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Development of Quality Requirements for BIM-based facility management

Master thesis

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Abstract

As projects in the construction industry adopt more and more digital techniques, the need for regular information updates and maintenance within the digital construction framework has become essential.

Until now, research was primarily oriented towards the design and construction phases in regard to the digital management of data. The absence of a structured framework that follows the project throughout the following operational and maintenance phases has been recognized as a great deficiency.

Building Information Modeling (BIM) for Facilities Management (FM) is a recently developed and expanding area of study working to meet the informational requirements of assets in the digital environment. The main focus being the operational and maintenance phase in construction. Although it fills the gap in the digital construction workflow, BIM for FM is still not utilized effectively as there are many issues appearing in the process Which will be outlined in following chapters.

To resolve those issues this paper proposes a solution for the recurring difficulties arising in facility management due to the lack of an organized digital information management workflow. The Paper improve the BIM based facility management through three steps:

1- involving the facility manager from the initial stages of project development.

2- developing a structured workflow and guideline that can be followed throughout the whole process of BIM-based facility management to avoid ambiguity and setbacks.

3- ensuring high-quality BIM-Model development by following quality check-lists.

This research investigates methods to enhance the quality of BIM-Model based facility management (FM) by addressing individual issues within BIM-based FM through the development of a comprehensive framework. A checklist for assessing the quality of the BIM model is recognized as an efficient step in minimizing initial errors and ensuring high-quality throughout the process. The framework proposed in this study aims to mitigate quality issues in BIM-based FM by advocating for the involvement of facility managers in the early project phases and improving the Exchange Information Requirement (EIR) through client-facility manager collaboration.

Keyword: Building information modeling, Facility management, Information requirements, Quality Management.

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List of Abbreviations

AIR	Asset Information Requirements
AIM	Asset Information Model
AM	Asset Management
BEP	BIM Execution Plan
BIM	Building Information Modelling
BMP	BIM Management Plan
CAFM	Computer Aided Facility Management
CMMS	Computerized Maintenance Management System
COBie	Construction Operation Building information exchange
EIR	Exchange Information Requirements
FM	Facility Management
FMS	Facility Management System
GSA	General Service Administration
IAM	Institute of Asset Management
IFC	Industry Foundation Classes
IR	Information Requirements
IWMS	Integrated Workplace Management System
LOD	Level of Detail
LOI	Level of Information

MVD	Model View Definition
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
O&M	Operations and Maintenance
OIR	Owner Information Requirements
PAS	Publicly Available Standards
PIM	Project Information Model
PIR	Project Information Requirements
PM	Project Management
QA	Quality Assurance
QC	Quality Control
QM	Quality Management

1 Introduction

The built environment influences all aspects of human life and provides the setting for fulfilling necessary everyday tasks as well as specific personal and professional aspirations. In order to ensure a smooth performance on the wide variety of everyday life tasks and desires, built assets need to be in a functional condition and continuously maintained.

From the initial design and construction phase, throughout the operation and maintenance of built assets, data is constantly recorded and exchanged. It is not a rare occasion that the information and data in this process are not documented in an organized manner, which subsequently leads to making the process more labor intensive and error prone. However insignificant data omissions in the initial stages of building design may seem, they inevitably cause confusion throughout the continuation of the construction process, as well as difficulties in subsequently determining the accuracy of the given data. The key to ensuring not only quick handover and commissioning of the built asset, but also proper operation and maintenance is accurate data transfer and documentation (Atkin, 2009).

BIM has emerged as a valuable instrument primarily employed in the design and construction phases. Nonetheless, it is evident that significant benefits can be realized during the Operation and Maintenance (O&M) phase by enhancing various processes and establishing a repository of exhaustive information for the constructed asset (Motamedi et al., 2014). BIM is instrumental in populating facility operations databases with essential geometry and parameters, thereby providing comprehensive support for the information technology infrastructure utilized by owners' organizations . In addition, BIM provides a variety of other helpful features for O&M, such as visual representations of asset locations, their interconnected relationships, and a complete history of maintenance activities (Leygonie et al., 2022).

Given the potential utility of BIM in O&M, a growing number of owners express a strong wish to possess comprehensive and highly useful BIM models at the conclusion of a construction project (Becerik-Gerber et al., 2012). Despite the well-defined processes for commissioning and handover, standardization, guidelines, and established procedures are lacking in the domain of digital project delivery. This deficiency hinders the ability of proprietors to precisely define deliverables, thereby impeding the effective implementation of BIM in O&M processes (Williams et al., 2014).

Although proprietor awareness of the opportunities presented by BIM for facility operations is on the rise, determining the specific information requirements can be difficult (Asare et al., 2021). On the other hand, designers demonstrate a limited understanding of the precise operational requirements, resulting in ambiguity and uncertainty regarding the information they should provide (Kassem et al., 2015). Moreover, this deficiency in defining information requirements has a negative influence on the effectiveness of the quality management process, as there is no suitable reference for determining and assessing the content quality of BIM models. As a result, the delivered models frequently contain insufficient or extraneous data, rendering them unfit for immediate use by operators (Asare et al., 2021).

Considering these obstacles, there is an urgent need for research and intervention in BIM-based O&M to bridge the divide between owners' expectations, designers' deliverables, and the overall quality management process. By addressing the current deficiencies in standards and guidelines, stakeholders can cultivate a more seamless and efficient transition from the construction phase to the operation and maintenance phase, ensuring the availability of comprehensive and trustworthy BIM models. Additionally, efforts should be directed toward facilitating a collaborative environment that promotes knowledge exchange and aligns owners' information requirements with designers' capabilities, thereby maximizing the utility of BIM in O&M processes.

1.1 Research objective

This paper targets to reduce the gap between the handover of construction projects and facility management. The main goal is to generate a high-level BIM model-based facility management. The thesis acts as an incentive to smoothen the relationship between facility managers and construction stakeholder with the common objective of generating a high-level information obtainment that will be a foundation for the quality control of the BIM model.

1.2 Approach

The approach is built upon in-depth analysis of the existing methods used for improving the reviewed for determining the main problems faced in facility management and the existing coping mechanisms and solutions. Additionally, main issues in facility management are reviewed in practice by collecting feedback from personal experience of parties involved in the construction process from beginning until the handover stage and the following continuous facility management. The analysis and practical experience combined represents a highly valuable source for precisely defining the main challenges that arise in the construction industry regarding facility management and provide ground for developing optimal solutions.

The primary task in the process of developing solutions for the recognized problems is clearly defining the existing quality management workflow. The workflow further enables the design of a quality control checklist that is repeatedly applied on the BIM model of the built asset throughout the whole building process. The checklist provides a reference for identifying errors and taking immediate action to eliminate them in order to ensure quality throughout the process and avoid build-up of issues from small and seemingly irrelevant omissions.

1.3 Structure

The thesis is organized as follow:

Chapter 1 – Introduction – provides a basic outline of the main topics covered in the paper and leads into the second chapter that goes in depth to explain the concepts and ideas of the previously mentioned themes.

Chapter 2 – Related Work – lays out deeper analysis of ideas that are insightful in the scope of this paper including literature review, standards and practices in the construction industry.

Chapter 3 – Research Methodology – explains the scientific methodological approach that has been used in this research, and concisely presents the main problems regarding the research as observed in literature and practice whilst at the same time laying out already present and developed solutions for the problems.

Chapter 4 – Requirements and proposed solutions – focuses on the informational requirements in the construction process, which have been recognized as main factor in solving the research problem and additionally proposes solutions for generating high quality BIM Models as an extension to providing efficient long-term facility management.

Chapter 5 – Automated Tools for QC and case study – introduces automated and semi-automated tools that can be used for enhancing the quality of the BIM model. The developed tools are implemented in a case study together with solutions and improvements in BIM-based facility management explained in the previous chapters.

Chapter 6 – Conclusion – provides a summary of the research and briefly states the proposed quality management workflow and control checklist developed in the scope of the research. The final chapter additionally provides suggestions for future work on the related topic and possibilities for further improvement.

2 Related Work

In order to illustrate the function of BIM in facility management and the role that Quality of the BIM model plays in this regard, this article gradually builds the necessary background knowledge through a series of phases. It begins with the definition, nature, and necessity of both building information modeling and facility management. The section then discusses various studies and techniques performed in the topic. The article concludes by discussing the actual topic of BIM-based FM. This is accomplished by a systematic literature review described in the subsequent chapters.

2.1 Building Information Modeling (BIM)

Building Information Modeling is the process of data creation and management of an asset during design, construction, facility and operation management, and demolition in the AEC industry with the goal of increasing efficiency and decreasing costs (Lee, 2005).

2.1.1 BIM throughout the Entire Building Lifecycle

Building Information Model refers to a data-rich 3D depiction of an object. It comprises non-graphical information such as type information, technical qualities, and expenses in addition to geometrical information. Therefore, Building Information Modeling defines the process of enhancing a 3D representation of an asset during its execution, modification, and management with the necessary software tools (André Borrmann, 2018).

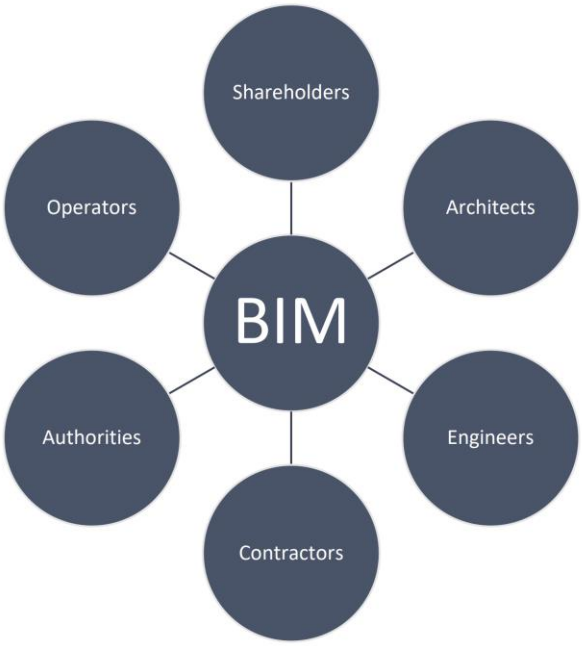


Figure 2. 1 Relationship between parties in the BIM process (Ahmad AlQuosi, 2022)

In addition, BIM used to describe the process of managing information throughout the life cycle of an asset, beginning with the planning phase and continuing through execution, management, and eventual decommissioning. This procedure, where the significant potential of BIM-technology lies, aims to re-use data across the lifecycles and reduce error-prone and time-consuming operations.

Figure 2. 2 Building Life Cycle (Ahmad AlQuosi, 2022)

BIM Dimension and Level of development (LOD)

Building Information Modeling (BIM) is an innovative approach for creating information-rich models throughout the entire project lifecycle. BIM models evolve and increase in detail as the project advances through different stages, such as LOD 100, 200, 300, and beyond (United-BIM, 2020). Use-cases define the specific purposes for which a BIM model can be used, with criteria added based on the project stage and complexity. BIM dimensions enhance predefined use-cases by enriching the data associated with a model, enabling a deeper understanding of building projects. BIM technology has advanced from 3D and 4D dimensions to 5D, 6D, and 7D dimensions, which are poised to revolutionize the architecture, engineering, and construction (AEC) industry (United-BIM, 2020).

