methodologies that demonstrate the benefits of BIM, the limited knowledge of implementation requirements, the interoperability between BIM and FM technologies, and the shortage of BIM skills in the FM industry (Kassem et al. 2015). Another significant obstacle is the accuracy of data capture and BIM model generation for existing buildings (Volk, Stengel, and Schultmann 2014). This also includes issues related to interoperability between BIM and existing CAFM systems (Pärn, Edwards, and Sing 2017; Soliman et al. 2021). Finally there is a lack of real-life case studies and cost-benefit analysis related to BIM implementation, especially for existing buildings (Kassem et al. 2015; Volk, Stengel, and Schultmann 2014).

2.2.4 IFC

There are several technological developments that are necessary to know in order to understand the potential of BIM based FM. Therefore, the report provides a concise introduction to some of them here beginning with Industry Foundation Classes (IFC).

IFC is specified and developed by buildingSMART and is described as "an open, vendor-neutral BIM data repository for the semantic information of building objects, including geometry, associated properties, and relationships to facilitate:

- cross-discipline coordination of building information models, including architecture, structural, and building services,
- data sharing and exchange across IFC-compliant applications,
- handover and re-use of data for analysis and other downstream tasks" (Thein 2011).

IFC is capable of representing both the geometry and the semantic structure of a building using an object-oriented approach, including details, as well as interrelationships (Borrmann et al. 2018).

As a vendor-neutral format IFC allows the transfer of models and information between different software. As highlighted earlier the integration between BIM and CAFM is recognized as major challenge and IFC is a tool which provides a solution. It is also a format which has all of the functionality to enable BIM facilitated improvement, such as semantic richness or comprehensive and extensible object properties.

Figure 2.8 shows an example of relations between spatial objects in the different hierarchical levels. This is to demonstrate the capabilities and the structure of IFC.

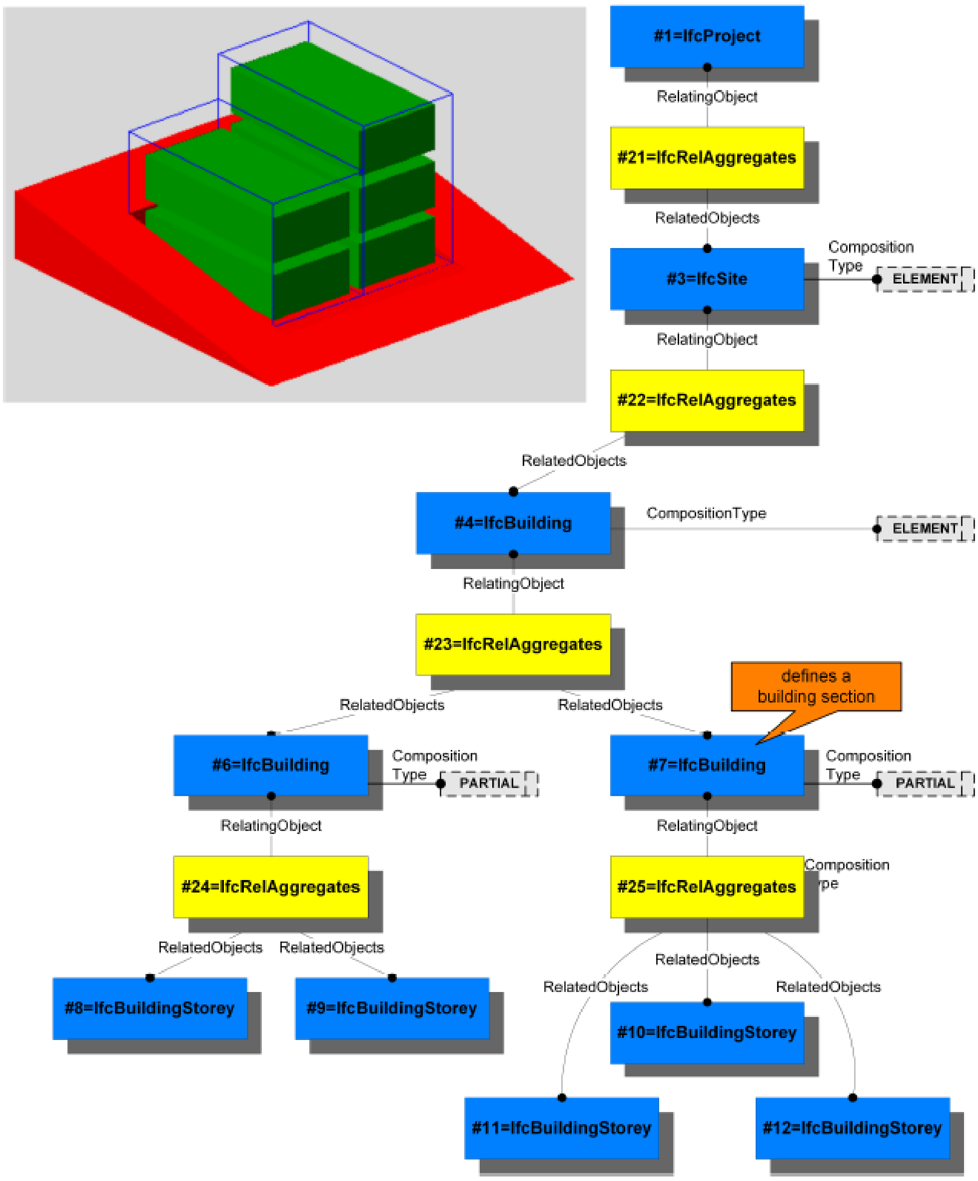


Figure 2.7 Example IFC structure(Borrmann et al. 2018)

2.2.5 COBie

There are solutions that are specifically targeted at facility management such as the Construction Operation Building Information Exchange (COBie). COBie was developed to manage non-graphical BIM data and in particular its handover during building commission. It was designed to provide all information necessary to maintain, operate and manage the facilities. In order to do this COBie uses an open international standard data exchange format aiming to provide longevity of the information as well as easy access and integration. There are three information formats used today – STEP, ifcXML and SpreadsheetML. The first two are related to IFC and are oriented to computer-to-computer interactions. The third is to ensure simplicity and human readability and provides COBie information in a spreadsheet format for which a set of translation rules were developed between IFC and the spreadsheet format (East 2018).

The structure of COBie can be seen in Figure 2.8. It is divided in three main categories. The first is information provided by the designers, second being from contractors, and the third is by both. Inside are seen the main data types that COBie requires (East 2018).

In summary COBie provides structured information for built assets in a format that is easily accessible. It is aimed at semantic data rather than geometrical representation.

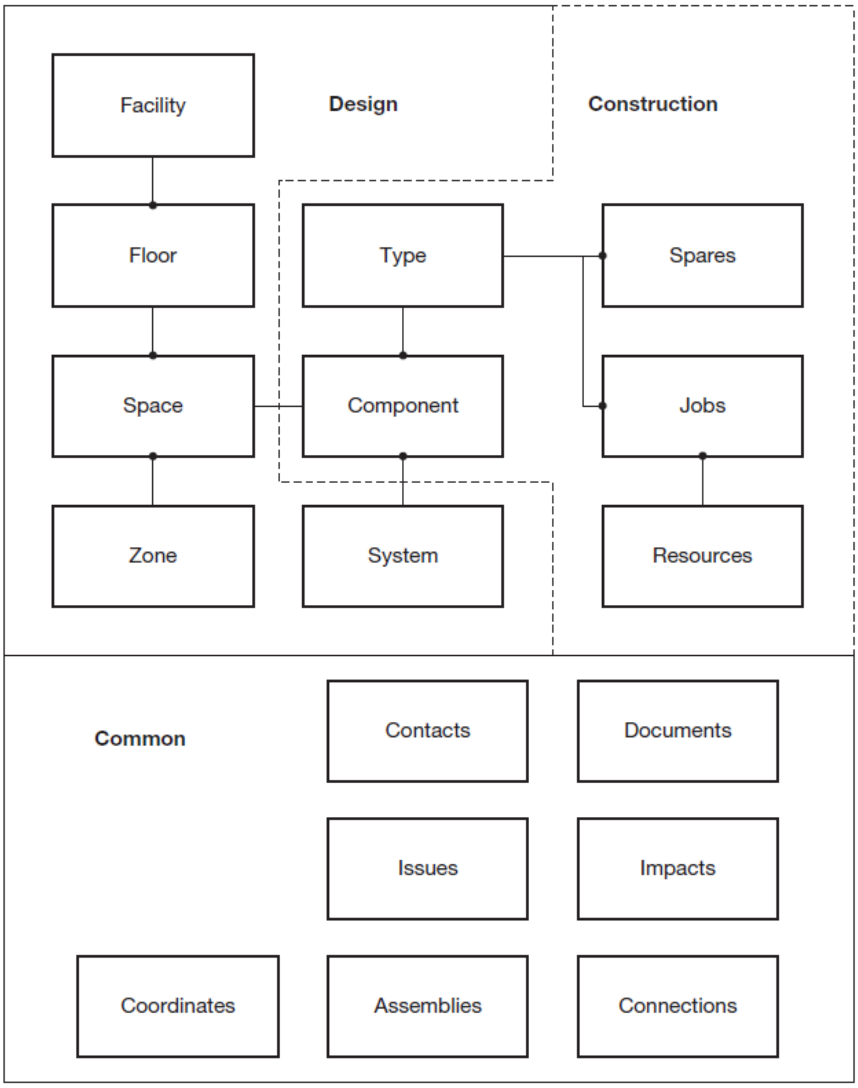


Figure 2.8 COBie organization (East 2018)

2.2.6 Classification systems

Classification systems are helpful for the uniform storage of information which is a prerequisite for its successful management. There are different methods to classify information, however, when it is standardized across an entire industry, than it facilitates the more efficient transfer of information and the interoperability of software.

There are four main construction classification systems:

- Omniclass (North America)
- Uniclass (UK)
- MasterFormat (North America)
- UniFormat (North America)

Each of these systems is created with a specific purpose and uses specific grouping principle, organization and taxonomy. (Kereshmeh Afsari and Eastman 2016)

Farghaly et. al. (2017) proposes a taxonomy of the required data for successful implementation of BIM based on literature review of different classifications and expert interviews. Figure 2.9 shows a diagrammatic representation of this proposal.

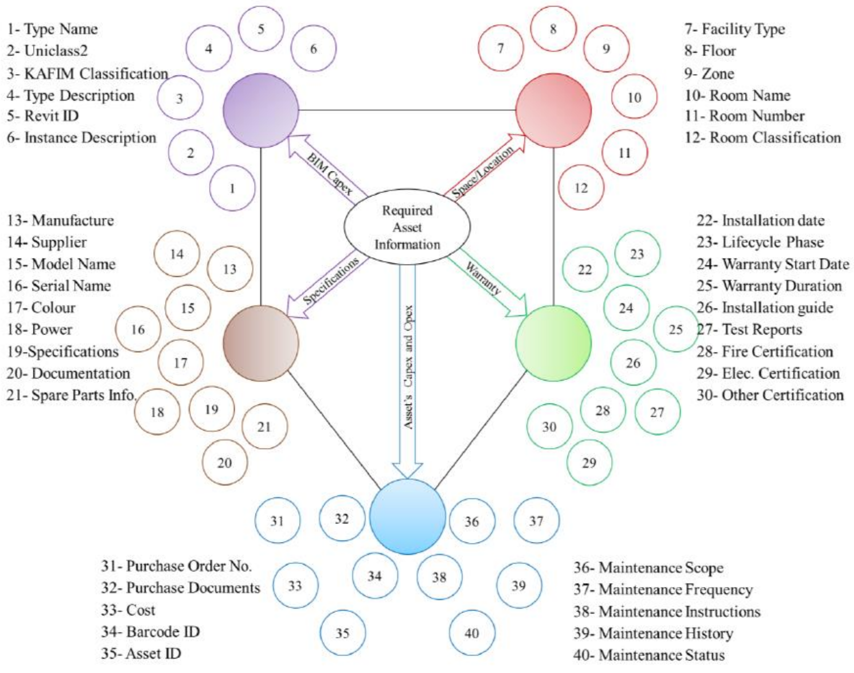


Figure 2.9 Proposed taxonomy for required parameters for asset management (Farghaly et al. 2017)

A classification system may adopt different structure or naming convention, but it is clearly necessary for the industry. Standardizing naming of information is of great importance and this is also demonstrated in case studies (GSA 2011).

3 BIM models for existing buildings

The implementation of BIM in the AEC industry faces a variety of challenges, however, existing buildings present a major one. The idea of BIM is that it should span through the entire lifecycle of a built asset from conception to end of life. There are a lot of already existing buildings which can also benefit from the implementation of BIM. This brings up the challenge of implementing BIM for existing buildings. As discussed earlier the operational stage in the life of a building is responsible for the majority of cost, therefore it can also have some of the biggest saving potential. BIM can be a facilitator for the realization of this potential with its ability to improve the process of maintenance, refurbishment or decommissioning of existing buildings.

A comprehensive literature review on the topic of BIM for existing buildings suggests BIM implementation is scarce due to three main reasons. These are (1) high modelling effort from captured building data into semantic BIM objects, (2) updating of information in BIM, and (3) handling of uncertain data, objects and relations in BIM occurring in existing buildings (Volk, Stengel, and Schultmann 2014).

Perhaps the most significant challenge in implementing BIM for an existing building is the gathering of information and creating an accurate and semantically rich model. This can be done using a variety of methods. In this chapter the report gives a review of existing practices, as well as promising concepts.

3.1 Process

To begin let's consider the process of creating a BIM model for an existing building. There are different techniques which can be used, and these depend on the current situation and the final goal. However, the process can usually be divided into three stages – (1) data collection, (2) processing and (3) modelling of the BIM model (Tang et al. 2010). The data collection or data capture involves the process of gathering the necessary information for the given asset. This information includes geometry, as well as semantics. Preprocessing refers to the manipulation of the gathered data in order to refine and raise the information quality to a standard which makes it suitable for the modelling stage. Finally, the BIM model can be created by using the gathered and preprocessed information. Creating it involves modelling the geometry of the components, assigning object category and properties and establishing relationships between components (Tang et al. 2010). This is usually a process involving a lot of manual work.

The creation of the model can vary in its execution depending on the building, new or existing, as well as availability of BIM information as seen in Figure 3.1 where three different cases are presented. However, in this report the main interest lies in the third case where the building is existent and there is no BIM information. This is also the most challenging case.