The American Institute of Architects (2008) first introduced Level of development (LOD) as a set of specifications that enables experts in the AEC industry the ability to properly document, describe, and specify BIM material. LOD, which serves as an industry standard, describes the development stages of various BIM systems. Using LOD standards, architects, engineers, and other professionals can communicate without ambiguity in order to expedite the execution process (The American Institute of Architects, 2008).

LOD specifies the extent to which the component's specification, geometry, and information have been considered, while the Level of Detail refers to the amount of information contained in a model element. The Level of Development (LOD) standardizes the development stages of BIM systems and is divided into different levels, including LOD 100, 200, 300, 400, and 500. LOD 100 represents the basic conceptual design stage, while LOD 200 includes the general shape and size of the project components. LOD 300 involves a detailed layout of each component, and LOD 400 includes fabrication, assembly, and installation details. Finally, LOD 500 represents as-built conditions and ongoing facility management (U.S General Services GSA, 2015).

Model Content	LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
3D Model-based Coordination	Site level coordination	Major large object coordination	General object-level coordination	Design certainty coordination	N/A
4D Scheduling	Total project construction duration. Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	N/A
Cost Estimation	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of the generic element (i.e. generic interior wall)	Estimated cost based on measurement of specific assembly (i.e. specific wall type)	Committed purchase price of specific assembly at buyout	Record cost
Program Compliance	Gross departmental areas	Specific room requirements	FF&ampE, casework, utility connections		
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled and/or locally purchased materials	Specific manufacturer selections	Purchase documentation
Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on the specific manufacturer and detailed system components	Commissioning and recording of measured performance

Figure 2. 3 The capability of a BIM Model according to LOD level (U.S General Services GSA, 2015)

2.1.2 Industry Foundation Classes (IFC)

Since the mid-1990s, an international team has been developing the present version of the IFC schema, which is commonly used in the AEC–FM industries as an open BIM for interoperability purposes. The IFC schema was envisioned as the internationally agreed upon common language for building information interchange. IFC is now published as an ISO standard (ISO, 2013) and is described as "an open international standard for exchanging and sharing BIM data between software programs used by the various participants in a building construction or facility management project."

The standard also notes that it is unlikely that the full standard would be implemented in a single software application. To utilize IFC, MVDs are necessary (East B, 2016).

According to the IFC website, a model view definition is a subset of the data schema and referenced data (Liebich and Chipman, 2017).In the building construction and facilities management industry, a particular model view definition is established to enable one or more recognized workflows. Each process outlines software application data exchange requirements (Patacas, 2020).

Given that the goal of IFC is to serve the information demands of all stakeholders across the entire lifecycle of a facility, the IFC model can represent a wide variety of items. In IFC 4, 766 distinct object classes describe physical and mental items in the following domains: architecture; building controls; construction management; electrical; fire protection; HVAC; plumbing; structural construction; and structural design (Patacas, 2020).

2.2 Facility management and Building Information Modelling (BIM)

2.2.1 Facility Management

This chapter provides an overview of FM with an emphasis on information management. There is a need to compare the types of tools now utilized in FM with accessible BIM tools and their pros and weaknesses in following chapters. Collaboration on information throughout the building phase aids facility management by lowering reorganization costs and effort. The parameters of project management and the significance of why structured data should be collected and transferred with care are vital for the successful reuse of data in facility management (Sophia Theresa Vega Volk, 2016).

Facility management definition

The phrase "facility management" refers to the use of technologies and services to support the long-term viability, usability, and safety of an organization's infrastructure, including its buildings, grounds, and other comparable real estate. It ensures that these facilities remain functional and effective while ever sacrificing safety and comfort. With facilities management, you can ensure that every system in a given building, from the main entrance to the meeting room, performs seamlessly together (Manish K. Dixit, 2019).

Facility management purpose

The purpose of FM is to manage an asset by coordinating the duties of the many groups of specialists required for the building's operation. There are a variety of specialist subject areas within facility management, including commercial asset management, communication, technical asset management, general services, and area management. These groups are backed by IT equipment like as management systems, building control systems, computer-aided design (CAD) software, and networks. The relationship between facility management and asset management is unrelated to administration. The objective of FM is to provide quick access to relevant information for the efficient completion of tasks or for communication purposes. Building information system data is utilized for focused control to assure intelligent judgments, decrease expenses, and generate profit. Information management begins with an asset's conception and construction and concludes with its destruction (Sophia Theresa Vega Volk, 2016).

Facility management tasks

Tasks related to facility management rely on vast volumes of asset-related data. A portion of this data originates from the building phase, while the remainder comes from the operational phase. During construction, architectural data is collected, such as floor plans, facades, and areas. Equipment documentation, such as electrical, plumbing, and HVAC information, is necessary for optimal operation and maintenance. During the operation period of a resource, architectural and specialized data undergo modifications. The operational phase of an asset's lifecycle is the longest. For this reason, processes and technological solutions are always evolving to meet the needs of the asset. Data management necessitates adequate storage and upkeep. Facility managers utilize specific IT systems for organized, consolidated, and accessible storage (Braun et al, 2014).

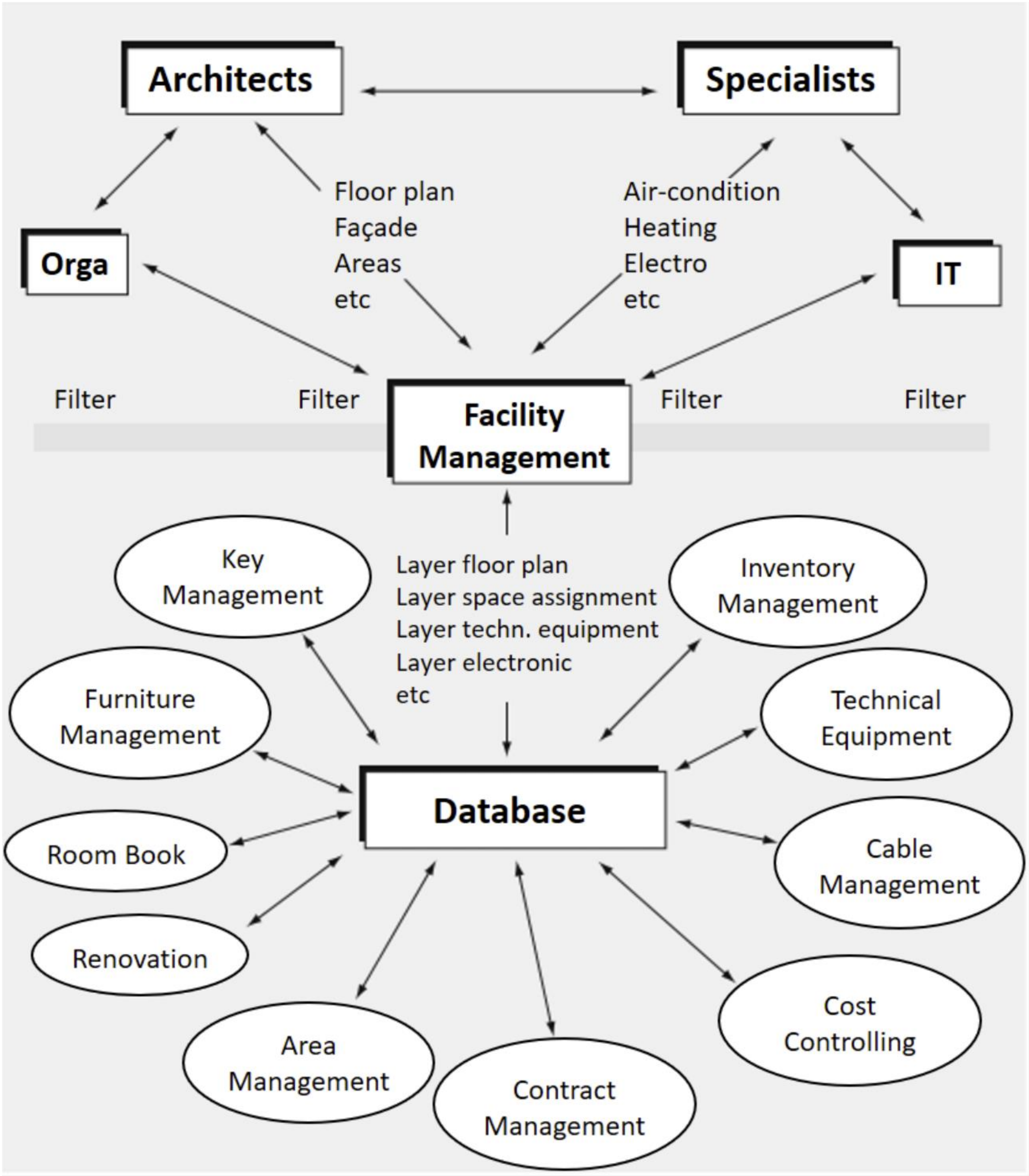


Figure 2. 4 Facility management tasks (Braun et al, 2014)

IT tools and data management are pertinent to this study and will be discussed in coming chapters. Since this thesis does not address this topic, information about external specialized advisers and service providers is irrelevant and will not be further explored.

2.2.2 facility management platforms

There are many facility management applications, such as Computerized Management Systems (CMMS) and Computer Aided Facility Management (CAFM) (CAFM). Facility management software (FMS) aims to manage and monitor equipment, assets, and work order procedures, as well as save rent and other overhead costs. The bulk of facility management software offers an automated version of the system for managing an organization's facilities and assets. It provides superior tools for working efficiently and submitting data on supply, repairs, and parts. In addition, it provides managers with a tool for management and visibility into the status and maintenance history of commercial property. Some of the best platforms for facilities management software.

Traditionally, FM data and information are stored and managed in dispersed information systems, such as Computerized Maintenance Management Systems (CMMS), Electronic Document Management Systems (EDMS), Building Automation Systems (BAS), etc. The essential information and data for such systems originates from several sources, is created and edited multiple times throughout an asset's life cycle, and is typically not synchronized amongst systems, resulting in error-prone processes (Becerik-Gerber et al., 2012). Korpela et al. (2015) emphasized the issues in the integration of many IT systems used for the maintenance of the University of Helsinki's Center for Properties and Facilities, and how BIM could assist in addressing these challenges (Patacas, 2020).

2.2.3 BIM for facility management

The construction sector makes extensive use of BIM technology during the design and construction phases of projects. However, its use during the phase of operations and facility management is minimal.

BIM serves as a repository for information that facilitates the management of a facility by providing facility managers with accurate and exact digital information on the functional aspects of the building and lifecycle-related information. BIM's Level of Development (LOD) and Level of Accuracy (LOA) provides the facility management team with detailed and accurate information about the building parts. BIM influences facility management by increasing its efficacy and efficiency (Tsay et al., 2022).

Table 2. 1: Construction Industry Sectors BIM Contributes to Facility Management Development (OneStep AEC, 2021)

Areas	Definition
Asset Management	The 3D model of Building Information Modeling (BIM) shows the layout, floor plan, size, and space requirements of a building, which helps facilities managers plan, track, evaluate, and manage the building's space. This understanding of space utilization can lead to cost savings and improved building performance by reducing wasted space and optimizing space usage.
Analyses of Energy and Efficiency	The construction industry is integrating BIM with energy simulation technologies for sustainable buildings. BIM is being combined with FM systems to compare projected energy performance with actual consumption, identify issues and optimize energy efficiency. It helps select the best solutions and monitor the building's energy performance throughout its lifetime.
Reconstruction and Refitting	BIM technology can create an as-built model of buildings by using laser scanning of the original and retrofit design plans. This model provides information on all components of the existing structure, allowing facilities managers to monitor and benchmark systems and make informed decisions. BIM also suggests retrofit alternatives that suit the project, increasing operational efficiency and reducing costs for remodeling and retrofitting.
Streamlining the Process for Maintenance	The facility management team receives a 3D BIM model with comprehensive information on the asset, MEP components, and building features, including equipment warranties and maintenance manuals. This enables streamlined maintenance processes, planning of repair and replacement actions, and designing maintenance programs.

Lifecycle Management	BIM models have data on design, life expectancy, and replacement costs for building parts. This information helps estimate replacement time and costs, enabling informed decisions to invest in long-lasting materials with a one-time payback during the building's lifetime.
Emergency Management	BIM models and information systems improve emergency response effectiveness by providing real-time data on floor designs, equipment schematics, and hazardous locations. Integrated with the building automation system, it enhances emergency response for police, fire, and public safety authorities.
Capital Planning	BIM generates a Facility Condition Index and identifies assets most likely to fail, aiding in strategic capital investment choices. This leads to more uniform planning and management of building maintenance and more precise capital planning.
LOD Provides Detailed Information for BIM	The BIM Level of Development (LOD) accurately documents data and ranges from LOD 100 to LOD 500. LOD 500 provides precise information on elements such as purchase documentation, commissioning data, record cost, and maintenance requirements, which are essential for facility upkeep and administration.
LOA for Accurate Documentation	US Institute of Building specifies five levels of LOA (LOA10-LOA50) applicable to construction elements and projects. Precision in BIM and LOD data enhances operational efficiency and reduces hazards for facility managers.
Energy Efficiency Using BIM and LEED	LEED and BIM integration can aid in the development of sustainable buildings and help facility managers evaluate the impact of building components on sustainability.

Information Flow in Harmony with COBie and OCCS	COBie and OCCS data contribute to efficient and transparent information flow, assisting facility managers in maintenance and decision-making.
Cost Optimization	BIM reduces costs and optimizes facility management through space usage, energy savings, asset management, and timely decision-making
Enhancement of Customer Satisfaction	BIM enhances facility services and increases customer satisfaction by improving physical facilities, equipment, safety, comfort, accessibility, and dependability.

2.3 BIM Information Requirements

A Requirement is some sort of a legal contract between two parties, and it based on the owner's expectations of how the information model must be delivered. To enable better information production during the Asset's Lifetime Cycle and having a high-quality digital information, a clearly defined information requirements needed. Unclearly defined information requirements lead to unstructured and low-quality digital information model. Information requirements refer to set of data sheets to be filled by project stakeholders specifying details about building or construction information that should be clarified by answering to following questions:

- What information should be produced or presented?
- When this information should be produced or presented?
- How this information should be produced or presented?
- Who should produce or present this information and to whom it should be presented?

2.3.1 information requirement types

The types of information requirements defined in ISO 19650-1 (2018) determine the information models that are needed, including the project information model (PIM) and the asset information model (AIM). These models are utilized to provide the necessary information for the project or asset Depending on the specific information requirement type.

Organizational Information Requirements (OIR): it is a description of the information necessary for asset management systems and other organizational functions. In other words, these are information requirements at the organizational level as opposed to the asset or project level.

Project information requirement (PIR): it is high-level information needed by the client and/or their stakeholders to make key decisions concerning the project. It defines what asset information should be delivered for each certain project,

Asset Information Requirements (AIR): define the information required to operate and maintain a built asset in line with an organization's asset management strategy. ISO 19650 defines AIR as 'information requirements in relation to the operation of an asset'; an information requirement is defined as 'specification for what, when, how and for whom information is to be produced'.

Exchange information requirements (EIR): is a document drawn up by the client defining all the requirements related to responsibilities and the information production, process, and procedures as well the information exchanges of a BIM process. also known as “Employer Information requirements” in PAS 1192-2.

2.3.2 Information model types

Project information model is produced during the delivery phase (design and construction) then it gets upgraded to what is called Asset information model which is used for the operation and maintenance phase.

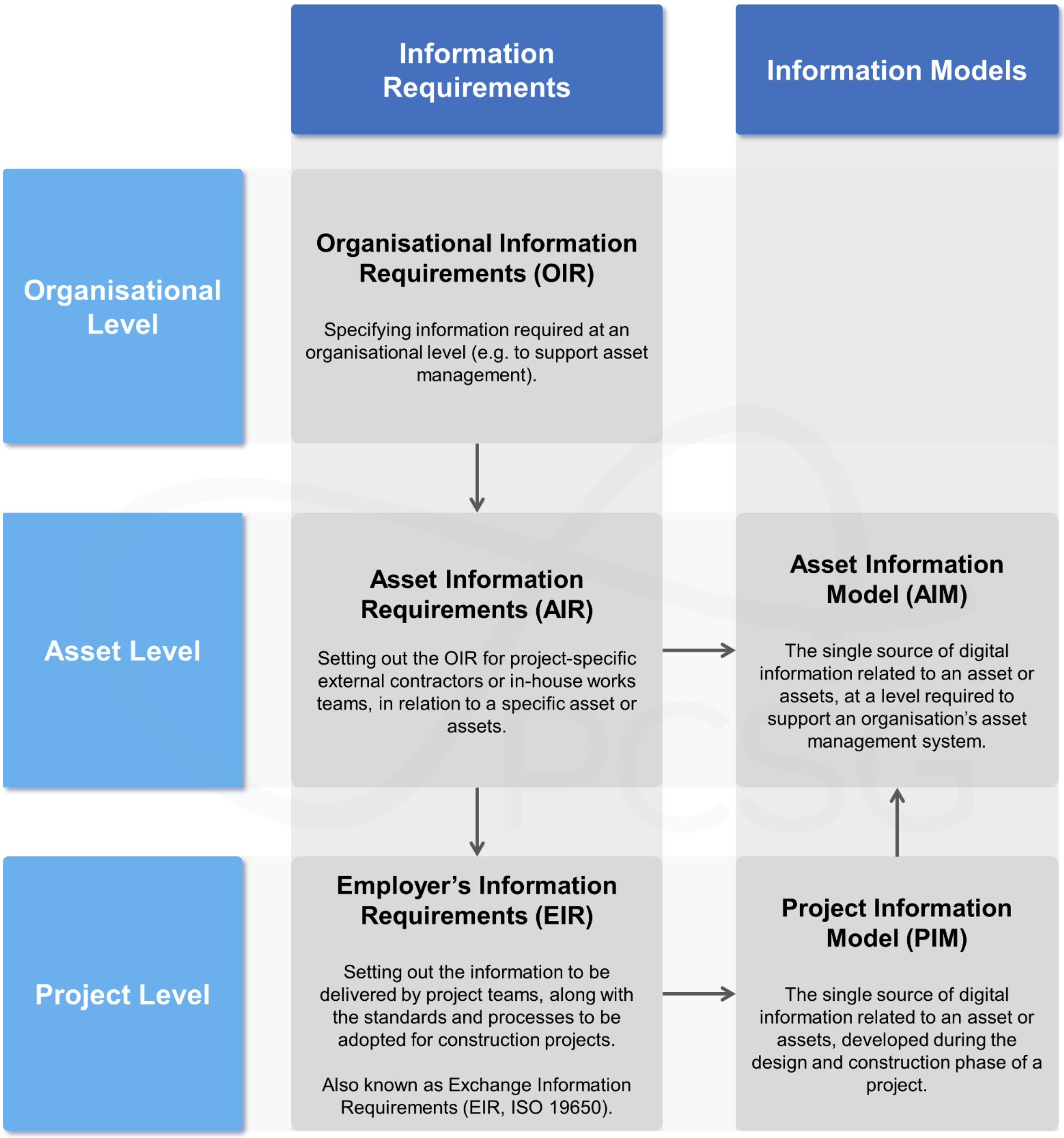


Figure 2. 5 Relationships between the information requirements types and Models (Cohesive, 2022)

2.3.3 Level of information Need (LOID)

The level of information required is described by BS EN ISO 19650:2018 as the quality, quantity, and granularity of information. Also, the aim of each project information deliverable must be chosen. Geometric information, alphanumeric information, and documentation can all be used as sources of information depending on the projects and design phases.

Methods to define the Level of information Need:

- **Descriptive method:**
  The requirement issuer (Client) provides a general description of the amount of information required for one or more stages of the asset lifecycle in this section.

Compared to other methods, this one is the simplest and fastest. Yet, it is the hardest for the providers to estimate (both in terms of time and cost), which can lead to disagreements and disputes.

- **Industry specification method:**

  This method offers the providers a well-known production guideline, and its on-going updating makes it one of the preferred methods. Nevertheless, neither specification defines the amount of information required at the system level or the product level (Not All Levels). The information that is generated will typically be more or less what was intended. Moreover, documentation has no definitions. There are two main specifications used in this method Level Of Definition Specification and Level Of Development Specification. These two specifications are very different from one another.

Level Of Definition Specification	Level Of Development Specification
UK	US
NBS (National Building Specification)	BIMForum (buildingSMART US Chapter)
Online Directory	Downloadable Document
Graphics Models And Non-Graphical Data	Graphical Models Only
Delivery Phase And Operational Phase	Delivery Phase Only
Metric	Imperial
Uniclass	Omniclass
Level 1/2/3/4/5	LOD 100/200/300/400/500

Figure2.5: Comparison between Level of Definition Specification and Level of Development Specification (Ahmed AlQuasi, 2022).

- **Asset definition method:**

  With this approach, the requirement issuer defines the level of information required at each level of the asset breakdown structure at each stage of the asset's lifetime cycle using a customized organizational standard. The Assets Range (Asset Data Dictionary) And the Assets Hierarchy (Asset Breakdown Structure) To Be Set In Preparation. This is the most time-consuming and difficult method (for both sides), but it is also the most thorough (All Assets Will Be Included). And the most fruitful (just what is required). Also, it is the simplest to validate and check.

2.3.4 Relevant Barriers in BIM-Enabled Facility management

According to the present research, there are still substantial obstacles limiting owners and facility managers from applying BIM on a broad scale in facility management. These problems are framed in numerous ways across the literature. Tsay et al., (2022) mentioned these problems in Table 2.2 classifies some of the most significant obstacles:

Table 2. 2: Challenges facing applying BIM in the Facility management (Tsay et al., 2022).

The Issue	Description
Limited interoperability	There are still several limitations with BIM integration with existing CAFM systems; yet, this interaction is required because not all FM-related data is suitable for hosting in a BIM Environment.
Undefined or Low-quality BIM requirements for facility management in the earlier phases of the project	Since facilities information systems vary depending on the case of the project, it will be a significant challenge to implement BIM based FM.
Absence of integrated BIM FM guidelines, norms, and standards	Lack of standardized methods and tools Remains a significant obstacle for both the design team and the building owner."
Lake of communication between the FM and the delivery phase	Generally, FM do not involve in the delivery phase and most of the time do not get hired before the end of the construction.
Insufficient evidence of worth	Many asset owners are still unsure about the benefits of adopting and integrating BIM technology and procedures into their current organizational infrastructure and operations.