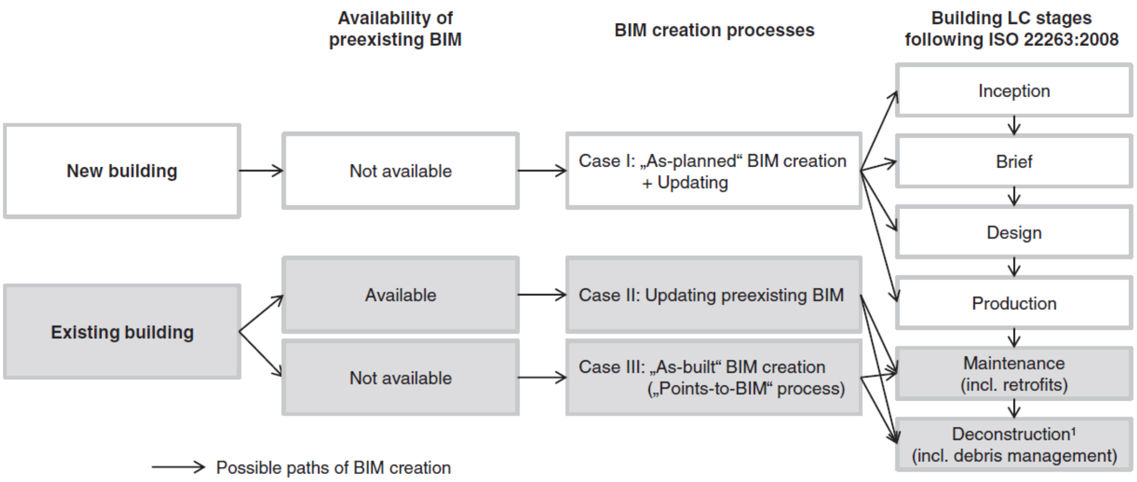


Fig. 2. BIM model creation processes in new or existing buildings depending on available, preexisting BIM and LC stages with their related requirements [45,46].

Figure 3.1 BIM model creation process (Volk, Stengel, and Schultmann 2014)

3.2 Data capture

Many existing buildings have obsolete or missing as-built information and the accuracy of data capture is a significant challenge (Volk, Stengel, and Schultmann 2014). This makes the process of creating a model, also called reverse engineering, hard and costly. The first step is data capture and the rest of the process depends on it.

In practice many older buildings have 2D plans in paper or digital format which can be used to create a 3D BIM model. However, this does not solve the problem for a couple of reasons. First, as discussed, this information is often incomplete or out of date, which incapacitates the creation of a full and accurate model. And second even if complete and accurate information is available, the manual creation of BIM model of a large asset will be labor intensive leading to long timescales and high costs (Soliman et al. 2021; Kassem et al. 2015).

Therefore, in most cases the data capture of information on site is a definite requirement. In industry there are different methods to do that. Older ones include using a total-station and measuring tape, which can be too time-consuming or inaccurate at large scale. The more modern and most prevalent techniques are terrestrial laser scanning and photogrammetry (Son, Kim, and Turkan 2015). Laser scanning can measure the distance from the sensor to nearby surfaces with millimeter to centimeter accuracy at speeds of thousands to hundreds of thousands point measurements per second (Tang et al. 2010). This method tackles both accuracy and speed and is therefore seen as one of the most promising. The basic theory behind the technology is illustrated in Figure 3.2 below. The method does not come without drawbacks. In practice the use of total station is often also necessary, the equipment is costly and fragile, and requires significant postprocessing (Volk, Stengel, and Schultmann 2014). Image-based methods photogrammetry and videogrammetry, which in principle have inferior accuracy, show promising results, especially to be used in combination with laser scanning (Tang et al. 2010; Soliman et al. 2021).

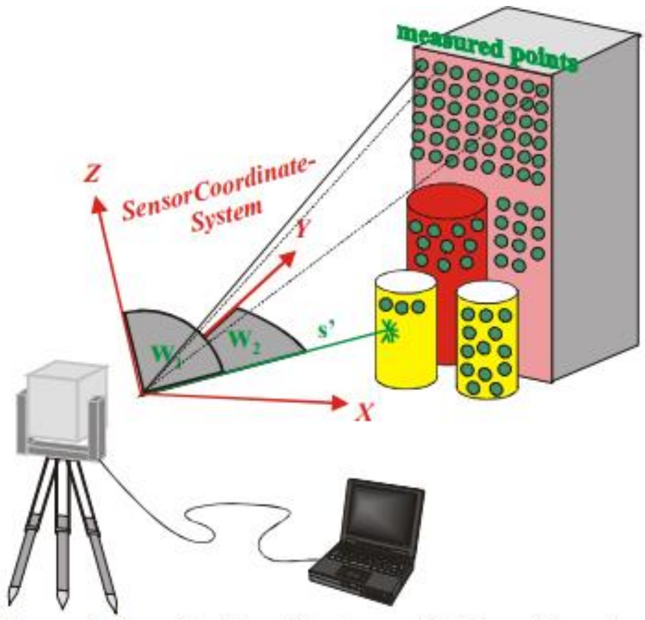


Figure 2. the principle of tacheometric Laser Scanning

Figure 3.2 Laser scanning principle (Staiger 2003)

Other methods include tagging or preexisting information which can be a good source, but they are dependent on availability and quality as discussed earlier. A graphical summary of the available techniques can be seen in Figure 3.3. Currently the industry shows the most interest for non-contact techniques, especially, image-based and range-based, due to their speed, accuracy and ease of application.

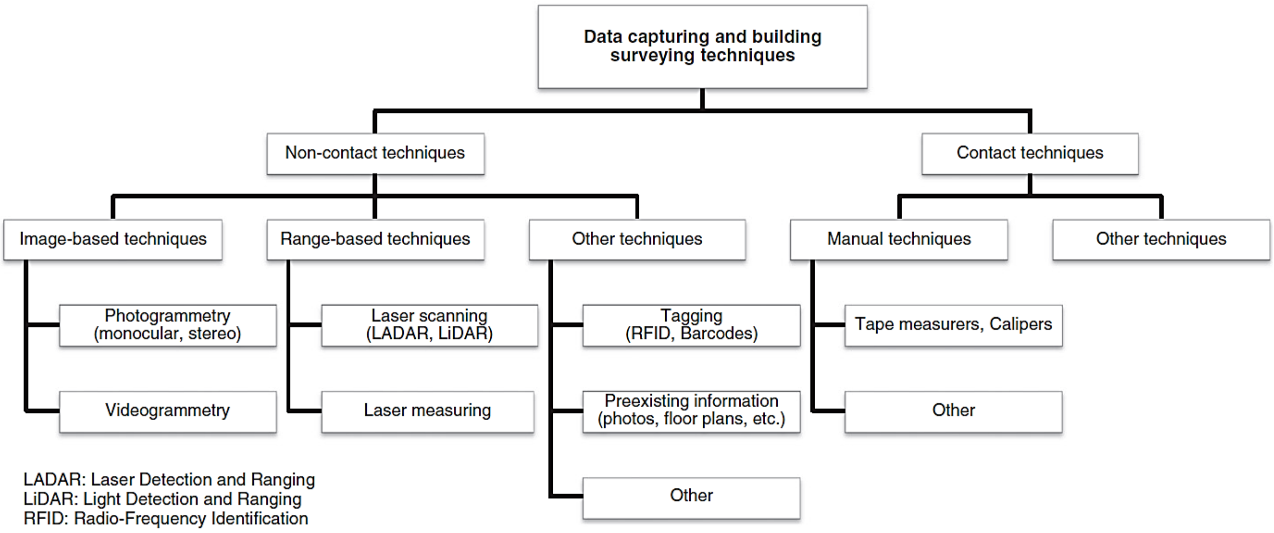


Figure 3.3 Data capturing techniques(Volk, Stengel, and Schultmann 2014)

3.3 LoD and LOD

The ‘Level of Detail’ (LoD) originates from the computer graphics field and was adapted to the AEC industry by describing the necessary semantic and geometric information in a model with a set of five levels. Based on that was developed the ‘Level of Development’ (LOD), which also initially defines five levels from LOD 100 to LOD 500. The first level, LOD 100, is a conceptual model and only includes generic representation. The detail is subsequently raised with each level by adding geometric and semantic information until the final level, LOD 500, where the model is an as-built representation including verified size, shape, location, quantity, and orientation of the elements. Apart from LoD and LOD numerous other similar definitions exist by country and professional bodies (Abualdenien and Borrmann 2022).

The fundamental difference between LoD and LOD is that the ‘Level of Development’ represents the availability as well as the reliability of the geometric and semantic information. This is relevant for design and construction phases of a project when certain element properties may be subject to change and the LOD reflects that, while LoD is concerned only with the availability and detail of information. Therefore, purposes such as the representation of existing buildings are better suited to the ‘Level of Detail’ (Abualdenien and Borrmann 2022). The difference between the two is illustrated below in Figure 3.4.

Furthermore, other concepts exist such as the Level of Information Needed (LOIN), which is a European standard, that specifies the information required at a particular design phase to perform a specific task by a specific actor. The LOIN does not include reliability or maturity information, but focuses on which information is required for which task (Abualdenien and Borrmann 2022).

Being more suitable to the task of existing buildings COBie uses LoD to define technical equipment requirements. For maintenance applications the required functionality determines the LoD and therefore cost and effort (Volk, Stengel, and Schultmann 2014). Figure 3.4 shows the difference between LOD and LoD and it demonstrates why for existing buildings only the 'Level of Detail' is relevant. LOD includes reliability of information which is irrelevant for an asset which is already constructed. For existing buildings model information is either accurate or inaccurate in comparison with site conditions.

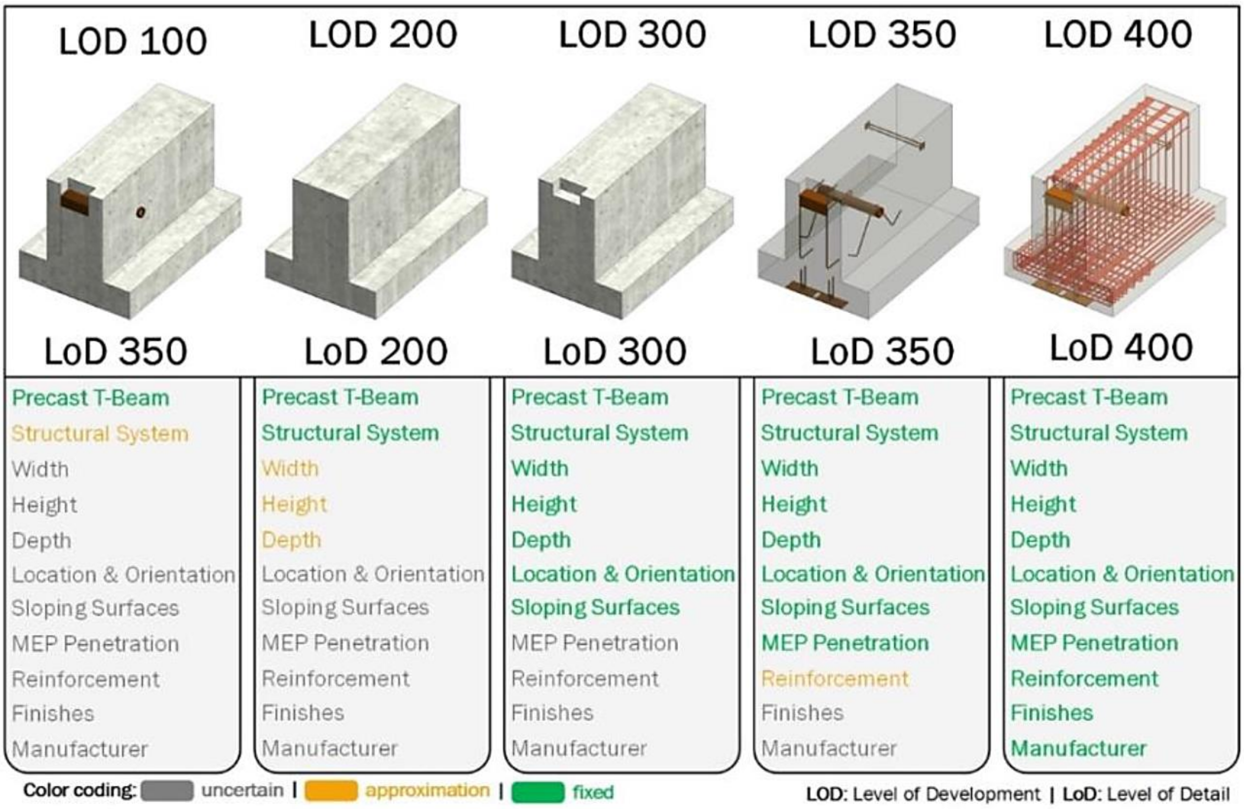


Figure 3.4 Example of difference between LoD and LOD (Abualdenien and Borrmann 2022)

3.4 Process automation challenges

So far it is clear that the process faces significant challenges and can be costly and time consuming due to its manual nature (Huber et al. 2011; Tang et al. 2010). These challenges include the reduction of effort in capturing, processing and as-built BIM creation, capturing and integrating semantic information into BIM, as well as addressing technique-specific restrictions such as concealed, distorted, structural or semantic building information (Volk, Stengel, and Schultmann 2014). However, there are significant efforts made in research and industry to tackle those challenges.

A case study by Soliman (2021) compares three methods including both conventional and state-of-the-art solutions. These are (1) 2D-to-3D, (2) Scan-to-3D and (3) UAV-to-3D. The first one uses existing CAD drawings to manually create a BIM model in Autodesk Revit. The second one employs a laser scanner which produces a point cloud model, which is used to create the BIM model. And in the third method the building is surveyed by a drone producing a 3D photogrammetric model which after some processing is once again used to create a BIM model in Revit. The findings of the case study point out to the fact that the first method is the most time-consuming, however, yielding a complete and accurate BIM model. The second and third both prove to be more costly, but with a significant advantage in terms of timescale. What is also evident in this case study is that in the last two methods the creation of the model requires the use of several software packages to arrive to the end goal. This is a known issue in BIM where no single software tool is able to cover all aspects of the process and it results in the back and forth transfer of information which can lead to loss or errors, as well as complications leading to significant time increase (Tang et al. 2010).

Another case study of the creation of BIM model for a larger university complex shows the preferred method was using existing CAD information rather than laser scanning (Kassem et al. 2015). This points out to the fact that the laser scanning process does not offer significant advantage, when CAD information is available. This was true at the time of this study and it can be attributed to the modeling effort which in both cases involves a lot of manual input.

In order to improve and automate the current process perhaps the most needed solution is the automated object recognition, as well as surrounding challenges. It is already demonstrated that walls, ceilings, floors, doors and windows are recognizable by software, however there is need for further improvement of LoD and handling of data uncertainty. Furthermore, current commercial technology does not provide automatic recognition of HVAC/MEP objects and requires intensive user input (Volk, Stengel, and Schultmann 2014; Xiong et al. 2013).

3.4.1 Commercial software

Both industry and academia make a huge effort in automating the process of scan-to-BIM, however, current solutions still include intensive manual user input which is cumbersome and can lead to errors (Son, Kim, and Turkan 2015).

Current progress in commercial software packages is summarized below with a list of tools which is representative, but not exhaustive. The list includes smaller free open-source tools, as well as large enterprise products. All of them show rapidly improving object recognition and other technologies that were not available 5 to 10 years ago.

- PointCab – Semi-automated floorplan production from point cloud data.
- 3Dash Tool – Revit plug-in for semi-automated creation of walls from point cloud data.
- Pointfuse – Semi-automated production of 3D BIM model from point cloud.
- Edgewise by ClearEdge3D – Object extraction from point cloud including semi-automated pipe modeling as shown in Figure 3.5 (Son, Kim, and Turkan 2015).
- Trimble RealWorks - Can recognize objects like columns, beams, walls and others including semi-automated pipeline modeling function (Son, Kim, and Turkan 2015).
- Leica Cyclone – Semi-automated pipe modeling; integration with AutoCAD, Revit and Microstation (Son, Kim, and Turkan 2015).

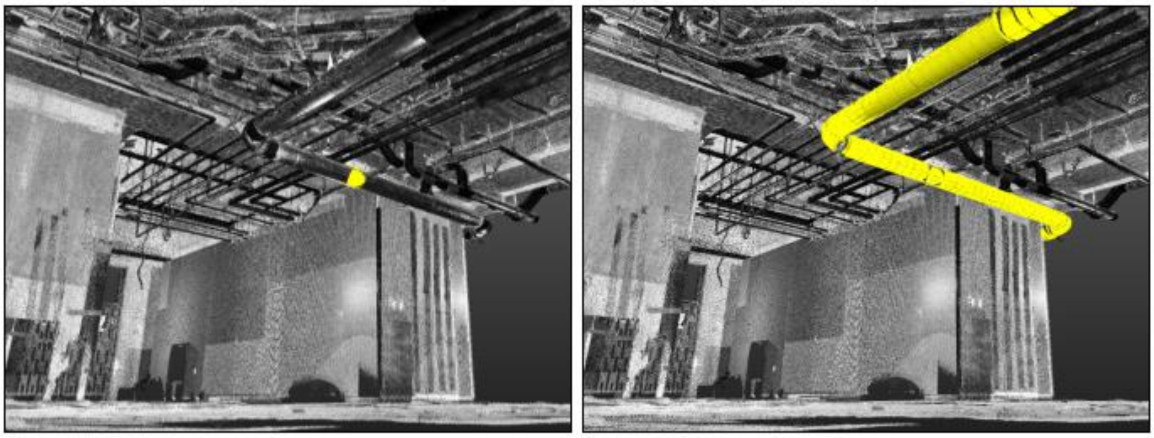


Figure 3.5 Semi-automated pipeline extraction (Son, Kim, and Turkan 2015)

3.4.2 SLAM

Other technological developments which have seen commercial application include Simultaneous Localization and Mapping (SLAM). SLAM is a problem in robotic science dealing with the navigation of autonomous robots through unknown environments. The goal of SLAM is to produce a map of the unknown environment while simultaneously determining the position of the device. (Durrant-Whyte and Bailey 2006)

In the context of building models, the application of SLAM is in data capturing devices. As it is clear from the name the device can simultaneously determine its position and map surroundings while moving which makes its use faster and easier. Modern devices can combine laser scanning, photogrammetry and the SLAM technology in order to deliver fast and accurate results. Market ready devices which use this technology promise an accuracy under 20 millimeters (Navvis 2020) and literature suggests typical accuracy of existing SLAM systems is in the order of a few centimeters (Esfahani et al. 2021).

Research shows that semi-automated modeling can provide significant accuracy and precision improvements, and most of all time saving (Esfahani et al. 2021). Increase in the level of automation of the modelling process is shown to be feasible with promising results. The combination of quick and accurate data capturing techniques with automated modeling gives hope for the development of more BIM models for existing buildings.

3.4.3 Data processing and object recognition challenges

Currently one of the areas undergoing the most significant development in research is the Scan-to-BIM process, however, it remains a labor-intensive process and even with training different modelers can produce very different results for the same model, therefore the need for automation is recognized. While different solutions exist, terrestrial laser scanning still gives the best accuracy and consistency, but it is expensive and time consuming (Bassier and Yousefzadeh 2015).

The solution to this challenge is in data processing and object recognition. One of the main approaches in this field is the data-driven approach. In this technique the software can use features, shapes, materials or statistical based methods to extract building information. Coarser building components such as walls, ceiling, floors, doors and windows have recognition rates between 89 and 93%. However, for many purposes of the

AEC industry further improvement in the LoD is required. Researchers use different methods to try and overcome this challenge, but higher detail in modeling still requires higher user input. Concealed elements such as ducts, pipes or other HVAC parts are currently modeled mostly by manual input. (Volk, Stengel, and Schultmann 2014)

While the industry has come a long way in terms of automation, the available solutions still require manual input to achieve the necessary model detailedness.

4 Requirements

In chapter 4 the paper outlines the requirements for BIM based FM based on the findings of the existing technological development and needs of the industry. Some areas of FM are already highlighted with significant potential for improvement. The goal is to find the requirements for this to happen. The successful implementation of BIM in FM can depend on a variety of factors and therefore will have many requirements in many different areas. These will range from willingness of the organization and cooperation of its employees to legal issues. However, this paper focuses predominantly on technical requirements of the solution.

4.1 Requirements in literature

There are multiple research efforts to list, describe or define the requirements for a successful BIM based FM system. Some of them are developed on the basis of a case study, while others aim to provide a more generalized approach. Here the report reviews some of these efforts and highlights topics which are recurring and are considered to be the most significant.

The requirements for successful BIM based FM are extensive, as well as case specific, which makes their definition challenging. However, Eastman pays special attention to the following four: (1) space object support, (2) merging capabilities, (3) updating and (4) sensor control monitoring. That is to say the system should be able to import space objects and related properties. It should be able to merge different sources of information, for instance MEP and spaces. It should also be able to track changes and apply them to the facility model. Finally, it should have capability to incorporate live feed from sensors. (Eastman 2011) This gives a high-level list of requirements for a modern facility management system. These requirements can be summarized in four more general areas:

- Semantic richness
- Interoperability
- Ability to apply updates
- Live monitoring

The topic of semantic richness can be expanded by increasing the level of detail and describing specific requirements. As-built BIM models should include architectural, structural, MEP, control systems, lighting, fire protection, special equipment and data. It is also suggested that the owner should provide requirements list for each type of asset. Key asset properties include manufacture, model and serial number. The overall system however should be lean and only contain and track data which is necessary. The system should be consistent and easy to replicate. This includes standard naming conventions, object types, type attributes and instance attributes. Data source and responsibility will enable traceability which is necessary for the efficient management of the system (Schley et al. 2016) It is proposed that there are information requirements for the system which are necessary for its operation, however, this information should be lean, consistent and organized.

Others describe requirements in terms of characteristics, namely accuracy, information richness and actuality of the underlying data. Richness could be defined by the ‘Level of Detail’ or ‘Level of Development’, the first being more suitable to FM as discussed in chapter 3.3. This includes both geometric and nongeometric properties. These properties could also be temporal and relational such as lifecycle stage and dependencies. The point is that certain functionalities require this information and system capability in order to exist (Volk, Stengel, and Schultmann 2014). This is an attempt to standardize the requirements by proposing a measuring system for geometric and nongeometric properties and connecting it to required tasks.

At the next level are perhaps frameworks which aim to assess the minimum requirements and capabilities for an entire system. Such frameworks already exist for BIM, and one example is the Capability Maturity Model (CMM). It measures maturity in ten levels for the following categories: spatial capability, roles/disciplines, data richness, delivery method, change management or maturity assessment, business process, information accuracy, lifecycle views, graphical information, timeliness and response as well as interoperability and IFC support (NIBS 2012). This is an assessment method, which can be used for an organization to understand its current level of development. However, this assessment of the current situation can point the organization in the right direction to achieve its goals. Such a system can potentially be used to produce requirements based on goals by reversing the process. It can be used to define minimum capabilities and characteristics of the system.

4.2 Definition process

The method of definition of requirements is in itself a significant topic. While it may be possible to make a comprehensive list of requirements, it is unlikely that it will be applicable to any given organization. It is therefore suggested that each organization should work through the process of defining its own requirements. Below in Table 4.1 are listed the main elements of interest for facility managers that are necessary for the successful space management in universities as identified by buildingSmart (Wallis et al. 2022). The findings of the buildingSmart report suggest that an organization should work through these items to compile a BIM protocol which will satisfy the requirements of space management. The proposed method involves the organization identifying its needs which are then employed to identify space information requirements and properties of the space information model. Then the exchange information requirements can be defined and finally a strategic space management plan.

This report highlights the importance of clear information requirements and process definition. Rather than attempting to define specific characteristics of the FM process or properties of the employed system, a methodology is suggested, which is going to provide unique solutions for different organizations.

Table 4.1 Elements of space management requirements definition for BIM based FM(Wallis et al. 2022)

Order of defintion	Elements
(1)	Organization information requirements
(2)	Space information requirements
(3)	Space information model
(4)	Exchange information requirements
(5)	Strategic space management plan

4.3 Stakeholders and interests

Stakeholders also play a major role in the development of requirements. Figure 4.1 shows different possible participants in the BIM lifecycle. Clearly, the different stakeholders will have different objectives and therefore different requirements. For instance, a space planner will need different information from a maintenance technician or an energy manager. Even if a structured process is undertaken, such as the one proposed by buildingSmart and described above, it is likely the results will vary significantly on a project by project basis. This will be in large part due to the involved people who have significant influence on the final product. To achieve all goals of the organization the requirements definition will require input from all stakeholders, or a representative that will be competent in the subject matter.

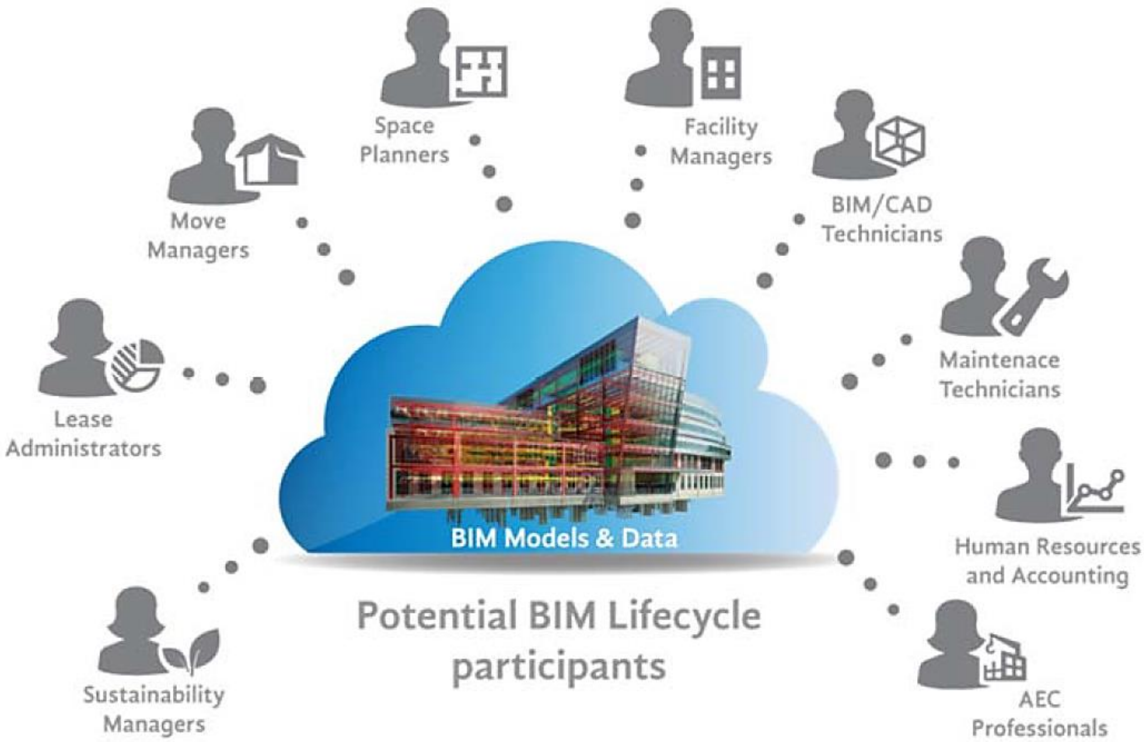


Figure 4.1 BIM stakeholders (Schley et al. 2016)

Another aspect to developing a BIM based FM system is the potential and interest of the organization developing it. Different organizations might have different levels of potential which they can realize due to existing conditions. Therefore, Hosseini (2018) suggest the matrix seen in Figure 4.2. On one axis is the delivery model for maintenance activities. It shows that the more in-house delivery an organization has, the greater the interest they will have. On the other axis is the ownership structure and it suggests that developers have the least potential for applying strategic data and information, while owner-occupiers have the most. Hence, this table suggests that owner-occupiers who use in-house delivery model will have the highest interest and potential. It can be deduced that organizations in this situation will benefit the most from a BIM based FM system. For instance, an educational institution which owns its buildings and performs maintenance mostly using its own resources will have high potential and interest. This is not true for another institution which is only an occupier, not an owner, and also uses predominantly external resources for the maintenance of the building it occupies.

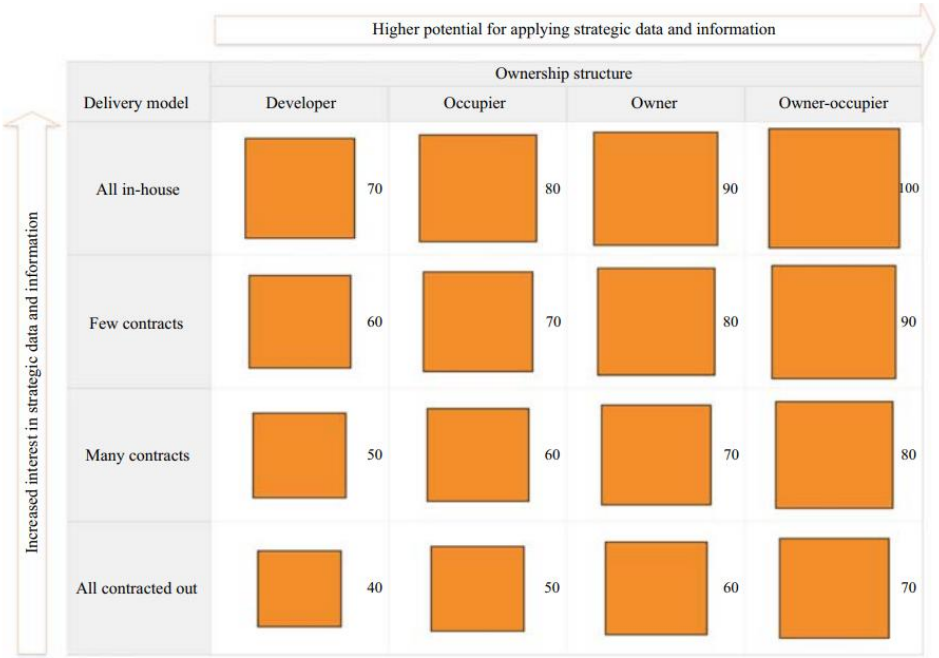


Figure 4.2 Interest and potential matrix for data and information (Hosseini et al. 2018)

4.4 Proposed requirements structure

To incorporate this knowledge in usable format the requirements are first split up between model and system. The model is the digital representation of the built asset containing all geometric and non-geometric information. The system describes the functionality, and it includes primarily information management aspects such as editing, classification, representation and tracking.

The requirements are designed in a way that will be suitable for the assessment of a current system or for the design of a future one. Therefore, each table of requirements is separated into levels and each level has a description.

The model maturity is separated in four levels from 0 to 3. The levels are devised to start at 0 representing ground level or close to no BIM model implementation, and finish at level 3 which defines the state-of-the-art possibilities and beyond. The following level definitions are given:

- Level 0 – Primitive sketch representation or no geometric model of the building asset; information is stored in the form of separate files with little to no integration between them.