Limited knowledge in FM sector	Lack of BIM expertise in the FM business

Tsay et al, (2022) described those challenges which facing the Facility managers regarding to the information accessibility by characterizing the BIM enable facility management delivery process to eight main activities and mapping the challenges faces implementing BIM in facility management to stablish connection between them, however he did not propose a real practice solution to solve the unclear information requirement or the lack of the communication between different teams during the project.

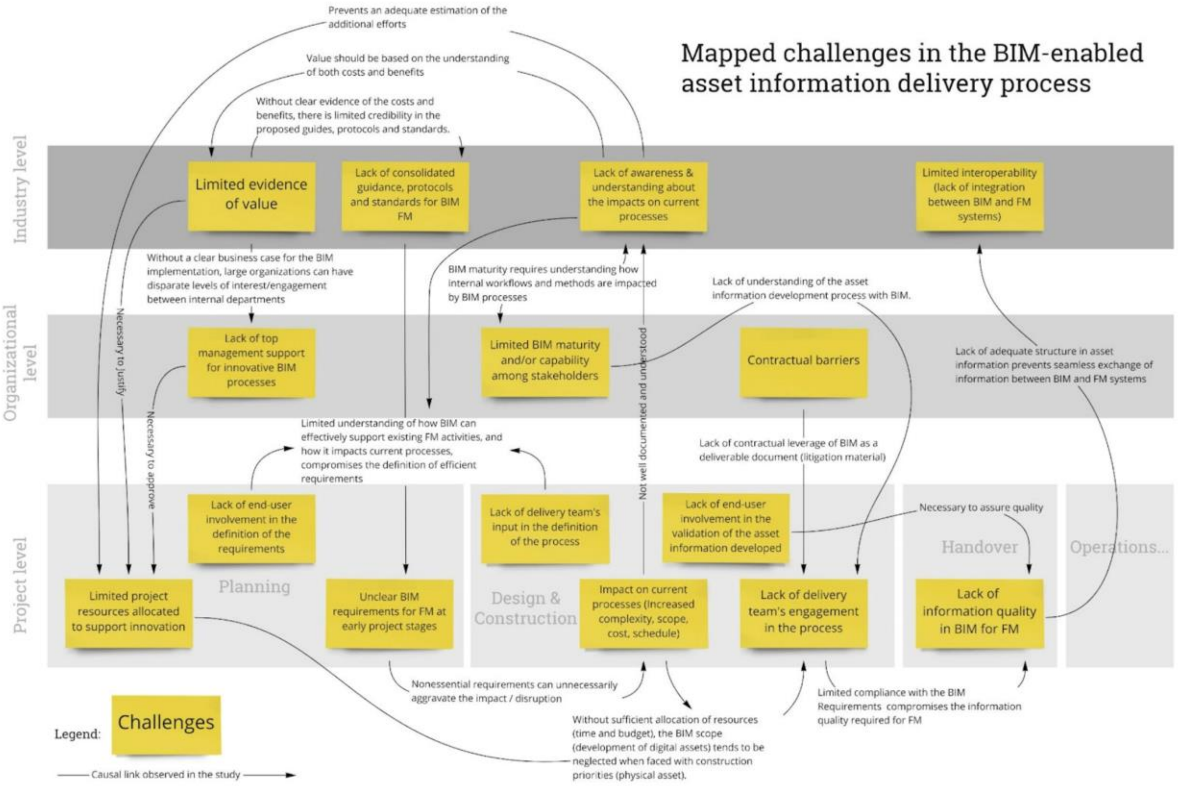


Figure 2. 6: Stablishing the connection between challenges faced BIM based FM by (Tsay et al., 2022)

Becerik-Gerber (2012) define the data requirements for BIM based facility management depending on the application areas for the organizations which can use the BIM model in facility management. Then he specified the data structure of nongeometric data requirement and the scope of data needs and the parties responsible for data provision. However, he did not go through the management problems that faces the facility management requirement from the lack of participation of the client and the facility managers in the earlier phases of the project.

Table 2. 3: The organizations and the potential application areas of BIM in FM (Becerik-Gerber et al., 2012)

Organizations	BIM applications area in facility management
- Education - Government - Large AEC Firms - Healthcare - Professional FM organizations - Retail - Information technology - Other	- Locating building components - Facilitating data access - Visualization and marketing - Checking the maintenance - Creating a digital twin - Space management - Planning and feasibility studies for non-capital construction - Emergency management - Controlling and monitoring energy - Personal training and development - Other

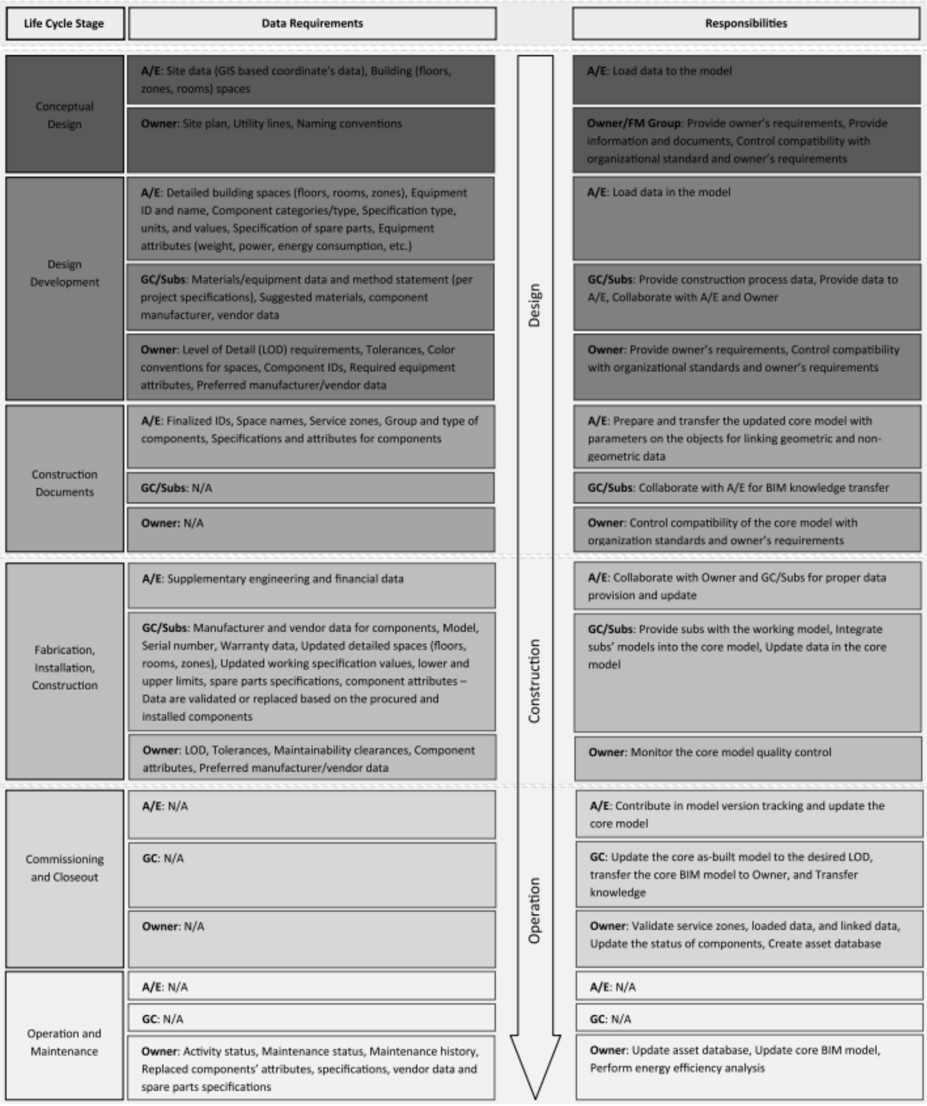


Figure 2. 7: The continuum of data requirements and stakeholders responsible for data provision (Becerik-Gerber et al., 2012)

2.4 Data quality management of BIM Model

To understand data quality, it is crucial to distinguish between data and information. Batini and Scannapieco (2016) proposed a fundamental principle that differentiates between the two terms. Information can stand alone and be used, while data needs to be organized by similar concepts or associated with a system or object. Data provides information about items or individuals and can be processed or transmitted. A single value, or datum, is often referred to as a data point. In the context of projects, data generated for various aspects, from meeting recordings to complex models and management.

While almost everyone agrees that data and information are distinct concepts, the same cannot be entirely accurate of data quality and information quality. ISO 8000-

8:2015 defines Information quality includes data quality, but it also addresses the project challenge of deriving value from information and how to manage information as a product in a wider context. Information producers must comprehend the needs of content consumers to generate high-quality information. Once these are comprehended, they can be converted into data specifications that form the basis for and define data quality (ISO, 2015).

Quality management is the process of achieving and fulfilling high-quality output by meeting customer-defined specifications (Ramesh, 2016). Assurance and control of quality are two intertwined facets of quality management.

Quality assurance & quality control

Quality assurance (QA) assures that the product will have a high level of quality by guaranteeing that the process's output is error-free and fulfills all the specifications. It is a method based on procedures, and its purpose is to minimize errors in deliverables at the planning phase of a project to avoid costly reworks. The quality assurance procedure is proactive, with a focus on planning, documenting, and meeting standards. This occurs at the very beginning of the project and adds to improved product needs communication (Leygonie, 2021).

Quality control (QC) is a product-based strategy that entails activities and methods for meeting quality specifications. This is a reactive method for detecting defects in deliverables. The objective of the quality control procedure is to ensure that all deliverables are flawless and satisfy all quality requirements (Leygonie, 2021).

The quality control process tries to accomplish the following objectives: identifying product defects, resolving those defects, and validating the deliverable.

QA and QC are interdependent; the quality control process gets input from the quality assurance process and offers feedback to the quality assurance process in order to validate the process.

Table 2. 4: Quality Assurance & Quality Control (Leygonie, 2021)

Quality Assurance	Quality Control
Defect prevention	Defect identification
Avoid defects in the deliverable	Corrects defects in the deliverable
A proactive process	A reactive process
Process-based approach	Product-based approach
Quality managing processes	Quality verification
A quality audit is an example tool	A quality inspection is an example tool

2.4.1 Quality model issues

To enable BIM in facility management, The BIM model must be checked and tested against all the shortage of the modeling process. The quality of the BIM model has been understudying by several research but still need to be more applicable in the real-life projects.

Zadeh & Staub (2012) identified various types of BIM quality issues (e.g. incompleteness, inaccuracy, incompatibility, incoordination, incomprehensibility) and categorized them based on different model perspectives (i.e. objects, attributes, relationships, locations) and pertinent facility management perspectives (i.e. assets, MEP systems, spaces).

Table 2. 5: BIM-IQ analysis framework for FM (Zadeh & Staub, 2012)

	BIM-IQ Perspectives					
FM Categories	**Entity Level**			**Model Level**		**User Level**
Asset	Incomplete Assets (Table 2)	Inaccurate Values for Asset Attributes (Table 4)	Inaccurate Asset Placement (Table 6)			
MEP Systems	Incomplete MEP Systems (Table 3)	Inaccurate Values for System Definitions (Figure 4)	Inaccurate Spatial Allocation of MEP Systems (Table 7)	Compliance with BIM Standards (Table 8)	Model Clashes	Understand-ability of Information
Space	Incomplete Spaces	Inaccurate Values for Space Definitions (Table 5)	Inaccurate Space Placement			
Issue Type Categories:	*Information Incompleteness (sec. 3.1)*	*Value Inaccuracy (sec.3.2)*	*Spatial Inaccuracy (sec. 3.3)*	*Model Incompatibility (sec. 3.4)*	*Uncoordinated Information*	*Incomprehens-ible Information*

Leygonie (2021) continues Zedah & Staub (2012) work and extend it to make it more applicable to the practice field by proposed a framework of quality management process (quality control and quality assurance) and creating a checklist of the BIM model that should be checked at the handover process at the end of the delivery phase, both Zedah & Staub (2012) and Leygonie (2021) did not take consider of their work the way of receiving the Information requirement for FM and building their assumption on the delivery phase got right information requirement and the understand their tasks. beside their workflow need further improvement to implement other perspective like Automation and Open BIM and to be more realistic to be implemented in the industry.

2.4.2 Interoperability

Interoperability is the ability of two or more parties to exchange (required and available) information and utilize it . Because the information contained in a BIM model must be transferred for it to be functional, it is one of the pillars of Building Information Modeling (Fallon & Palmer, 2007). In a specific project phase, all stakeholders (architects, engineers, designers, surveyors, contractors, etc.) use computer applications that consume and/or supply data processed by various software used by other collaborators on that phase. Each communicating pair of apps must be able to access (enter, retrieve, update, or alter) a subset of the information created by the other (one- or two-way). Similarly, BIM information must flow throughout the building's lifecycle and be handled by a variety of professions using their software. Interoperability is essential for preventing the duplication or re-entry of data and enabling the efficient use of information (Pazlar, 2008).

2.4.2.1 Construction-Operations Building information exchange (COBie)

As described in the IFC schema, it is expected that a subset of the schema, an MVD, is required to use IFC in a software system (Venugopal M & Eastman C, 2012) One of the most successful specifications of an MVD for such an exchange purpose is the COBie specification (East B, 2016).which is based on the practice of the design and construction industry to define the timing, content, and quality of design and construction deliverables within a project to ensure the contractually defined and accurate transfer of information from one party to another at a specific point in the project—in this case, the delivery of information from the design phase to the construction phase.

As with any MVD, the COBie MVD describes the objects included and excluded from this particular set of building information (East B, 2016). First, it is believed that a COBie file contains data on a single building. Therefore, the COBie MVD simplifies the

IFC project/site organization that might supply many buildings in a single IFC file. Next, only object types that indicate unitary managed or maintained assets are permitted in the COBie MVD. Last but not least, the information provided in operations and maintenance manuals is defined precisely. COBie data contains building, floors, spaces, zones, types, components, systems, assemblies, connections, components, resources, and documents. The United States National BIM Standard COBie version 2.4 specification lists the rule classes that are applied to COBie data (East,B 2016) as follows:

- OneAndOnlyOneFacilityFound—one building;
- NotNull—text value that is not empty or n/a;
- NotEmpty—text value (n/a is acceptable);
- ValidNumber—valid number;
- ValidNumberOrNA—valid number or n/a;
- ZeroOrGreaterOrNA—valid number greater than zero, or n/a;
- AtLeastOneRowPresent—minimum one object in top-

However, merely listing the objects that can be found in a COBie file is insufficient. This is because competent software is able to generate COBie-compliant data files, but may not verify that the data is actually genuine, such as by ensuring that the names of each ifcSpace and ifcProduct are unique. Additionally, each ifcProduct must be identified in the ifcSpace that offers access for maintenance. Without such a business rule, it would be useless to instruct a technician to do maintenance on Pump 5 in Room 3. COBie also specifies the level of information required for facility managers to accurately describe product assembly. From the perspective of COBie, the only relevant information is that which pertains to the typical facility manager of a conventional structure. The facilities manager must estimate the cost of janitorial services, for instance. A note describing the type of floor covering and the size of the floor to be cleaned is required for this task. COBie often does not include information regarding the individual layers that comprise the floor covering. The only usual use of product assemblies in COBie involves items with moving parts, such as chillers and electrical distribution panels.

Finally, COBie specifies in detail how equipment location inside a facility is represented. This is significant because site managers do not need to know the location of a given piece of equipment to a millimeter's precision, but rather to a human-scaled accuracy of around one meter. In big multipurpose equipment rooms, for instance, similar equipment is frequently collocated, and COBie allows these areas to be built within a larger physical mechanical room. Equipment located within walls or above ceilings must be situated in the room from which it is most likely to be operated. Additionally, there are simplifications required to illustrate the assembly of unitary items.

COBie's emphasis on higher conceptual completeness makes it more difficult to query COBie information. This is mostly due to the necessity of appropriately structuring the data to meet the requirements of facility managers. Frequently, such structures are difficult to query because the actual logic employed to organize the data may not adhere to other criteria database designers would utilize. One example is the existing depiction of links between different building systems, which only permits 11 interactions rather than the simpler 1n or nn relations. Similarly, the increasing conceptual completeness affects the COBie standard's software implement ability. To create software for information sharing, it is necessary to comprehend the COBie framework's

core ideas.

2.4.3 Classification Systems

The operations performed during the lifecycle of a facility generate a vast amount of data that must be kept, accessed, shared, and utilized by all stakeholders. This increase in the quantity and variety of information produced, as well as the AEC industry's subsequent dependence on this information, necessitates an organizational standard capable of addressing the full breadth of this information. This organizational standard will facilitate the exchange of information across parties separated by miles, countries, or continents, while also enhancing its reliability (Autodesk, 2021).

The classification system's application can vary depending on the user, for instance.

- Owners use classifications to organize data for facility and asset management, development planning, and cost estimation.
- Contractors Use classifications for construction management, scheduling, and cost estimation.
- Architects and Engineers use classification to develop project specs, use classes.

Classification Management is a preprocessing step for the constructed environment. Multiple Classification Management systems are utilized on a global scale. The following are the most frequent:

- MasterFormat: A master list for arranging the outcomes, needs, goods, and activities of building projects. MasterFormat originated in North America and is produced by the Construction Specifications Institute (CSI) and Construction Specifications Canada. It is mostly used for bidding and specifications (CSC).
- UniFormat: For organizing construction information, arranged around the physical features of a facility known as functional elements, and used primarily for cost estimates. UniFormat was created by the Construction Specifications Institute (CSI) and Construction Specifications Canada in North America (CSC).
- Uniclass: For the design and construction process in its entirety. In particular, for the organization of library materials, product literature, and project information. Uniclass was created by the Construction Industry Project Information Committee (CPIC) and the National Building Specification in the United Kingdom (NBS).
- OmniClass: For the organization, classification, and retrieval of product information for all built environment objects across the project lifecycle. Originating in North America, the Construction Specifications Institute (CSI) and Construction Specifications Canada develop OmniClass (CSC).

Classification Systems	OmniClass	MasterFormat	UniFormat	Uniclass
Country of Origin	North America	North America	North America	UK
Produced By	CSI and CSC	CSI and CSC	CSI and CSC	CPIc and NBS
Language	English	English	English	English
Purpose and Properties	Organization, sorting, and retrieval of product information for all objects in the built environment in the project lifecycle.	A master list for organizing construction work results, requirements, products, and activities. Mostly used in bidding and specifications.	For arranging construction information, organized around the physical parts of a facility known as functional elements and mainly used for cost estimates.	For all aspects of the design and construction process. For organizing library materials and structuring product literature and project information.
Framework	ISO 12006-2, ISO 12006-3, MasterFormat, UniFormat, EPIC	Industry practice and gradual development	ISO 12006-2, Professional judgment	ISO 12006-2, SfB, CAWS, EPIC, CESMM
Grouping Principle	faceted	hierarchical	hierarchical	faceted
Organization and Taxonomies	15 inter-related tables categorized by number and name. A combination of Table 21, Table 22, and Table 23 allows for classifying a product precisely.	One table with a series of six numbers and name: Level one with 50 divisions (2004 version) each is made up of level two, level three, and sometimes level four numbers and titles for more detailed areas of work results.	One table with alphanumeric designations and titles in five levels: level one is in nine categories separated by their special function. Level 2 separates them into constituent parts, level 3, 4, and 5 further subdivide them.	The division among facets is based on the alphabet in 11 tables and within each facet by decimal scale up to 6 digits. Table G, J, K, and L can be used for classifying product models.

Figure 2. 8: Comparison between the classification system (Autodesk, 2021)

2.5 Project Delivery Method

Owners use various methods to get design-build services for their buildings. A simple house can be done by one firm, but complex structures like hospitals may need multiple organizations. Regardless of complexity, decisions must be made to obtain services. These choices form the Project Delivery strategy (S. Z. Syed Zuber, 2018).

Design – Bid – Build (DBB)

The most conventional method of project delivery, also known as traditional project delivery, entails a design team and general contractor working directly for the owner under separate contracts.

Drawings, specifications, and other exhibits are drafted by the design team in collaboration with the owner. Once the design is complete, it is forwarded to general contractors so they can submit bids for the project. The design team and owner then review the GC proposals and choose one to put into a contract with. After the contract is signed, construction supplies and equipment are ordered so that work can commence.

Due to the competitive nature of the bidding process, the project may be completed at a reduced price. By separating the design team from the construction crew, possible conflicts of interest might be reduced. On the other side, the design phase can require the owner to invest a substantial amount of money before obtaining an accurate estimate for the construction project. Depending on the quality of the design, the owner may be susceptible to change orders, delays, and additional expenses initiated by the contractor, who is unable to provide input prior to the commencement of construction (Dawn Killough, 2020).

Design – Build (DB)

It involves an owner engaging in a contract with a sole firm to handle both the design and construction aspects of a project. The entire project is managed from start to end by either the architect or the contractor, in striking contrast to the design-bid-build process described previously. Theoretically, when the design team and construction team are combined, the project becomes more efficient.

Depending on who the contract is with, DB projects can be architect-led or contractor-led. Architect-led agreements are typically utilized for complex design projects, such as new construction, renovations, etc. Typically, contractor-led projects do not rely on intricate designs and involve repetitive work, such as infrastructure or road construction. Regardless of how the contract is written, the architect and contractor are typically contractually linked, and one of them is tied to the owner and has project management responsibilities (Dawn Killough, 2020).

Due to the better collaboration between the design and construction teams, this method may be more efficient and less expensive, and it simplifies communication and financial obligations for the owner, as there is only one contract. Potential conflicts of interest between the contractor, who wants to keep prices low, and the owners, who want a high-quality product. Supplementary liability for general contractors, who may be required to get additional errors and omissions insurance (Dawn Killough, 2020).

Integrated Project Delivery (IPD)

The most recent addition to the project delivery palette is integrated project delivery (IPD). In these initiatives, each member of the project team is contractually bound to a single contract. Before design begins, each team member is chosen, and they each have a role in the entire process, from design to building.

IPD is gaining popularity because to the fact that everyone shares the project's risk equally. Additionally, this process produces the most inventive and collaborative project approaches. When integrated with other building approaches, such as lean construction, they can dramatically increase the efficiency of construction methods and significantly reduce project durations.

The advantage of this method is the Risk shared equally among all project stakeholders, which leads to the collaboration between them, which can be enhanced by bringing together all parties at the commencement of the project. On the other hand, it can be difficult to make adjustments as the project progresses, and it requires a high level of preparation and planning in the project's earliest stages.

3 RESEARCH METHODOLOGY

To address the research questions and objectives, a mixed-methods approach was proposed. First, a comprehensive review of the existing literature on BIM and facility management was conducted to identify the current issues and barriers related to BIM adoption in facility management, as well as the quality of BIM models. This was followed by a series of interviews with industry professionals to gain a deeper understanding of the challenges they face in implementing BIM in facility management and their proposed solutions.