- Level 1 – Geometric information is in the form of 2D floorplans which include basic semantic information such as room id; most information is still stored separately in file format.
- Level 2 – 3D BIM model including relevant disciplines such as MEP, architectural, and structural; semantic information is incorporated into the model.
- Level 3 – Dimensionally accurate 3D BIM model; geometric and semantic richness can facilitate all possible FM activities.

There are two important aspects for the model requirements. These are accuracy and semantic richness. Both will develop as it is progressed from level 0 to 3. The accuracy encompasses geometric accuracy as well as temporal. This means that the model should be an accurate representation of the current state of the building. Geometric data also includes objects such as room furnishing or equipment, not only building elements. Semantic richness involves the object properties, as well as relationships which make information useful. Semantic data includes both building and equipment information such as identification, manufacturer, model, maintenance instructions, etc.

Table 4.2 Model maturity levels

Semantic richness

Level	**0**	**1**	**2**	**3**
Description	● Simple database	● 2D floorplans with basic semantics ● Separate database	● 3D BIM model ● Architectural ● Structural ● MEP ● Object library	● Dimensionally accurate ● High semantic richness

Accuracy

The system maturity is also divided in levels 0 to 3. These levels describe the capabilities of the supporting software (and hardware) necessary to meet the requirements of BIM based FM. The levels are defined as follows:

- Level 0 – Only basic capabilities available; Information is stored on an isolated database such as a local hard drive; most of the information is not editable.
- Level 1 – Information is stored in a CDE; the ability to edit or update information is limited to nongeometric information; collaboration is file based.
- Level 2 – Both geometric and nongeometric information is editable; the system works with interoperable file formats; it uses a classification system for objects and properties; the collaboration is model/object based; information is easily retrievable in automated processes including information processing.
- Level 3 – The system has multiple visualization options across devices and platforms facilitating access by all stakeholders; the system works on the principle of cloud-BIM; there is capability for live monitoring of information. Maintenance activities and work orders are integrated with model semantics including update of information on the model.

Two aspects of the system play a key role in terms of its capabilities. These are the ability to apply updates and the interoperability. Going from level 0 to 3 the system will have increasing requirements for both factors. The ability to apply updates starts at level 1 as a manual task of changing object properties and at level 3 it is in the form of real time automatic update of information reflecting the current condition of the building. This increasing integration of live monitoring should facilitate activities such as energy analysis or occupancy management. Interoperability starts with the introduction of a CDE. At its final level it includes interoperable file format which allows model-based collaboration. Interoperability also includes the automatic synchronization of information between the model and other systems.

Table 4.3 System maturity levels

Interoperability →

Level	**0**	**1**	**2**	**3**
Description	• Read only • Isolated database	• Edit/update (restricted to nongeometric information) • CDE	• Models/objects editable • Classification system • Interoperable file format (IFC) • Model-based collaboration • Retrievability of information	• Multiple visualization and accessibility options • Work orders / maintenance activities integration • Real time monitoring capability • Cloud-BIM

Ability to apply updates →

Finally, the two tables are combined in matrix form in Figure 4.3. On the vertical axis is the 'Model Maturity Level' and on the horizontal axis is the 'System Maturity Level'. Based on the level rating of each axis as defined in Table 4.2 and Table 4.3 the matrix gives an overall maturity level.

<table>
<tr><th></th><th></th><th colspan="4">System Maturity Level</th></tr>
<tr><th></th><th></th><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td rowspan="4">Model Maturity Level</td><td>0</td><td colspan="2">0</td><td></td><td></td></tr>
<tr><td>1</td><td colspan="2">1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td colspan="2">2</td><td></td></tr>
<tr><td>3</td><td></td><td></td><td colspan="2">3</td></tr>
</table>

Figure 4.3 Overall BIM based FM maturity matrix

4.5 Requirements structure assessment

To test the adequacy of the requirements table a set of facility management activities (Becerik-Gerber et al. 2012) is assessed in Table 4.4. Each activity is evaluated against levels 0 to 3 from the requirements table. For each level the table gives the extent to which this activity would be possible ranging from not possible (-) to all aspects are achievable (all) and a middle level of only some aspects (some). The assessment shows that none of the activities can be incorporated into level 0, which is expected since this list only contains potential FM applications. At level 1 approximately half of these applications can be incorporated, but only some aspects of them. At level 2 all activities are incorporated and a little under half to their full extent, the rest only partially. At level 3 the system should be able to incorporate all activities to their full extent. This assessment demonstrates that the levels are defined to realistically represent the maturity of a BIM based FM system.

The same way the proposed requirements matrix is assessed it can also be used to design a BIM based FM system. By reversing the process above an organization can determine the system requirements based on its needs.

Table 4.4 Assessment of requirements level matrix against FM activities

FM Activities \ BIMFM Level	0	1	2	3
Locating building components	-	some	all	all
Facilitating real-time data access	-	some	all	all
Visualization and marketing	-	some	all	all
Checking maintainability	-	-	some	all
Creating digital assets	-	-	some	all
Space management	-	some	some	all
Planning and feasibility studies for noncapital construction	-	-	some	all
Emergency management	-	-	some	all
Controlling and monitoring energy	-	-	some	all
Personnel training and development	-	some	all	all

5 Case study

The final part of this report presents a case study demonstrating the process of creating a BIM based FM model for an existing building with no existing building information. The build asset in the case study is a university building, however, the model includes only interior parts and is limited to a single floor. The purpose of creating this model is to analyze the current model creation techniques and to test the model suitability for FM application in a BIM based system.

5.1 Motivation and challenges

The motivation for this report and case study stems from the needs of the TUM Department of Chemistry. The building of the department is more than 40 years old and has no existing model. Facility management is undertaken based on historical arrangements and local knowledge where data management and process are limited to basic information storage tools such as spreadsheet files. A dedicated FM system or software is not being used. Therefore, the administration is investigating options of creating a 3D model of the building which will be used in a BIM based FM system. For this purpose, the minimum requirements for this model have to be determined based on selected use cases which are relevant for the owner. This case study is motivated by the challenges arising from the situation described above. However, the rest of the project has been conducted independently from the Department of Chemistry and it takes a more generalized approach.

An interview with the Department of Chemistry was conducted in January 2022 in order to identify facility management issues and challenges. Some of the findings include:

- Only limited asset information such as asset registry, plans, and O&M manuals is available, and most of the existing asset information is outdated. As-built drawings are not available.
- No transparency of the status of work orders for repair.
- Space related information is currently stored in sketches and spreadsheet format.

In regard to as-built drawings it is highlighted that these may be available at another institution, but the interviewed people have no access. This is illustrative of the problem of information storage, accessibility and interoperability. While it may be available, it serves no purpose since the right people have no access to it.

The interview was targeted at asset and space management, and below are listed some of the findings on these topics.

Space Management:

- The space management process is for the onboarding process.
- The main reasons for the outdated space information are (1) the end-user modification of existing space without a notification and (2) the regulation/requirement changes over time.
- Room booking system used to be available, but it is not in use anymore.
- Annual space utilization (room utilization) update seemed a broken process.
- Seeking ways of gaining efficiency in managing space.

Asset Management:

- There are no formal processes in place for assessing asset condition and planning for future work.
- Limited asset management systems and tools are available.

This describes the basic motivation for this case study. However, instead of it being specifically applied to this building, the study takes a more general approach. In its scope it was not possible to obtain access and get required information from the department, therefore another similar building is considered with the aim of achieving results that are applicable on a wider level.

5.2 Methodology

In this case study a BIM model is created for part of a floor in a university building with no existing information. Then this model is used to incorporate facility management data. In particular it is attempted to incorporate the required information and demonstrate basic space management capabilities. This is the area in which the Department of Chemistry at TUM names the most challenges as seen from the motivation description in the previous chapter. Therefore, it is considered to be of the greatest interest.

It is assumed that there is no preexisting geometric or nongeometric information, which means that the source of all model information will be data capture. Data capture includes two laser scans which cover parts of the interior of one floor in a TUM university building. The laser scan data is used to create a 3D model of this part of the building. The 3D model is then manipulated to introduce relevant semantic information such as walls, floors, ceilings, doors, windows and spaces. In the following step the model is converted to the interoperable file format IFC. The IFC model is then further developed to meet the requirements for space management application. The required properties and attributes are added. It is demonstrated how the model can store all relevant information, how it can be edited and updated. The process can be divided into three main steps which are seen in Figure 5.1 below. Each of the three steps is described in detail in the following chapters.

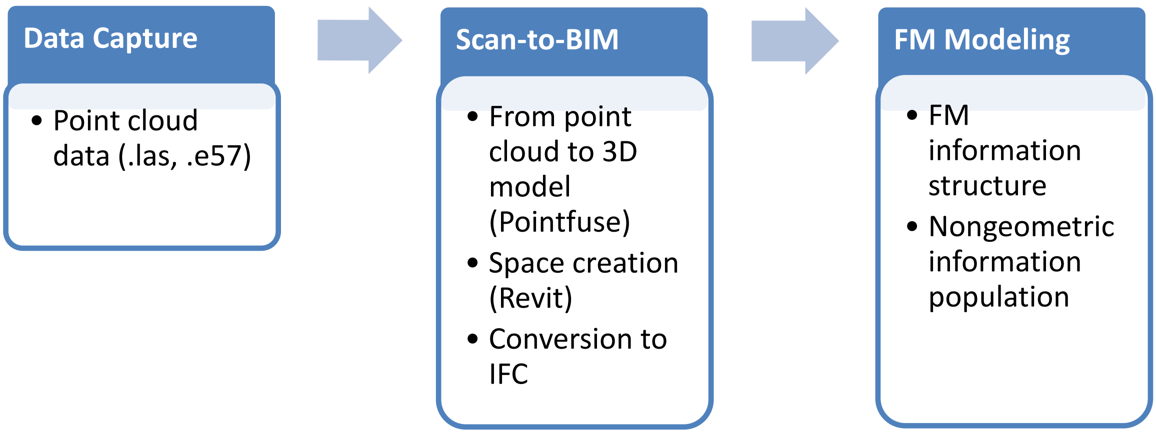


Figure 5.1 Main steps of the case study from point cloud to 3D BIM model for FM

5.2.1 Choice of software tools

Before the methodology is described it is highlighted that several different software options were explored for different parts of this case study. The ones used in the study below are chosen on the basis of their capabilities, as well as license availability.

The first category of tools which was considered can be described as conventional CAD or BIM and includes tools such as Revit and Archicad. They are developed for the AEC industry with extensive authoring capabilities, but they have little to offer in terms of facility management specific functions. Tools falling in this category were used in the creation of the 3D BIM model, namely Revit, as well as other authoring software Pointfuse and BlenderBIM. The latter two are introduced in more detail below in chapter 5.2.3 and chapter 5.2.4 respectively.

On the other hand, the thesis attempted to investigate tools in the category of facility management or CAFM, which include solutions such as Archibus, ArchiFM, Asset-works or YouBIM. These tools are specialised for the facility management process. It was attempted to obtain trial versions or other licensing options, but unfortunately it was unsuccessful. Some of the reasons behind this may include the fact that these software solutions are often tailored to the specific organization using them. So it is not a single piece of software that is available to buy, but a service which includes adapting it to the specific need. In any case it makes it has prevented the analysis of their capabilities and evaluation of the current state-of-the-art in facility management software.

5.2.2 Data capture

Two laser scan point clouds are available. The first one is produced by a terrestrial laser scanner by Leica. The scanned area covers three rooms comprising offices and meeting rooms. The point cloud visualization is seen in Figure 5.2 below, where ceiling points are removed for visualization purposes and the seen coloring of the points is based on height. The scan does not include realistic coloring of the point cloud.

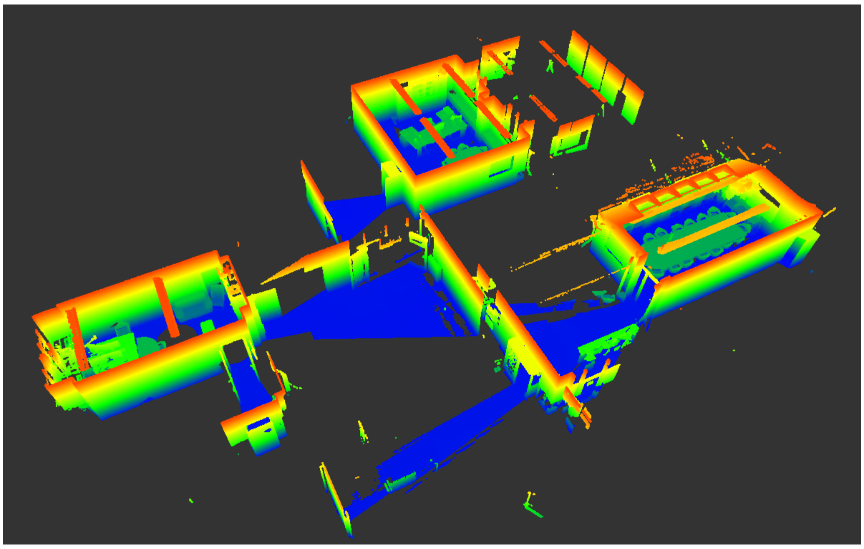


Figure 5.2 Leica raw laser scan point cloud data

The second point cloud is more comprehensive, and it covers a whole floor of the building including the area of the first Leica scan. This laser scan was conducted with a mobile device by NavVis. This scanner uses a combination of Lidar and photogrammetry technology, as well as SLAM to make it mobile (Navvis 2020). The raw point cloud data is seen below in Figure 5.3. Here it is noticeable that the data includes actual color of the scanned surfaces which makes recognition of objects and other details easier.

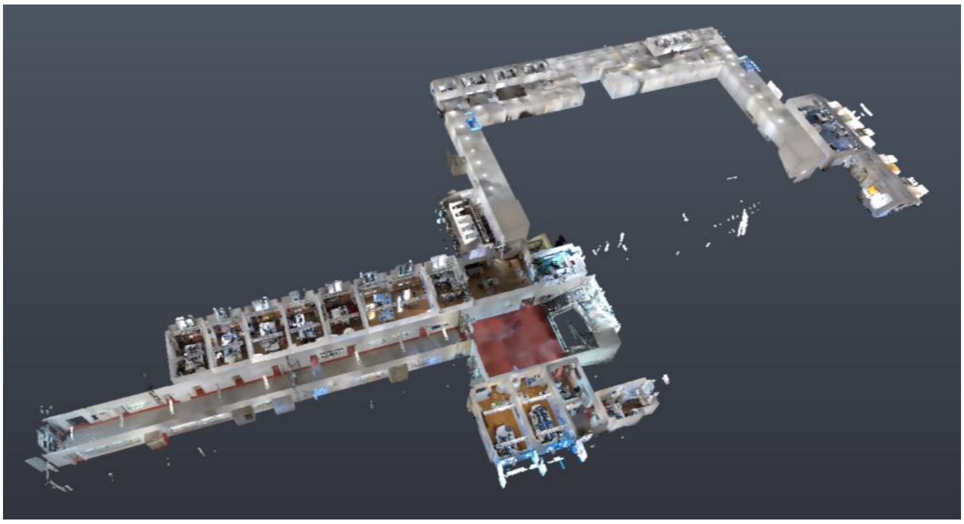


Figure 5.3 NavVis raw laser scan point cloud data

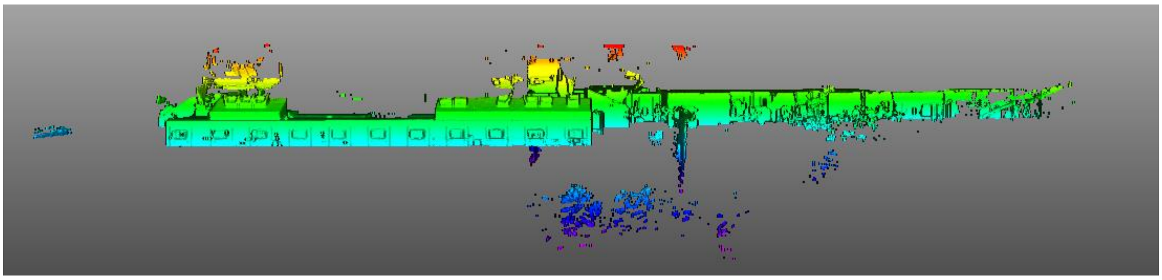
5.2.3 Scan-to-BIM

The process of converting the point cloud data to a BIM model was undertaken for both laser scans. However, an existing model from the Leica scan is also available from an earlier project and it is used in this paper for comparison purposes. This model was created manually in Revit from the point cloud data from the Leica scan.

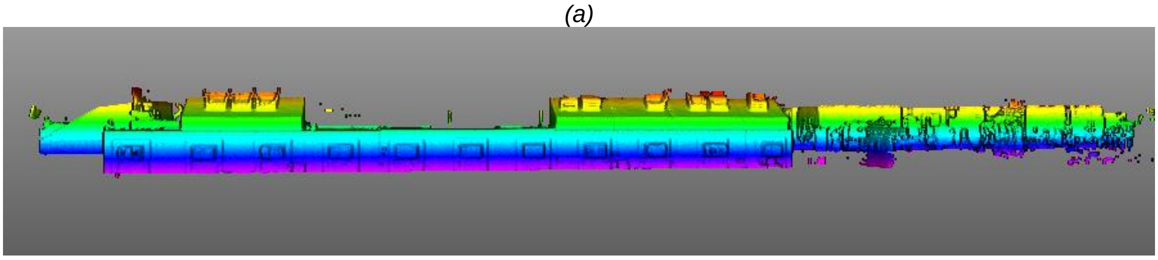
The creation of a BIM model from the NavVis data goes through the following steps. First the original point cloud files in '.las' format are converted to '.e57' format using a CloudCompare software tool. The purpose of this is to have the file in a suitable format for the rest of the processing.

Then the BIM model is created using the Pointfuse software tool. This tool is capable of converting the point cloud to a mesh and then to a model with a significant degree of automation (Pointfuse 2022). In the process of software review it was found to be suitable to one of the main purposes of the study, which is to investigate the level of automation offered by commercial software. It was also possible to obtain the required license thanks to the company's educational offer.

The process begins by uploading the point cloud. At this step the user can crop out parts of the point cloud which are not relevant before the meshing process. This is the first step where some manual input is required to reduce the noise. The result of this step is seen in the difference between the two snapshots in Figure 5.4.



(a)



(b)

Figure 5.4 Cropping out irrelevant data before meshing. Before (a) and after (b) cropping

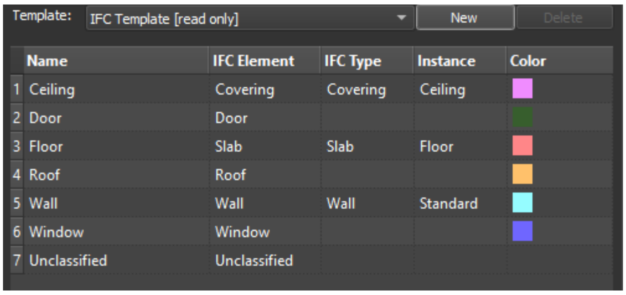
Then the point cloud is processed into a mesh which is performed automatically with a few available settings, in this case using the ‘High Detail’ setting and the rest as recommended by the software. The mesh model is created, and it is seen in Figure 5.6 (a) below. In the next steps are demonstrated the software’s object recognition capabilities.

During ‘classification’ as the process is named by Pointfuse, the mesh model is automatically classified in four categories. All data is split into surfaces in either horizontal, vertical or angled planes, as well as one additional category of unclassified surfaces. This looks like the snapshot in Figure 5.6 (b) where the different surface types can be seen in different colors. Here also begins one of the two most labor-intensive parts in terms of manual input. Before the BIM model can be generated the mesh model has to be further classified manually. In this step the model will be split up in the following hierarchy:

- Site → Building → Building Story

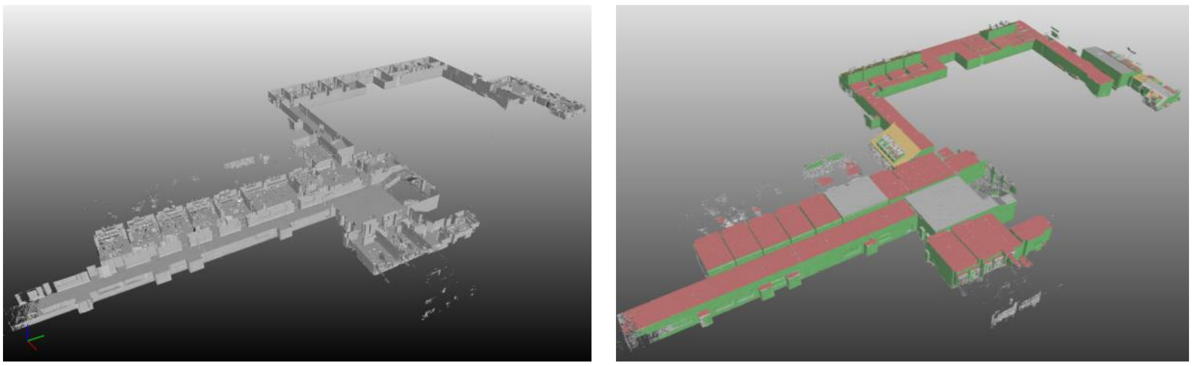
The project is limited to one ‘Site’, however, the next two levels are modifiable and the user can enter multiple buildings and building stories. In this case only one building and one story is defined. The next level of the hierarchy is the classification template, and this will define how the different surfaces will be split up between categories. From a list of templates, or manual template input, the ‘IFC Template’ is chosen. In Figure 5.5 it is seen what categories it contains. While it is possible to split the model down to the tiniest detail, the software’s automatic recognition is limited to floors, ceilings, walls, doors, and windows. Therefore, these are the categories which take up all the classification effort. The classification is undertaken using simple select tools and after a rigorous process the results are seen in Figure 5.7 (a) and (b). Here all relevant surfaces are classified into one of the categories listed above and the rest is separated in the 'Unclassified' category. This mesh model is now ready to be converted into a BIM model.

The BIM model is automatically generated and, in the process, the classified meshed surfaces are converted into the corresponding objects – ceilings, floors, walls, doors, and windows. However, the automatically generated model is inaccurate and has a considerable number of errors as seen in Figure 5.8 (a) and Figure 5.9 (a). All of these have to be corrected manually. These include issues such as missing or incorrect size doors and windows, walls not joining up properly or incorrect wall heights. The correction of these errors is possible inside the software. It is a manual editing process similar to those in many other CAD authoring tools used in the AEC industry. An analysis of this process is presented in the following chapter. After all of these corrections are made the model's manual revision is finalized. The final state is seen in Figure 5.8 (b) and Figure 5.9 (b).


Template: IFC Template [read only] New Delete

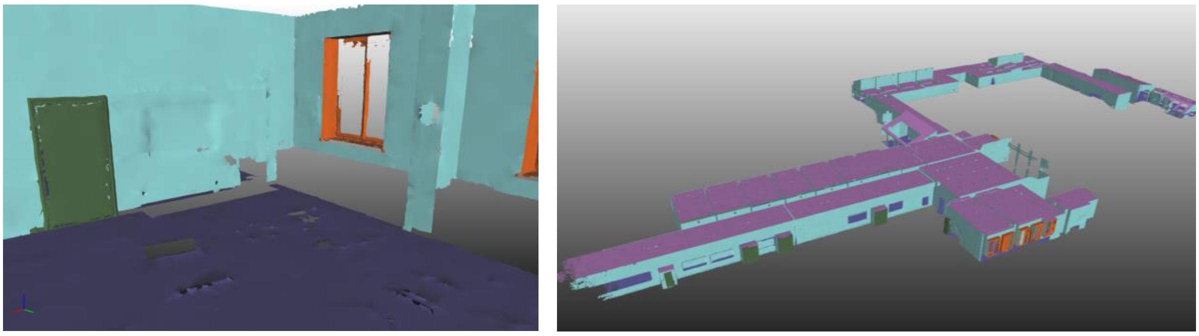
	Name	IFC Element	IFC Type	Instance	Color
1	Ceiling	Covering	Covering	Ceiling	
2	Door	Door			
3	Floor	Slab	Slab	Floor	
4	Roof	Roof			
5	Wall	Wall	Wall	Standard	
6	Window	Window			
7	Unclassified	Unclassified			

Figure 5.5 Pointfuse classification categories 'IFC Template'



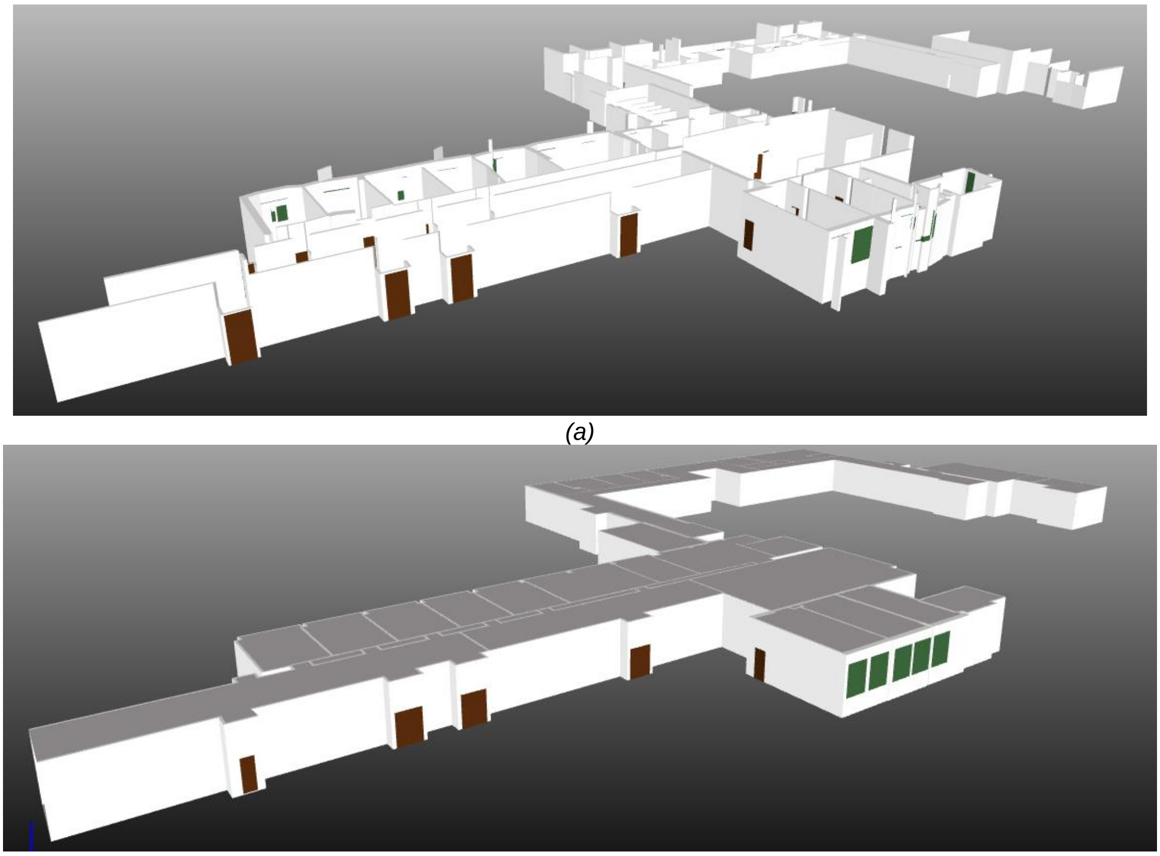
(a) (b)

Figure 5.6 (a) Mesh model in Pointfuse after applying the mesh function and (b) after applying the automatic classification function



(a) (b)

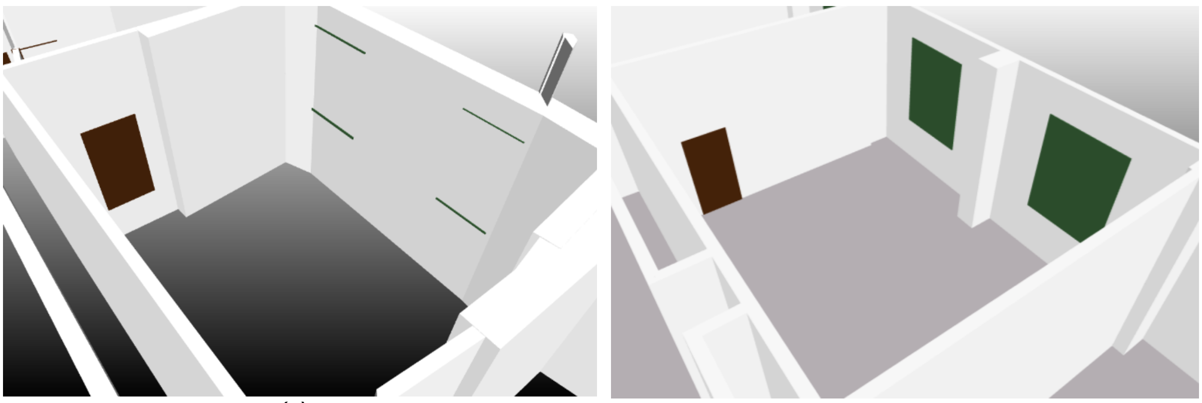
Figure 5.7 Mesh model in Pointfuse after manual classification of floors, ceilings, walls, doors and windows. Room (a) and model (b) view



(a)

(b)

Figure 5.8 Automatically generate BIM model in Pointfuse before (a) and after (b) manual corrections



(a) (b)

Figure 5.9 Automatically generated BIM model in Pointfuse room view before (a) and after (b) manual corrections

At the end of this process the model is both geometrically and semantically improved. However, the rest of the case study will require one key element, which is the assignment of spaces. The most straightforward process to do this is in Revit, therefore, the model is exported as an IFC and then imported in Revit. The spaces are created, and the model is again exported as an IFC.

5.2.4 FM modeling

Following the creation of a basic BIM model it is now further improved for facility management use. In order to do that the model is edited in the Blender software (Blender 2022) using the BlenderBIM add-on. BlenderBIM is a free, open source, native IFC authoring tool (IfcOpenShell Contributors 2022). It is used to add space management information to the model.