Based on the findings of the literature review and interviews, a set of proposed solutions were developed to address the identified problems and barriers. The proposed solutions include:

1- Involving the facility manager from the initial stages of project development.

2- Developing a structured workflow and guideline that can be followed throughout the whole process of BIM-based facility management to avoid ambiguity and setbacks.

3- Ensuring high-quality BIM-Model development by following quality checklists.

One proposed solution is to involve the facility manager from the initial stages of project development. This can be achieved by choosing the suitable project delivery method and ensuring that the facility manager is included in the project team. By involving the facility manager, the BIM document can be tailored to meet the specific facility management needs, thus improving the quality of the BIM document.

Another proposed solution is to develop a structured workflow that can be followed throughout the whole process of BIM-based facility management to avoid ambiguity and setbacks. This workflow and guideline should be designed to cover all aspects of BIM-based facility management, from data collection and model development to maintenance and operation. This would ensure that the BIM-based facility management process is well-structured and transparent, and that all stakeholders are aware of their roles and responsibilities.

Overall, the mixed-methods approach provided a robust and comprehensive methodology to address the research questions and objectives of this study. The methodology allowed for the identification of current issues and barriers, as well as proposed solutions, which were then validated through the case study project. The results of this study can provide valuable insights to industry professionals and academics in the field of BIM and facility management.

3.1 The Methodology

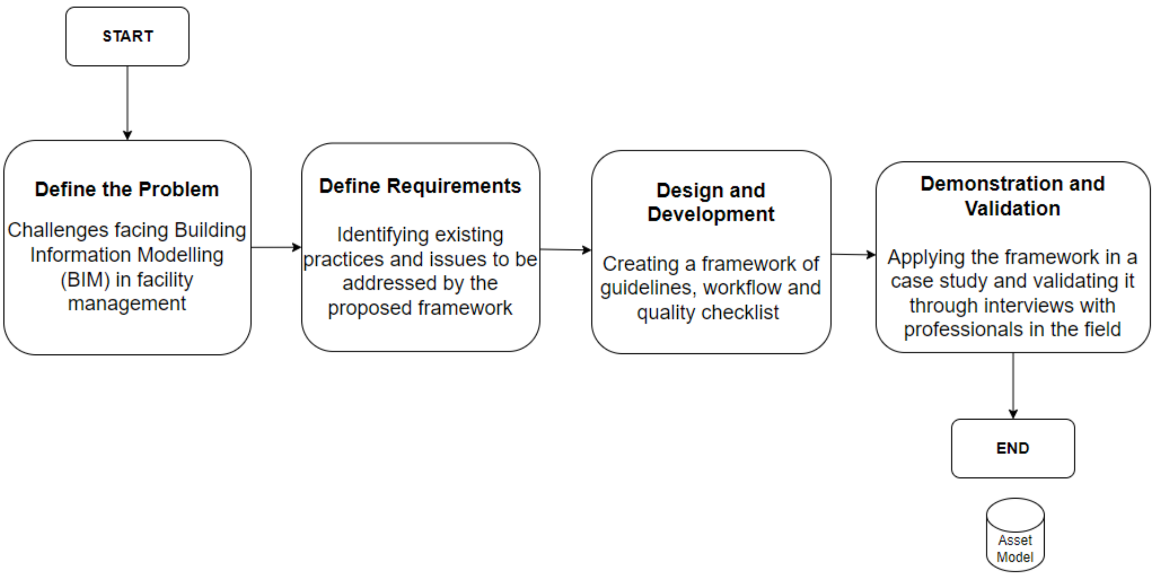


Figure 3. 1: Research Methodology

Table 3. 1: Information and the job description of the interviewee:

No.	Work Sector	Job Title/ Area	No. of experience
P1	BIM Consulting	CEO	12 years
P2	BIM Consulting	Technical Director Head of BIM Sector	10 Years
P3	BIM Consulting	BIM Specialist	7 years
P4	Construction	General manager	15 years

According to interviews conducted with professionals in the Architecture, Engineering, and Construction (AEC) industry, Building Information Modelling (BIM) has great potential for improving Facility Management (FM) processes. The ability to have a 3D digital representation of a building, which includes information on the building's components, systems, and maintenance requirements, can greatly assist FM teams in their work. The interviews revealed that BIM can provide more accurate and up-to-date information for asset management, space planning, and maintenance scheduling, which can ultimately result in cost savings and improved building performance. However, there are also challenges to implementing BIM in FM.

One of the biggest challenges facing the adoption of BIM in facility management is the lack of communication and coordination between the design, construction, and handover phases of a project and the subsequent management and maintenance of the facility. This is due in part to the fact that different parties may use different BIM software and standards, which can lead to data loss and inconsistencies. Additionally, the data requirements of facility management stakeholders may not have been adequately considered during the earlier phases of the project, which can lead to gaps in the information provided and a lack of understanding of how the information should be used.

Another challenge is the low quality of information requirements and guidelines for BIM in facility management. There is a need for more standardization and clarity in the information requirements for BIM models used in facility management. This includes the need for clear and consistent naming conventions, standardized data structures, and agreed-upon methods for capturing and storing data related to facility operations and maintenance. Additionally, there is a need for better guidance on how to develop and manage BIM models for facility management purposes, including the use of automated quality control tools to ensure data accuracy and consistency. These challenges are further compounded by the complex and dynamic nature of facility management, which requires continuous updates and maintenance of the BIM models over the life cycle of the facility.

3.2 Literature survey and the roadmap of the paper

Explicate The Problem:

A comprehensive literature study based on industrial and academic sources, allowed for a full exploration of the problem's scope and an understanding of how the solutions proposed in similar research projects might be improved. The research problems were mapped and represented in the Table below.

Table 3.2: Barriers in BIM-Enabled Facility management

The primary Problem	The associated problems
Lack of the Communication Between the Client, the Delivery Phase teams, and the Facility manager	- Unclear BIM requirements for FM - Lack of consolidated guidance, protocols, and standards for BIM - Lack of end-user Involvement in the definition and validation of the requirements - Lack of delivery team's engagement in the process - Impact on current processes (Increased complexity, scope, cost, schedule) - Lack of top management support for innovative BIM processes - Contractual barriers - Lack of information quality in BIM for FM

	- Limited evidence of value - Limited BIM maturity and/or capability - Limited project resources allocated to support innovation
Deficient workflow and guidelines to implement the Quality checks in the BIM Model.	- Inaccessible information - Irrelevant or useless information - inconsistency - missing information - Incomplete information

Define Requirements:

In this research, the workflow and quality checklist proposed in the literature (Becerik-Gerber al., 2012; Leygonie, 2019.; Tsay et al., 2022; Zadeh et al., 2017) is utilized and enhanced for the purpose of a BIM-based facility management workflow. The aim is to establish a high-level information requirement by improving communication between all parties involved in the project. The proposed workflow ensures a BIM model-based facility management with the application of quality assurance and quality control based on previous research.

Design and Development:

In order to generate a high-quality BIM model, it is essential to implement a high-quality control system. This requires a high level of information requirement, which can be achieved by involving the facility manager in the BIM process from the early phases of the project. To address this, the design part of this thesis proposes guidelines to avoid potential quality issues that may arise during the project, as well as a structured workflow that can be followed throughout the BIM-based facility management process to ensure quality assurance.

In addition, a comprehensive quality control checklist will be proposed to evaluate the BIM model's effectiveness in meeting facility management needs. This checklist will be customized based on the specific requirements of each project and cover all aspects of BIM-based facility management, from data collection and model development to maintenance and operation. The proposed solutions in this thesis help to ensure that the BIM-based facility management process is transparent, well-structured, and that all stakeholders are aware of their roles and responsibilities.

4 Requirements and Proposed Solutions

4.1 Quality Issues Avoidance

4.1.1 Project Delivery Method (PDM) and parties’ relationships

During the interviews, several interviewees suggested that the integrated project delivery (IPD) method would be the best project delivery method to implement BIM in facility management. This is because IPD enables all project-related teams to collaborate and work toward a single objective. The process of continual learning can produce high-performance teams, and the "lessons learned" from previous projects might be examined before the beginning of a new endeavor. This gives the chance to reduce the gap between delivery phase and operation phase.

The interviewees agreed that IPD is the future when integrated with BIM projects in general or BIM-based facility management in particular, as it can accelerate the digital transition that Germany is currently undergoing. The introduction of BIM has enabled the participation of a broader range of disciplines than the traditional design team, as well as client and contractor input. This has enabled higher value addition and improved design validation prior to construction.

However, interviewee P1 noted that IPD is still not fully adopted in Germany. This may be due to several reasons, including the difficulty of instilling behavioral and cultural change in the minds of individuals. To adopt IPD, stakeholders in the construction industry need to collaborate and cooperate more effectively. They must also be willing to share information and data in a transparent and collaborative manner.

One of the key advantages of IPD is that it involves all stakeholders from the beginning of the project, including facility managers. This increases the accuracy and trustworthy information will be collected, necessary for obtaining a reliable source from the BIM model and the data contained in it. Furthermore, implementing BIM in an integrated project delivery process increases the effectiveness of the entire process from the pre-construction phase to the post-construction phase. This leads to reduced time wastage and changes of the work.

In summary, the interviewees suggested that IPD is the best project delivery method to implement BIM in facility management. While the adoption of IPD in Germany may still be challenging due to behavioral and cultural changes required, stakeholders in the construction industry must work collaboratively to share information and data in a transparent and collaborative manner.

4.1.2 Information Project Management

Although there is a lot of study about the potential applicability and benefits of the BIM in the FM stage it is still unclear what requirements should be done in the Delivery phase for successful implementing BIM in FM. This chapter aims to understand the requirements that might be useful and asked from the clients in EIR.

One of the significant issues in generating a high-quality BIM model-based facility management system is the inadequacy of the existing EIRs, which fail to precisely define the required output of the BIM model during the delivery phase. This study aims to propose a set of guidelines for information requirements that can be used as a reference to enhance existing EIRs. The information requirements were derived from analyzing various literature sources and examining EIRs from different projects.

The proposed information requirements include:

- Hierarchy of information requirements according to ISO 19650 muss be obtained.
- Project Stakeholder table including Names, Title, Role, and contacts. It must include the responsible person of the facility management.
- EIR must include BIM Functional Requirements which describe the required contain in the BIM model.
- Clarify the responsibility of changes or modifications during the tender activities, during and at the end of the construction phase regarding to the handover of the project with the required LOD.
- Clarify the activities and the milestones from which the review and the check would be applied it.
- Clearly define the LOD required for the project.

One common issue found in existing EIRs is the lack of clarity regarding the required level of information for FM, often described in a descriptive manner. To address this, it is recommended to define the level of information need using the asset definition method with the input of FM personnel at the project's outset.

4.2 Quality assurance workflow

The paper proposes a quality management process, which involves the participation of FM members from the outset of the project. (Figure 4. 1) illustrates the roles of the various parties involved in the project in the proposed quality management process.