Once the IFC model is opened in Blender it is straightforward to navigate to plan view and be able to indicate the different spaces. As seen in Figure 5.10 the user is able to select a room (marked in orange) and it is identified in the hierarchy tree of objects (highlighted in blue). In the IFC hierarchy the room is designated as an 'IfcSpace' object. This object type has some attributes and properties by default. In Figure 5.11 are seen some of them as displayed in Blender after the import from Revit. The IFC Class is recognized as IfcSpace and there is a unique 'Global ID', as well as 'Name'. However, some of the information does not make much sense, such as the 'IFC Object Property Sets' where it seems like there are a lot of unnecessary repetitions.

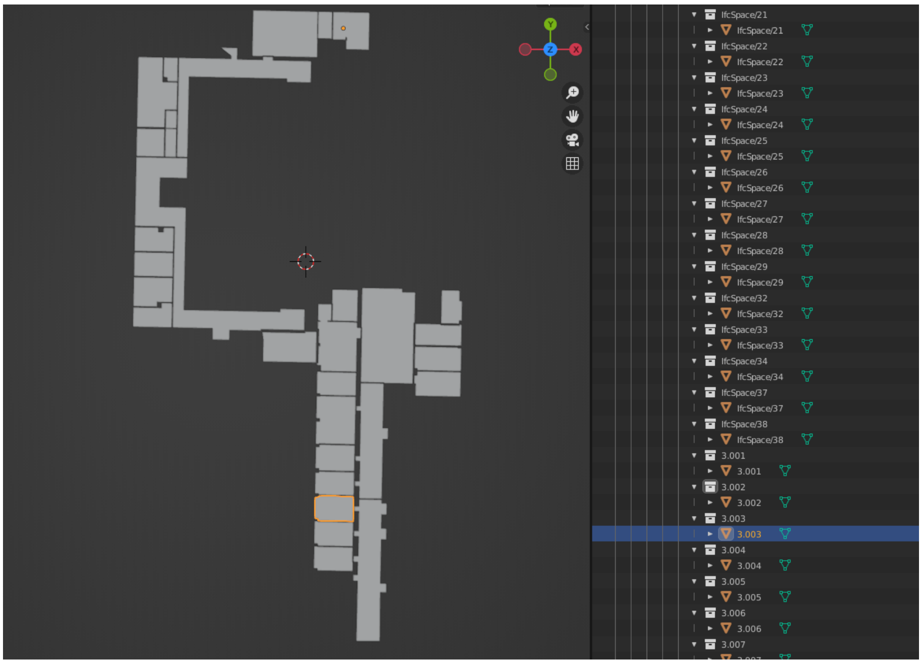


Figure 5.10 Plan view of spaces in Blender

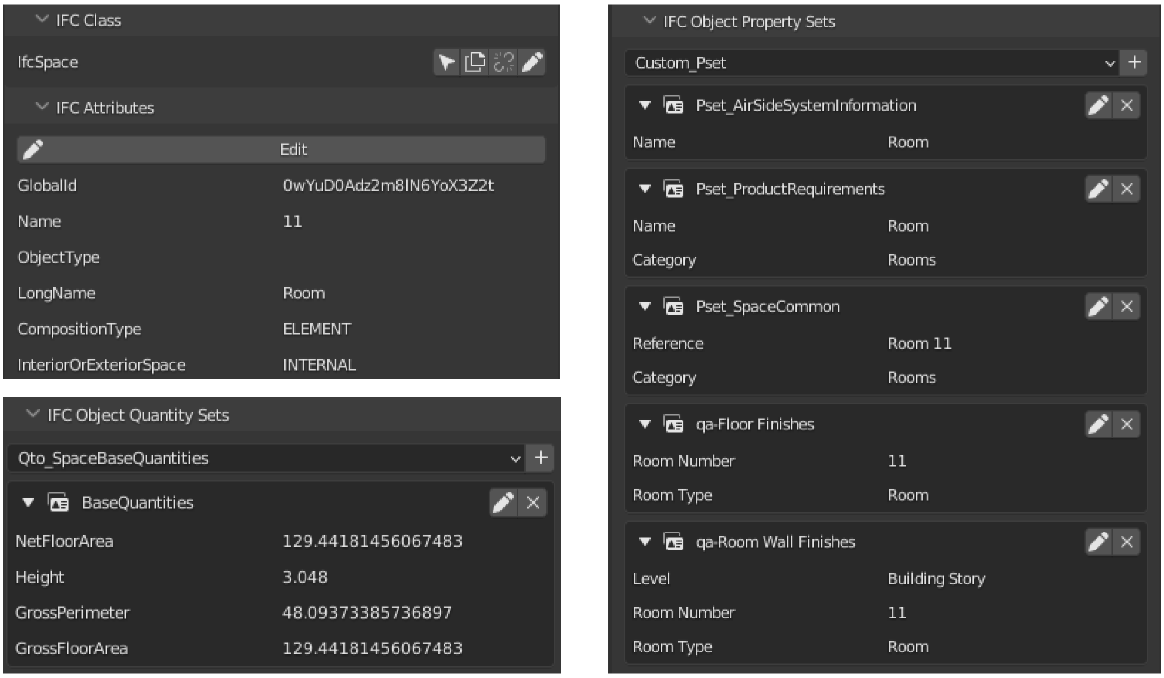


Figure 5.11 IfcSpace properties as seen in Blender using the BlenderBIM add-on

To explore possible facility management functionality, it is decided to develop a list of properties necessary for space management. The properties are initially selected based on the proposed by buildingSmart seen below (Wallis et al. 2022). To begin the ones marked in green are already seen within the existing model properties. The ones marked in blue are not currently present, but they are found within the default IFC properties, which makes them easy to add. Finally, the ones in orange are not found directly within the IFC properties.

FIELD NAME	ALIAS	FIELD TYPE
[SPACEID]	Space ID	Text
[SPACENAME]	Space Name	Text
[FLOORID]	Floor ID	Text
[FLOORNUMBER]	Floor Number	Short
[BUILDINGID]	Building ID	Text
[BUILDINGNAME]	Building Name	Text
[SPACEAREA]	Space Area	Double
[SPACEUOM]	Space Unit of Measure	Text
[SPACETYPE]	Space Type	Text
[OCCUPANTS]	Number of Occupants	Short
[OCCUPIED]	Occupied	Boolean
[OCCUPANCY]	Occupancy %	Double
[HOURSAVAILABLE]	Hours Available	Double
[HOURSOCCUPIED]	Hours Occupied	Double
[GEOMETRY]	Geometry	Geometry

Figure 5.12 Required space properties for space management (Wallis et al. 2022)

To address the problem with properties which are not currently available the BlenderBIM software offers functionality of creating custom property sets. A new property set named ‘SpaceMgmt’ is created to include the missing fields. Rather than adding all missing fields, only two are created to demonstrate the functionality. The first one is called ‘Occupant’ and holds a text value where the room occupant can be stored, and the second one is ‘Floor’ with a self-explanatory number value.

Figure 5.13 Custom property set for space management created using BlenderBIM

With this addition the required information for space management is stored in the model. After some information editing a more organized view of the model is seen in Figure 5.14. Here duplicating properties are removed, ‘Name’ is changed to a meaningful value, and the custom ‘SpaceMgmt’ properties are added. This is already a view which will allow basic space management activities such as checking room type, occupancy, area or other information.

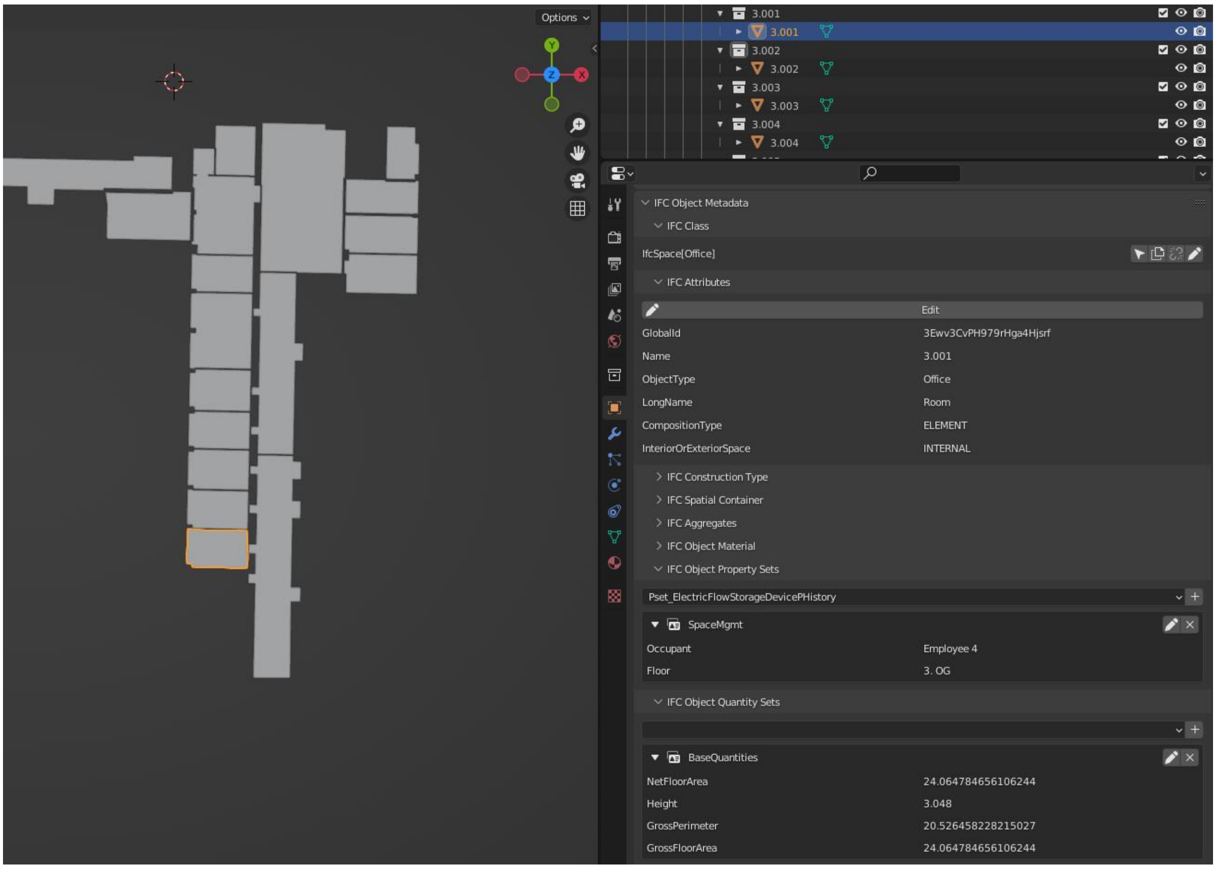


Figure 5.14 Space management model view in Blender with edited properties

The information on the model is manipulated in one of two ways. It is either directly edited in Blender, or it can be exported in spreadsheet format which also allows for bulk edits. An example of the spreadsheet format is seen in Annex B. In the second case an export template can be defined. In this instance the properties for the export are selected as seen in Figure 5.15. After the export is made to .csv format the file can be opened in Excel and edits can be made. It is then imported back, and the edits are applied to the IFC model.

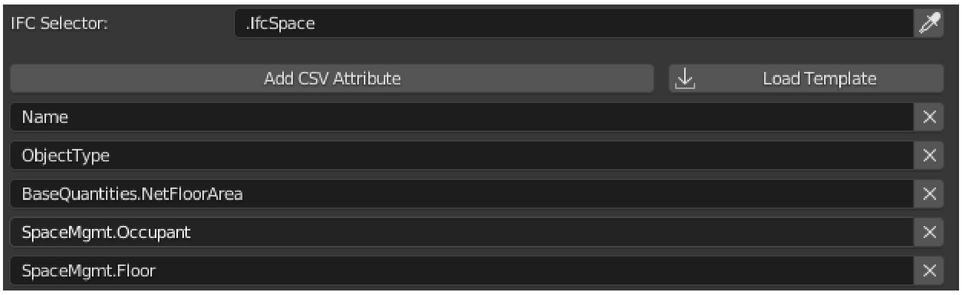


Figure 5.15 Export properties selector in Blender using the BlenderBIM add-on

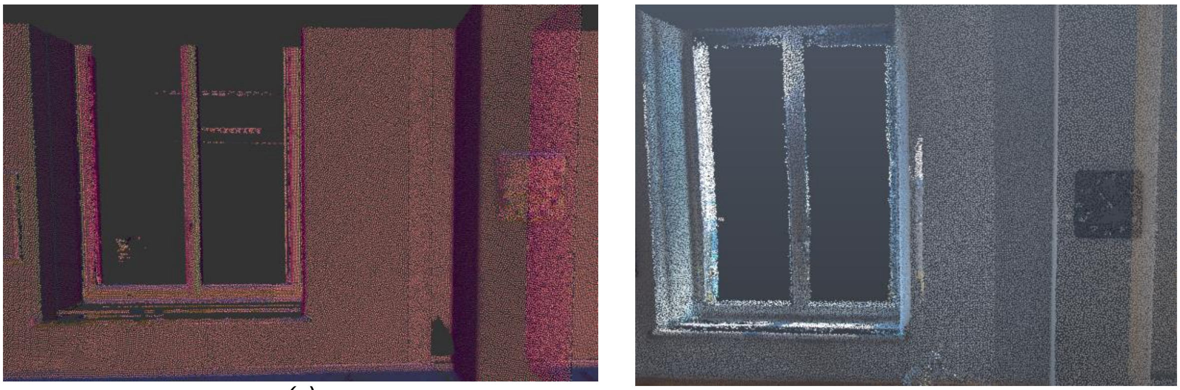
5.3 Results and analysis

The purpose of this case study is to identify requirements for the implementation of BIM based FM and in specific space management. However, it is also an evaluation of the whole process, as well as the tools which were chosen for its implementation. The findings of this evaluation are presented in this section.

5.3.1 Data capture

The process of data capture was carried outside the scope of this case study. However, there are present two-point cloud files from two laser scans. Each of the scans employs a different capturing method. The first one is undertaken with a stationery terrestrial laser scanner Leica instrument, and this reflects on the coverage area, which is quite limited comprising of three separate rooms. This is due to the slower scanning process limitation of this type of scanners. The advantage of the wearable scanner can immediately be recognized by the greater area covered owing to the faster process.

In terms of data quality, the two scans have comparable results as seen in Figure 5.16 and Figure 5.17. The two point clouds have similar densities and detail. There is one obvious advantage of the second scan and it is the color which makes the results easier to understand and work with. This can also be a significant advantage in automated object recognition. However, for the purpose of identification of planar objects such as walls, doors and windows, both have sufficient detail. It is possible that future more sophisticated software tools will have higher requirements for the level of detail in data capture, but for the techniques employed in this study the detail of both scans is sufficient.



(a) (b)

Figure 5.16 View of a point cloud of a window from the Leica (a) and NavVis (b) laser scan

(a) (b)

Figure 5.17 View of a point cloud of a meeting room from the Leica (a) and NavVis (b) laser scan

5.3.2 Pointfuse modeling

The Pointfuse modeling is the main part of the Scan-to-BIM process in this case study. It beings with data in point cloud format and through processing produces a 3D BIM model, which is also exportable in IFC format. The software shows significant automation capabilities, but also some challenges. These include a large amount of manual labor required to correct errors or inaccuracies from automated processing, as well as some functional incapacities. Together these are referred to as deficiencies of the software and the process and can be separated by the time of appearance – (1) at classification, (2) at model generation and (3) remaining.