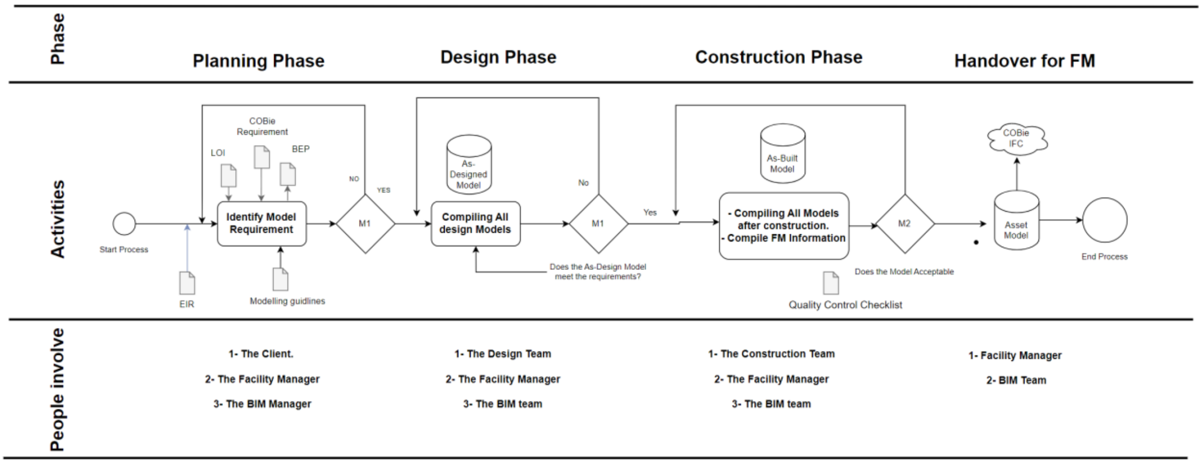


Figure 4. 1 The proposed workflow for the quality assurance

The workflow depending on the major four steps of the compliance process:

Requirements Analysis: in this stage all the typical BIM documentation and requirements regarding to the Model quality should be in detailed. This stage happens before the delivery phase as a proactive process that aims to the relationships between parties and the responsibilities among them. The stage starts with EIR which should be done with the coordination between the Client or the organization and FM member in order to generate a high-level of EIR that can be used afterward as a base to BEP. The EIRs need to define the operation demands in detail. Such as:

- How The Delivery Process Will Be (Continuous, Per Phase, Or All at Once).
- How The Collection and Coordination Process Will Be.
- What Classification System to Use.
- What Items Require Maintenance and Therefore Should Be Included.

- What Properties to Use for Each of The Items.

The BIM manager and other teams should start putting the BEP that needed to be followed in order to achieve the client information requirement with help from the FM member regarding to the FM activities.

Building model preparation: teams show start plan and design the the 3d model according to the information requirement in the BEP. In this process an As-Designed model should be extracted with the level of information required.

Rule execution and Reporting: this process involving reviews, testing, and checking the Model. The design teams, BIM Coordinator and BIM Model with coordination with the FM member will create the required Checklist for controlling the project against the information requirement. The creating of the checklist continues from beginning of the planning phase until the end of the delivery phase. The Quality control should perform at the defined milestones.

Reporting: with every quality control, all reports and results should be saved to provide a solid ground for all teams and FM team members to understand, follow and solve these problems effectively.

All those Milestones and their activities and the people who should participate should clearly define in EIR. Also, this meeting can more divided internal every phase for more quality checking.

4.3 Quality Control Checklist

A checklist is proposed to focus on the overall quality of BIM-based facilities management. Clearly, each building function have distinct aims and, consequently, requirements. For instance, a space planner's information needs will differ from those of a maintenance technician's or energy managers. However, there is a list of checks that must be performed for a Model to be high quality.

The proposed checklist has been collected from answering one question "What does facility management need from the BIM model and what does not need". In order to have a proper checklist which all the elements in our asset list must be included in the model so that data can be connected or extracted. All of these items must then share a parameter containing a unique identification and naming conventions.

Table 4. 1: Items needs from facility managements in the BIM Model

Information that should be removed	- Details - Annotations - Sections and elevations - Sheets - Most schedules except those needed to identify electrical circuits and other data need for building operations
Information that should be retained	- Floors and Roof plans - Reflected ceiling plans. - Mechanical ductwork and piping plans. - Lighting plans - Electrical power plans - Electrical panel diagrams and schedules - Fire protection plans. - Data system plans
Information from related disciplines	- Architectural - Mechanical, Plumbing and Control Systems - Electrical Power and Lighting - Fire Protection - Special Equipment - Data
Geometry should be in the Model	- Elements belong to last steps should be correctly modeled and identified. - Elements, Rooms, Levels should be related to each other. - Every system should be independent and isolated

It is important to be aware of the assets (the asset list) and their locations. This is where rooms and levels become relevant. If there are many Revit models, Rooms should be created using the Room tool in the Architectural model. Rooms should be labeled with a name and number, created from slab to slab, and bounded by the wall centerline. The rooms must be in a well enclosed area.

One of the advantages of adopting BIM for Facility Management is the ability to isolate systems in 3D to visualize asset relations. Using Revit's system creation feature for example is the proper method for incorporating this information into the model. And this case it is very important to have a clear worksets in the BIM model .Such feature can be found in most of BIM authoring tools as well.

To get a better version of the quality control checklist depending on every project, however, if the needed information has been transferred to a checklist and applying the needs of the IFC and COBie requirement, we will get a better version of the checklist which can be applied to the industry. The list of the tables shown in Figure (4.2) represents a general proposed QC Checklist which can be developed and use as a base point for a new detail one depending on the phase and the need of the project. The checklist should always be updated from the starting of the project and with collaboration from all members associated to the quality of the BIM model.

All questions are designed so that a "Yes" response indicates that the model passed the corresponding QC item. If there are any checks in the "No" column, the model must be revised. This can make forming the question somewhat challenging at times, but it pays off by allowing for a simple pass/fail grading system.

Project Information		
Items	**Yes**	**No**
Was the project Project name and number filled up correctly?		
Was the project Project location and site details filled up correctly?		
Was the project Project owner and stakeholders filled up correctly?		
Files and Links		
Items	**Yes**	**No**
Do all the central Revit model filenames match the Naming conventional standard?		
Are all linked files linked to the project folder on the net-work?		
Are all the linked files loaded and using the relative path type?		
Are non-Architectural/Structural linked Revit models in each their own workset?		
Are the correct models set to room bounding in its Type Proper-ties?		
Are all DWG links in worksets to control loading of the DWG links?		
Are all linked models pinned or in a design option?		
Linked File Coordination		
Items	**Yes**	**No**
Is the Shared Levels and Grids workset closed on all linked models?		
Are all elements from different disciplines assigned in specific worksets?		
Are all the grids copied and monitored?		
Are all the host model's grids and levels in the Shared Levels and Grids workset?		
Are all the host model's reference planes in the Shared Levels and Grids workset?		
Have all duplicated spaces been removed?		
If spaces are required, are all spaces placed?		
If spaces are required, are all spaces bounded?		
Id spaces are required, are all spaces' upper bounds set correctly?		
If spaces are required, are space numbers and names coordinated with room numbers and names?		

General Model Integrity		
Items	**Yes**	**No**
Is there any Model in place in the project or all the families are native		
Do all levels have Computation Height set to 0' 0"		
Do all wall-mounted elements have elevations other than floor or ceiling?		
Do all elements in the right Position?		
Do all Rooms associated to Story?		
All Elements must be associated to their spaces		
Are all ceiling-mounted elements on the ceiling (i.e. not floating in space or on the floor)?		
Are all floor-mounted elements on the floor (i.e. not floating in space or on the ceiling)?		
Are all electrical elements connected to power systems?		
Are all warnings resolved in the model? (Duplicate type marks are permitted for lighting		
Is the project browser containing any undefined system?		
Do all elements' attributes filled according to LOD required.		
Do all elements and Spaces Identified according to the classification system		
Clash Detection		
Items	**Yes**	**No**
1. Is the BIM model up-to-date with the latest design changes?		
1. Does the BIM model conform to industry standards and guidelines?		
1. Have all potential clashes been detected and resolved?		
1. Is the BIM model compatible with the facility management software being used?		
1. Is the BIM model accessible and usable by all relevant stakeholders?		
Linked Model Cleanup		
Items	**Yes**	**No**
Do All "Non Placed" Rooms Has deleted		
Have all groups been deleted?		
Are all non-sheet views deleted?		
Are all non-plan sheets deleted?		
Has the file been purged?		

Figure 4. 2: Proposed Checklist for BIM Model Quality Control

Reclassification of the Quality control Checklist based IFC Schema

To ensure that the quality control checklist for BIM model facility management aligns with the IFC schema, The paper has reclassified the checklist items according to the hierarchy of elements in IFC schema. This means that the checklist now starts with project information, followed by site details, building information, story information, space information, and finally, element information (Building Smart, 2023). By reorganizing the checklist in this manner, we can ensure that all aspects of the BIM model are covered in a logical and comprehensive manner, following the hierarchy of the IFC schema. This facilitates efficient and accurate quality control checks of the BIM model for facility management purposes.

Several factors influence the classification based on the Industry Foundation Classes (IFC) schema for quality control of the BIM model. The IFC schema functions as a standard format for information exchange in the construction industry, allowing for the transfer of data between stakeholders and software programs. It helps identify discrepancies or conflicts when integrating models and ensures the consistency and completeness of information across disciplines. Since many projects deliver the BIM model in IFC format, the classification guarantees standard compliance and facilitates data exchange. This classification provides a systematic framework for assessing compliance with IFC parameters in the thesis implementation, ensuring that industry-specific requirements are satisfied.

Table 4. 2 : The checklist classification according to IFC schema

IFC Classifications	Items	Yes	No
Project Information	- Was the project name and number filled up correctly? - Was the project owner and stakeholders filled up correctly?		
Site Information	- Was the project location and site details filled up correctly?		

Building Information	- Do all the central Revit model filenames match the naming conventional standard? - Are all linked files linked to the project folder on the network? - Are all the linked files loaded and using the relative path type? - Are non-Architectural/Structural linked Revit models in each their own workset? - Are the correct models set to room bounding in its type properties? - Are all DWG links in worksets to control loading of the DWG links? - Are all linked models pinned or in a design option? - Is the Shared Levels and Grids workset closed on all linked models? - Are all elements from different disciplines assigned to specific worksets? - Are all the grids copied and monitored? - Are all the host model's grids and levels in the Shared Levels and Grids workset? - Are all the host model's reference planes in the Shared Levels and Grids workset? - Have all duplicated spaces been removed? - If spaces are required, are all spaces placed? - If spaces are required, are all spaces bounded? - If spaces are required, are all spaces' upper bounds set correctly? - If spaces are required, are space numbers and names coordinated with room numbers and names? - Do all levels have Computation Height set to 0' 0"?		

	- Do all Rooms associate to Story?		
Space Infor-mation	- All elements must be associated with their spaces - Do all ceiling-mounted elements on the ceiling (i.e., not floating in space or on the floor)? - Are all floor-mounted elements on the floor (i.e., not floating in space or on the ceiling)? - Do all electrical elements connect to power systems? - Do all elements' attributes filled according to LOD required? - Do all elements and spaces identified according to the classification system?		
Element Infor-mation	- Is there any model in place in the project or are all the families native? - Do all wall-mounted elements have elevations other than floor or ceiling? - Do all elements in the right position? - Are all warnings resolved in the model?		

4.4 Automated and Semi- Automated Tools

This chapter presents several automated and semi-automated tools which can be use in the quality control of the BIM model based on the previous checklist. The tools can be differ depending on the application area of the BIM in the facility management. These tools help to achieve some items of the quality control checklist items.