In classification the most labor-intensive part was to remove vertical surfaces which are not walls, as well as identifying doors and windows. The software recognizes vertical surfaces as walls, and it employs methods of filtering out smaller objects which are not part of the wall. However, larger furniture or other larger items are easily mistaken by the software for a wall, and the following automatic model generation effectiveness depends on the correct classification of those surfaces. Therefore, the surfaces have to be selected manually and classified into the correct category where the software has not already performed this task. The next step in the modeling process is the identification of doors and windows. This process is performed manually by the user and it is also necessary for the effective model generation which follows. This involves a labor-intensive activity of selecting all doors and windows in the mesh model and separating them in their own respective categories. This is the most time-consuming task from the classification stage, but it is crucial for the next step.

After the classification is finalized the model can be generated and the second manual input stage which is the process of correcting the geometry begins. While the software successfully recognizes walls, doors and windows, most of them are geometrically inaccurate as shown earlier in Figure 5.8 and Figure 5.9 from chapter 5.2.3. Therefore, the user has to edit the walls alignment, correct doors and windows sizes, as well as add completely missing ones.

Finally, there are remaining deficiencies which are not resolvable in this software. The most significant of those include inclined surfaces not being modeled, detailed geometry representation not possible, and spaces not exported in IFC. This means that inclined roofs or other such surfaces cannot be modeled, and this results in a geometrical inaccuracy of the model. Also, multiple floor levels or window recesses are either impossible or very hard to model, which is another root cause for inaccuracy. Finally, even though the software has space creation capability (see Annex A), the space elements are not exported as part of the IFC.

In conclusion this software offers a highly automated process to today standards which can quickly generate a BIM model from point cloud. The main steps of this process are summarized below in Figure 5.18. However, some challenges remain. These are the high level of manual input, low level of detail or inaccuracy in modeling, as well as interoperability. These challenges are currently overcome by more modeling with other software, which in consequence results in longer and error prone process.

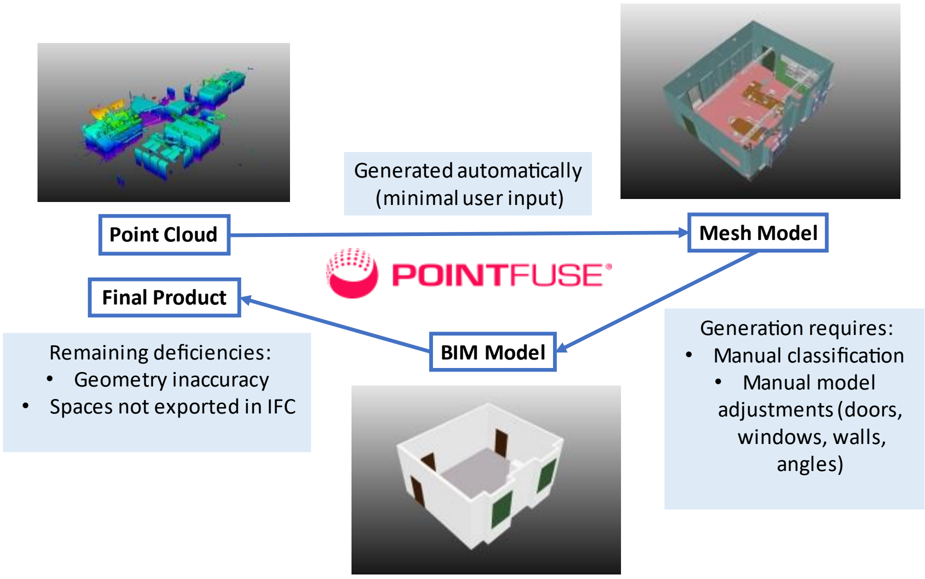


Figure 5.18 Pointfuse process from point cloud to model generation and export

5.3.3 Geometric results

The analysis of geometric results is based on two laser scans available out of which three models were developed. Below in Figure 5.19 there is a collection of snapshots of the same office room and window from the two different laser scans and at different stages of model development. In pictures (a), (b), (c) and (d) the snapshots are taken directly from the point clouds data. In pictures (e), (f), (g) and (h) the pictures are from the models produced in Pointfuse. All of the snapshots in the left column belong to the Leica scan, and the ones in the right column belong to the NavVis scan. In each of the instances the same dimensions are measured, and these are also tabulated in Table 5.1.

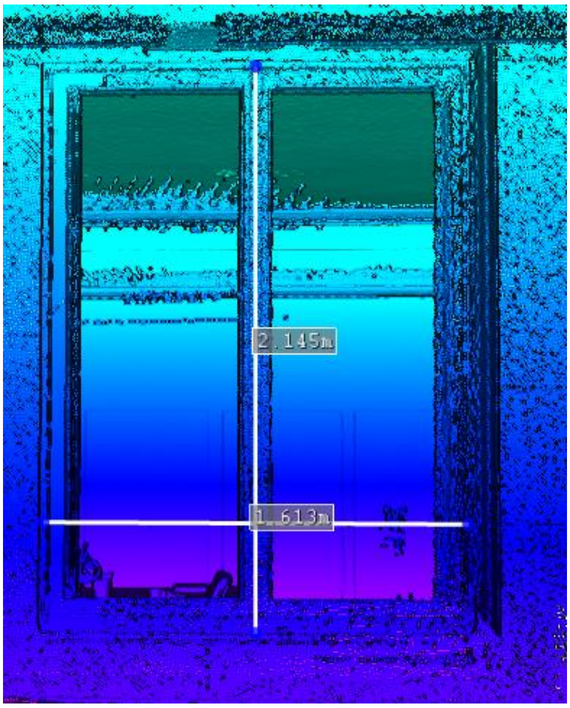
The first four pictures show that the point cloud data gives the same results with a total maximum difference in dimensions of 16mm. This is a small difference and some if it is attributed to measurement error. Therefore, the average of these values is taken to be the 'true' size. The rest of the measurements from the models are compared to these values and in brackets is seen the difference in decimal fractions. The largest difference observed is 0.09 or 9% in the Leica Pointfuse model where the window is smaller by 150mm from true size. The maximum absolute difference is 415mm and it is found in the Leica Revit model where one of the dimensions of the room is smaller by this amount. It can be summarized that maximum errors are in the region of 0.5m or up to 10%.

Table 5.1 Comparative table of dimensions of an office room and window at different stages and from different sources

[mm]	Room dimensions	Window dimensions
Leica point cloud	6328 x 7706	1613 x 2145
NavVis point cloud	6312 x 7696	1626 x 2133
Leica Pointfuse model	6370 (0.01) x 7783 (0.01)	1470 (-0.09) x 2054 (-0.04)
NavVis model	6488 (0.03) x 7742 (0.01)	1676 (0.03) x 2237 (0.05)
Leica Revit model	5905 (-0.07) x 7780 (0.01)	1500 (-0.07) x 1998 (-0.07)

Other inaccuracies are also found, but not measured. This includes wall details such as the ones seen in the bottom left corner of snapshots (e) and (f), as well as the window recess. In reality the recess does not extend from floor to ceiling, but this is the only option for modeling it in Pointfuse, so in one of the models it was ignored (f), but in the other it was modeled (e). Such inaccuracies clearly demonstrate the deficiency of the process and how two different models can produce different results for the same building.

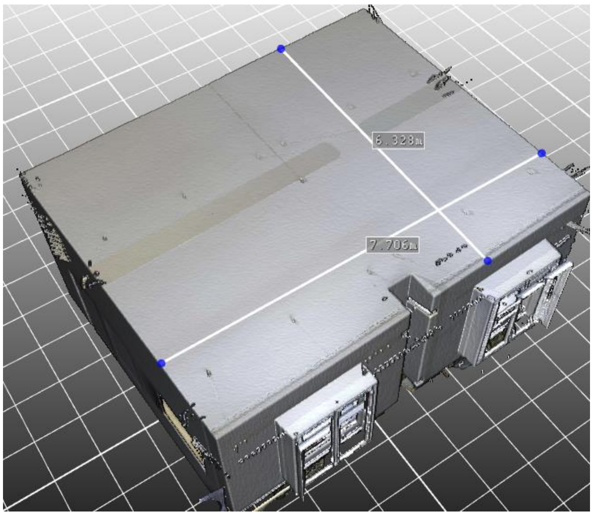
It is clear that major inaccuracies stem from the modeling stage. The automated processing produces significant number of errors and relies on manual input to correct them. However, the manual correction is time dependent and modeler dependent. In addition, inaccuracies are also attributed to modeling limitations of the software.


2.145m
1.613m

(a)


2.133m
1.626m

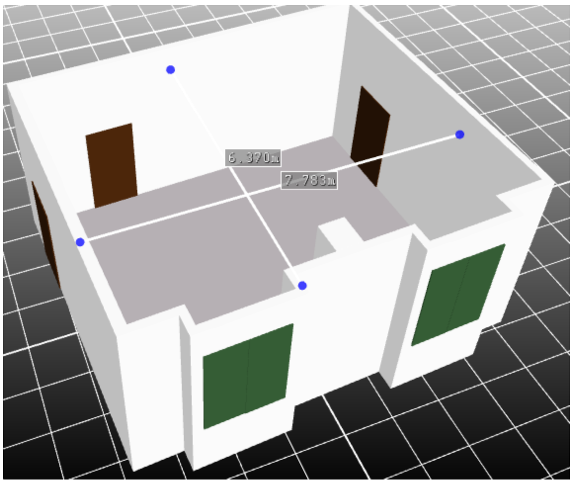
(b)


6.328m
7.706m

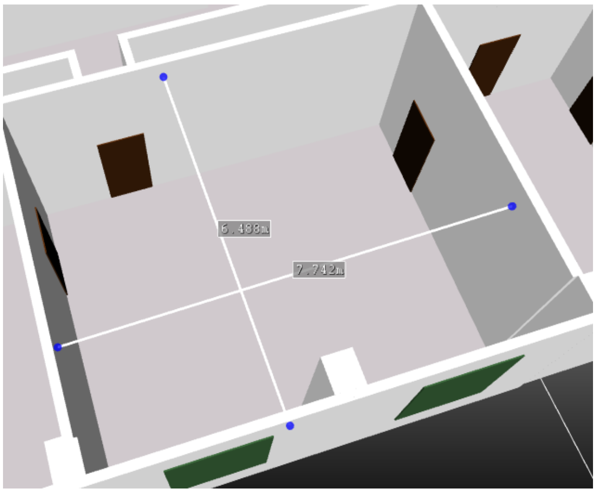
(c)


7.696m
6.312m

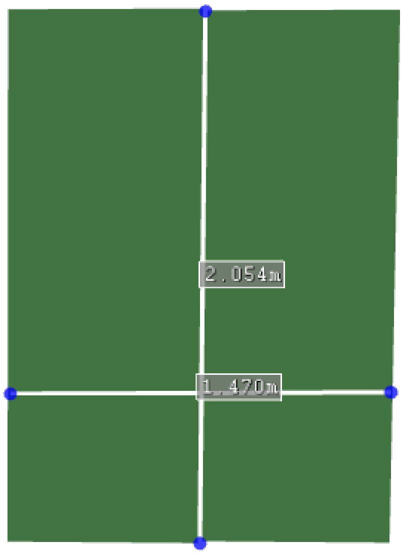
(d)


6.370m
7.783m

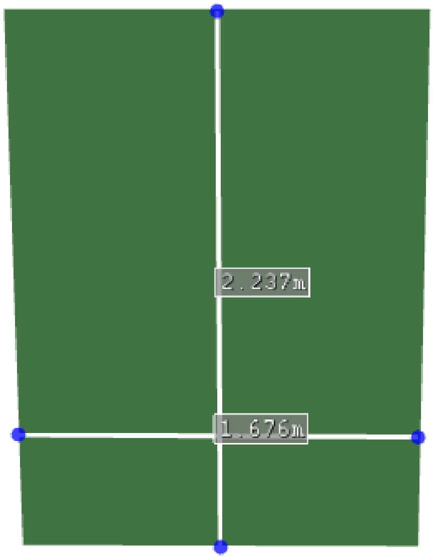
(e)


6.488m
7.742m

(f)



(g)



(h)

Figure 5.19 Dimensions of an office and window as measured in the Leica point cloud (a)(c), NavVis point cloud (b)(d), Leica Pointfuse model (e)(g), and NavVis Pointfuse model (f)(h)

5.3.4 Semantic information

Semantic information is at least as important, if not more than the geometric representation for the purpose of facility management. The results of the modeling in Pointfuse give a good basis for the model development. The main elements of the model (floors, ceilings, walls, doors and windows) are stored as objects with object properties and relations to each other. This is already a big step from a purely geometric model made from lines or surfaces. The next upgrade is the addition of spaces which was performed in Revit. After this step each room, hall or other type of space is also defined as an object with object properties and relations. The IFC schema provides a standardized method of storing most information which is required. Any additional information can be stored by introducing custom properties, as long as it is within the structure of IFC.

Working directly with the IFC model means that there is no information stored in software specific format. The model can be opened with any IFC enabled software. The semantic information is readable provided the required functionality to open IFC properties. Custom created IFC properties, such as the space management ones demonstrated in chapter 5.2.4, are directly accessible in Revit.

However, some challenges and deficiencies are also identified. Regarding semantics the greatest difficulty is that the majority of the information has to be added manually. Even when there is automatically generated information it is often not meaningful as demonstrated earlier in chapter 5.2.4 in the IFC export from Revit. So inevitably to create a semantically rich model a lot of manual input is required. Another deficiency is in space properties. The IFC schema allows for spaces and their properties, however, the modeling process is cumbersome. To achieve accurate geometric and semantic representation manual input is required.

5.3.5 System performance

Most of the effort in this case study was devoted to model development. However, it also demonstrates that some system capabilities are achievable directly from properly developed model properties. Others will require building software functionality, but they are again dependent on the model. In this case study it is demonstrated the model can already act as a centralized database. The model stores both geometrical information, as well as nongeometric such as the space management fields room id, occupant, and level. This provides functionality for activities such as recording room occupancy and connecting it to employees. Additionally, the model provides enough information to calculate occupancy rate or the area per occupant. This is a good demonstration that when the model has been developed to meet the requirements of a specific work activity, in this case space management, it is already capable of providing system functionality on itself.

5.3.6 Model and system evaluation

The model and system performance are evaluated against the requirements proposed in chapter 4.4 to validate the functionality achieved in the scope of the case study.

The first part of the evaluation is for the model. Initial assessment shows that the model covers level 1 and above. The model is in 3D therefore surpassing the 2D floorplans requirement and all information is stored inside the model, rather than external database. Therefore, a more detailed approach can be taken for the assessment in level 2. The model is 3D and provides semantic richness both in terms of geometry as well as nongeometrical information. It is an interior only model, therefore only covering architectural information. The rest of the disciplines such as structural or MEP are not covered. So, at level 2 the model meets the main requirements, but it lacks information to meet all requirements. Therefore, it can be concluded that it partially achieves level 2.

Level	2	3
Description	☑ 3D BIM model ☑ Architectural ☐ MEP ☐ Structural	☐ Dimensionally accurate ☐ High semantic richness

Figure 5.20 Model assessment against proposed requirements

The system maturity level is also evaluated. Similar to the model, the system meets the standards of level 1. The collaboration can be described as model based rather than file based. The model is editable both in terms of geometric, as well as nongeometric data. The last aspect of level 1 is CDE. The model is not formally stored on a CDE, however, this is easily achievable. This requirement is not met, but for the purpose of this study it can be considered that level 1 is achieved. Level 2 requirements are considered next and the system demonstrates most functionalities at this level. The model, as well as its properties and attributes are editable. Information is stored within the IFC schema, which provides a classification system. The model is stored in the IFC format which allows interoperability across a wide range of software tools supporting it. Finally, theoretical collaboration can be undertaken at model level. This requirement is difficult to assess as no such collaboration system exists in the scope of this case study. However, the necessary prerequisites are there, and this is achievable. Therefore, it can be concluded that the system achieves level 2.

Level	2	3
Description	☑ Models/objects editable ☑ Classification system ☑ Interoperable file format (IFC) ☑ Model-based collaboration	☐ Visualization and accessibility options ☐ Maintenance activities / work orders integration ☐ Real time monitoring capability ☐ Cloud-BIM

Figure 5.21 System assessment against proposed requirements

The next step of the evaluation is to identify the requirements which the model and system have to meet in order to satisfy level 3. On the part of the model these are the dimensional accuracy and the high semantic richness. Technically this is not a challenging task, however, a large amount of manual labor will be required to achieve it. As discussed earlier despite automation in the Scan-to-BIM process, higher level of detail is currently achievable only through manual input. The same is true for the modeling of structural and MEP information with the addition that it will also require more building surveying including intrusive techniques.

In terms of the system the required improvements to achieve level 3 include visualization and accessibility, integration of work orders and maintenance activities, as well as live monitoring and cloud-BIM. Out of this list the most challenging requirement is the real time monitoring due to the need for additional capabilities in terms of both software and hardware. The implementation poses many new questions including the installation of hardware, integration between software and hardware, data storage and management, as well as regulatory issues. The rest of the level 3 requirements are less demanding in terms of implementation. The introduction of visualization and accessibility options, as well as the integration of work orders and maintenance activities, can be achieved by relatively simple software solutions. Finally, to achieve full interoperability the system will have to function on the principle of cloud-BIM.

6 Conclusion and future outlook

The goal of this thesis was to analyze the requirements for the introduction of a BIM based FM workflow for an existing building, as well as the requirements for the model and system for its successful operation meeting the needs of the building owner and occupiers. The thesis did that in three ways: (1) with a literature review of existing research, as well as industry knowledge; (2) by proposing the definition of requirements in two tables of maturity levels for the model, as well as the system; (3) and finally with a case study for the creation of a BIM model of a part of an existing building for the purposes of BIM based FM.

It can be concluded that the integration of BIM in the facility management process has significant potential and both academia and industry are already aware and working in this direction. It was demonstrated that BIM has the capability to improve simple tasks such as the ability to store information and access it, as well as more encompassing processes such as space management or energy management. In both cases the implementation of BIM can lead to improvements in the life of the building users, as well as cost savings. However, the introduction of BIM based FM for existing buildings still has many challenges to overcome.

The main challenges are related to the adoption of this new workflow in FM as well as the necessary support that it requires for operation. They can be separated in two categories: (1) those which can be solved by technology and (2) those which depend on trust and willingness to adopt this method of work. This thesis has dealt primarily with the first type and it was found that one of the most significant challenges is obtaining a BIM model of an existing building with little to no existing building information.

While considerable automation is already offered by market solutions, this stage still requires significant manual labor and in consequence cost. The necessary detailedness of the final model is a controlling factor for the amount of work required, therefore significant thought is recommended in the process of requirements definition. However, technology has potential to seriously negate this challenge. As demonstrated the process of Scan-to-BIM is already automated to an extent and it shows potential for more. It can be expected that future market solutions will offer a process of Scan-to-BIM which requires minimal manual input and produces a detailed semantically rich product.

However, even if automation can provide ways of creating extremely detailed models in the context of facility management this is not necessarily required. Too much data can become inefficient to manage and keep up to date, therefore it is crucial to define the specific requirements for the amount and type of information which is needed. Given the variety of buildings that exist in the real world, this is a highly individualized process. It is also crucial that non-geometric information is maintained or accessed outside the model. While it is convenient to store everything centrally in one model, this may require significant technical knowledge for operatives. Maintaining data up to date should be made easier and not more complicated, therefore data should be easily accessible and editable and at the same time automatically updated on the centralized model. For this to happen the integration and interoperability of information is a crucial factor.

This thesis can name three areas which present the greatest challenge and therefore potential for research in BIM based FM of existing buildings:

- Automation of Scan-to-BIM
- Integration and interoperability
- Requirements definition and system design process

In the field of automation of the Scan-to-BIM process the greatest challenge lies in the improvement of object recognition technologies and specifically in the automatic preparation of accurate models, eliminating errors, and therefore the need for manual input.

In integration and interoperability, the challenge is to eliminate the need for multiple software tools and software specific formats, which makes the process of work cumbersome and error prone. It is also important to provide interoperability which guarantees the long-term storage of information and its maintenance, as well as ease of access by non-technical operatives.

Finally, the topic of requirements definition faces the challenge of defining a process suitable for application across different buildings and building user types. Due to the diversity of existing building stock, it is unlikely that a universal set of requirements will be able to provide a solution, therefore work should be focused on the process of definition. The facility management industry can benefit from guidance and standardization of this process. The proposed requirements structure in this paper is considered a step in this direction and it takes a generalizing approach that is applicable across a wide range of buildings and users. The definition of building type or building use specific guidance is the next step, however, the consideration and involvement of real life cases and facility managers is a prerequisite for its success.

As mentioned earlier the paper discusses mostly the technological aspect of this topic. However, it also highlights that the implementation of new technology or workflow always requires the trust and buy in of industry professional, as well as motivation to make the initial investment. Therefore, the future of BIM based FM also depends on the demonstration of its benefits by evidence from real life implementations. So far literature offers few examples of that, therefore there is open potential for the development of such studies which will make a convincing case for this method of work.

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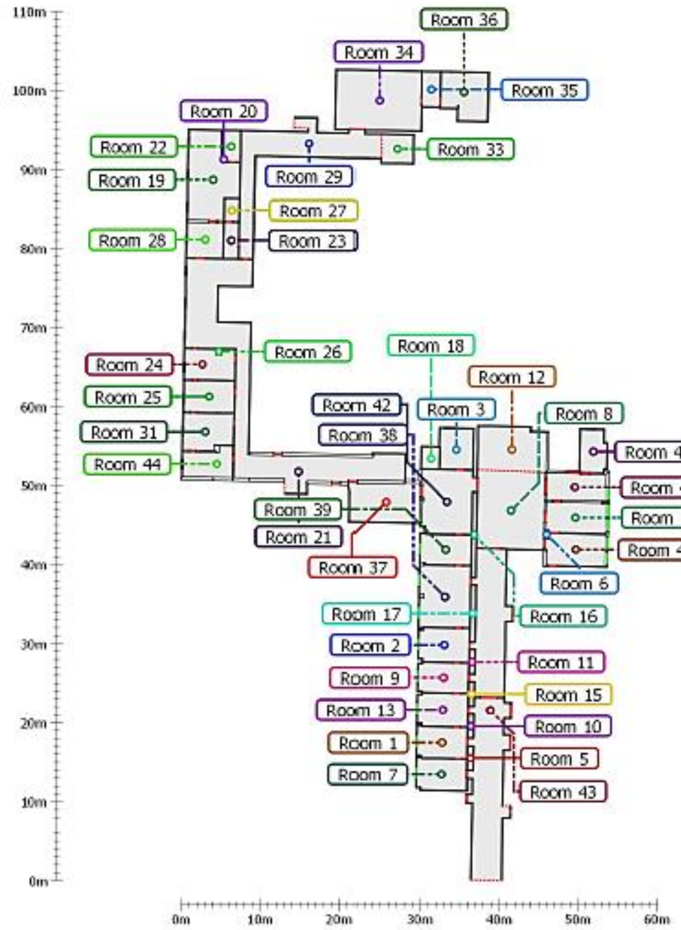
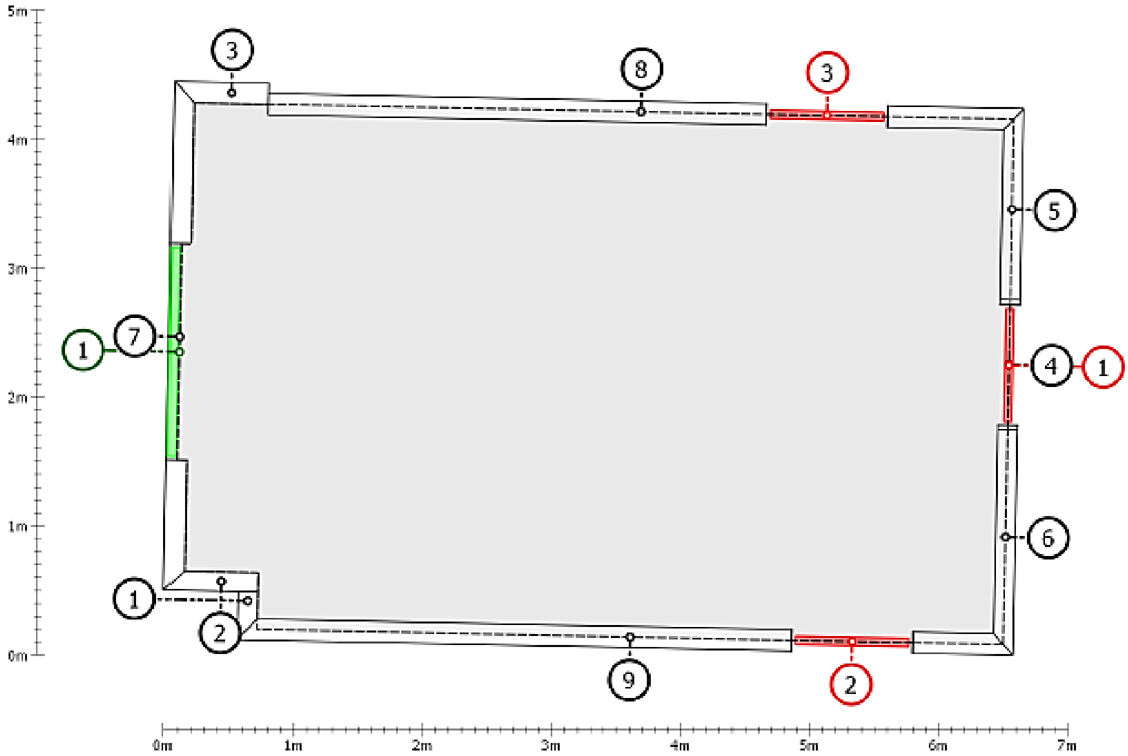
Annex A – Pointfuse report demonstrating room (space) assignment

Building / Building Story



Internal Area (IPMS 2)	1351.520m²
Total Doors	51
Total Door Area	200.749m²
Total Windows	26
Total Window Area	64.070m²
Total Rooms	42

Building / Building Story / Room 1



Internal Area (IPMS 2)	25.772m²
Ceiling Height	0.000m
Floor Elevation	-1.103m
Total Walls	9
Total Wall Surface Area	73.183m²
Total Doors	3
Total Door Area	5.682m²
Total Windows	1
Total Window Area	3.741m²

Walls

	Length	Height	Surface Area
1	0.358m	4.037m	1.446m²
2	0.568m	4.037m	2.294m²
3	0.576m	4.037m	2.324m²
4	1.027m	4.037m	4.148m²
5	1.350m	4.037m	5.452m²
6	1.532m	4.037m	6.186m²
7	3.634m	4.037m	14.674m²
8	5.703m	4.037m	23.027m²
9	5.711m	4.037m	23.056m²

Doors

	Width	Height	Surface Area	Style	Direction
1	0.937m	2.089m	1.956m²	None	Inwards
2	0.941m	1.981m	1.863m²	None	Inwards
3	0.941m	1.981m	1.863m²	None	Inwards

Windows

	Width	Height	Surface Area
1	1.679m	2.228m	3.741m²

Annex B – Example of IFC CSV export from BlenderBIM

GlobalId	Name	ObjectType	BaseQuantities.NetFloorArea	SpaceMgmt.Floor	SpaceMgmt.Occupant
0wYuD0Adz2m8lN6YoX3Z3j	23		23.72681945	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2C	13		20.7965965	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3z	28		5.014166278	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2b	3.003	Hall	25.19351276	3. OG	Employee 1
0wYuD0Adz2m8lN6YoX3Z3Y	25		20.04993232	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2I	20		21.08159668	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2c	3.004	Office	23.52671031	3. OG	Employee 2
0wYuD0Adz2m8lN6YoX3Z3_	29		8.11336433	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2g	2		72.07104934	3. OG	1
0wYuD0Adz2m8lN6YoX3Z31	34		9.850813217	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2T	18		41.73530274	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3C	33		32.07658707	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2N	21		27.74352023	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2x	3.005	Office	26.07682543	3. OG	Employee 3
0wYuD0Adz2m8lN6YoX3Z2O	17		29.26745971	3. OG	1
0wYuD0Adz2m8lN6YoX3Z27	16		28.70208179	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3d	26		57.67922024	3. OG	1
3Ewv3CvPH979rHga4Hjsrf	3.001	Office	24.06478466	3. OG	Employee 4
3Ewv3CvPH979rHga4HjsA4	37		92.39286996	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3u	27		8.285786755	3. OG	1
0wYuD0Adz2m8lN6YoX3Z21	14		17.03834139	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2t	11		129.4418146	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3k	24		165.288088	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3B	32		77.88360923	3. OG	1
0wYuD0Adz2m8lN6YoX3Z3e	22		24.29021912	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2y	3.006	Office	48.76957436	3. OG	Employee 5
0wYuD0Adz2m8lN6YoX3Z2n	3.007	Office	23.60513849	3. OG	Employee 6
0wYuD0Adz2m8lN6YoX3Z2o	10	Office	56.8225663	3. OG	Employee 7
3Ewv3CvPH979rHga4Hjs9q	38		92.44776397	3. OG	1
0wYuD0Adz2m8lN6YoX3Z2W	3.002	Office	24.38730451	3. OG	Employee 8
0wYuD0Adz2m8lN6YoX3Z22	15		25.29227256	3. OG	1

Erklärung

Hiermit erkläre ich, dass ich die vorliegende Master-Thesis selbstständig angefertigt habe. Es wurden nur die in der Arbeit ausdrücklich benannten Quellen und Hilfsmittel benutzt. Wörtlich oder sinngemäß übernommenes Gedankengut habe ich als solches kenntlich gemacht.

Ich versichere außerdem, dass die vorliegende Arbeit noch nicht einem anderen Prüfungsverfahren zugrunde gelegen hat.

München, 13. December 2022

Vorname Nachname