4.4.1 Semi-Automated Tools

This section presents a dynamo script accessing Revit-API to verify the components inside the rooms and make an automated check on the locations of the components in the stories depending on the position of the components in one story which has to be checked manually.

Checking (comparing) the Position of the Components:

A Dynamo script has been developed to solve one important item from the checklist. “All elements must have the right Location” this as a challengeable task and time consuming, that is why it is important to use automated or semi-automated tools to achieve out task.

The Dynamo script tracks the accuracy of the location of the elements in the duplicated stories building like Hospital and Schools. The script reduces the time of doing such task since it requires only to manual check the require elements on one floor of the building and it automatically check if these elements have the same location on all other floors or not. If the script finds any wrong items, it will highlight these elements in a view and send their location in an Excel sheet for further steps in the quality process and solving the problem.

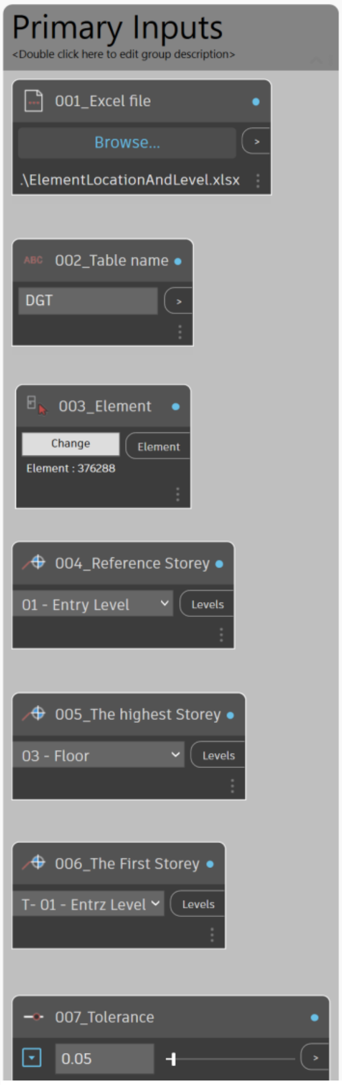


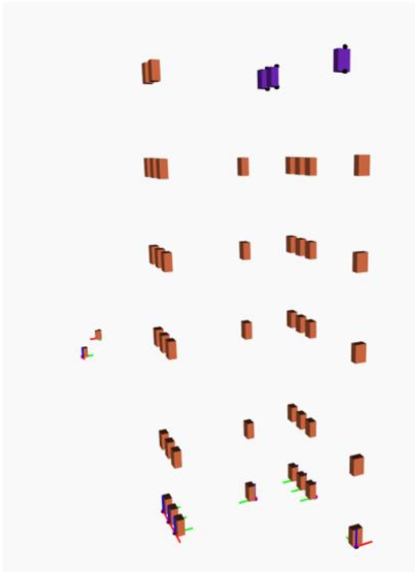
Figure 4. 3: Input required information

To achieve such task, python script knowledge and Revit-API required to create a family coordination system for the targeted elements represented in Figure (4.5).

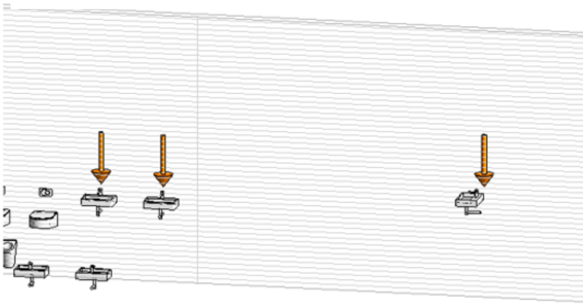
At first, the script requires a human input depending on the required information such as defining the reference floor and the targeted element. Then the script checks all other floors for the location of those selected elements depending on the reference floor.

The script presents the results through both visual and data representations, as depicted in Figure 4.6. Furthermore, the script identifies any incorrect elements within the same room or different rooms, providing the IfcGUID for both the elements and the rooms.

Dynamo



Revit



Excel

Family Type	ElementID	Element IfcGUID	ElementKoordinaten	Ebene	The Element in the same Room?	The Room Name	ROOM IfcGUID
Chair-Breuer	376288	35jp_04f56BACOKaLhiatL	Point(X = -8016.549, Y = -11715.411, Z = 7600.000)	3	FALSE	Conference	1wJoqPkIP4J8fINgm5A1pg
Chair-Breuer	376289	35jp_04f56BACOKaLhiatK	Point(X = -6616.549, Y = -11715.411, Z = 7600.000)	3	FALSE	Conference	1wJoqPkIP4J8fINgm5A1pg
Chair-Breuer	376290	35jp_04f56BACOKaLhiatN	Point(X = -5216.549, Y = -11715.411, Z = 7600.000)	3	FALSE	Conference	1wJoqPkIP4J8fINgm5A1pg
Chair-Breuer	376291	35jp_04f56BACOKaLhiatM	Point(X = -3916.549, Y = -11715.411, Z = 7600.000)	3	FALSE	Conference	1wJoqPkIP4J8fINgm5A1pg

Figure 4. 4: Script Outputs

Familien Koordinaten System

```python
import clr

clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript import Geometry as geom

clr.AddReference("RevitNodes")
import Revit
clr.ImportExtensions(Revit.Elements)
clr.ImportExtensions(Revit.GeometryConversion)

clr.AddReference("RevitAPI")
from Autodesk.Revit.DB import *

###### Definitions ######

# Ensure object is a list and iterable...
def tolist(obj1):
    if hasattr(obj1,"__iter__"): return obj1
    else: return [obj1]

# Create a coordinate system from the Element Transform...
def CreateCoordinateSystem(t):
    return geom.CoordinateSystem.ByOriginVectors(t.Origin.ToPoint(),t.BasisX.ToVector(),t.BasisY.ToVector(),t.BasisZ.ToVector())

# Create graphical Axes for visualisation purposes...
def VisualiseAxes(t,l):
    o = t.Origin.ToPoint()

    xAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisX.ToVector(),l)
    yAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisY.ToVector(),l)
    zAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisZ.ToVector(),l)

    return xAxis,yAxis,zAxis

###### Inputs ######

elems = tolist(UnwrapElement(IN[0])) # The Elements
l = tolist(IN[1])[0] # The length of the Axes for visualisation

###### Outputs ######

cSystems = []
vGeom = []

###### Main Script ######

for e in elems:
    t = e.GetTransform()
    cSystems.append(CreateCoordinateSystem(t))
    vGeom.append(VisualiseAxes(t,l))

# Return the results to the user...
OUT = cSystems,vGeom
```

Run CPython3

Figure 4. 5: The python node with access to Revit-API

Figure 4. 6: The Dynamo script to check the position of the elements

4.4.2 Automated Tools

Auxalia Parameter Tool:

Auxalia ParameterTool provide a great opportunity to achieve multiple tasks for quality control of the BIM Model and increase the accessibility and consistency of the information and solving a number of items In the quality control Checklist such as “All element must have the correct attributes”, All Elements should not have any missing attributes, All elements must follow a structured naming system and All components must be assigned to spatial element (Auxalia, 2021).

Auxilia parameter tool is an add-in for Revit that allows users to create custom parameters and add them to elements in the model. It can automate the process of creating and managing custom parameters and allows to easily add new parameters to the model, rather than having to manually create them one by one.

Creating and managing the parameter tools consider a challenge task. Since the information inserted in different phases and the creation of the parameter took much time.

Auxalia parameter tools depending on a predefined database that contain most of the parameters for every Element and it distributed according to the LOD from 100 to 500. This database can be extended with custom parameters depending on the case of the element and the project.

TGA – Modellentwicklungsmatrix open BIM IFC2x3			
TGA			
KG 410	Pumpe	IfcPump	
Parametername	Parametertyp	Parameter IFC	
Gewerk	Text	100_01_Gewerk	LOD100
Art/ Kennzeichnung	Text	100_02_Bauteil	
Systemtyp	Text	100_03_Kurzzeichen	
Druckstufe	Text	200_01_PN	LOD200
DN/ Größe	Integer	200_02_DN	
Hersteller Daten (ja/Nein)	Boolean	200_03_User_Daten	
Hersteller	Text	200_04_Hersteller	
Typ	Text	200_05_Herstellertyp	
Bauteilnummer	Zahl	300_01_Bauteilnummer	LOD300
elektrische Leistung	ElectricalVoltage	300_02_Spannung V	
Primärmedium	Text	300_03_Medium	
Betriebsarten	Text	300_04_Betriebsarten	
Fäkalienhaltig	Boolean	300_05_Fäkalienhaltig	
Baujahr	Text	400_01_Baujahr	LOD400
Lieferant	Text	400_02_Lieferant	
Bauart	Text	400_03_Bauart	
Inbetriebnahme	Text	500_01_Datum Inbetriebnahme	LOD500
Gewährleistungsbeginn	Text	500_02_Gewährleistungsbeginn	
Lebensdauer	Integer	500_03_Lebensdauer	
Anschaffungskosten	Number	500_04_Anschaffungskosten	
Wartungsfirma	Text	500_05_Wartungsfirm	
Wartungsvertragsnummer	Integer	500_06_Wartungsvertragsnummer	
Datenblatt	Text	500_07_Datenblatt	

Figure 4. 7: Requirements matrix for a pump in the Auxalia parameter tool (Auxalia, 2021)

Also, it detects the place of the element and make a naming system for it that contain the building, the floor, the room, the discipline, the group, the name and the functionality.

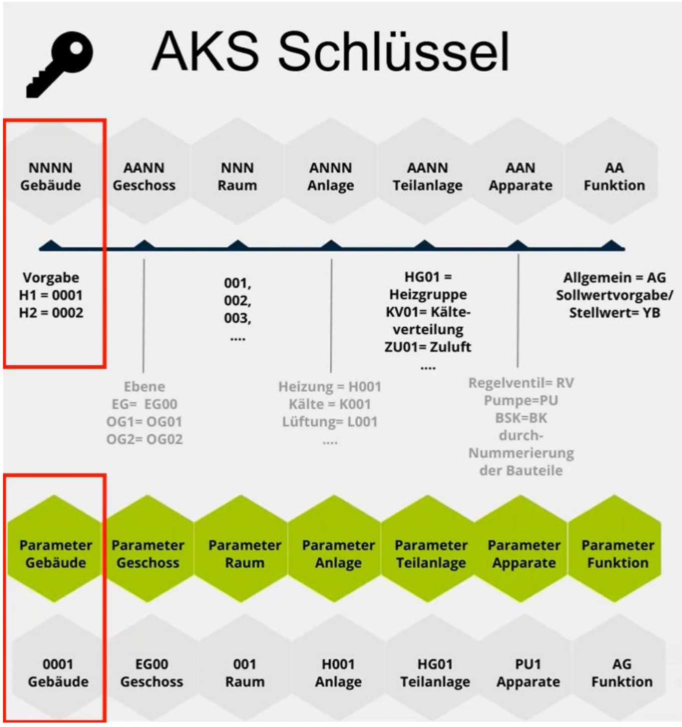


Figure 4. 8: Naming System for element using Auxalia (Auxalia, 2021)

It makes it easy to manage the parameter inside the project by separating the parameters according to the phase of the LOD and reducing the mistake of forgetting to fill these parameters by highlight the empty parameter.

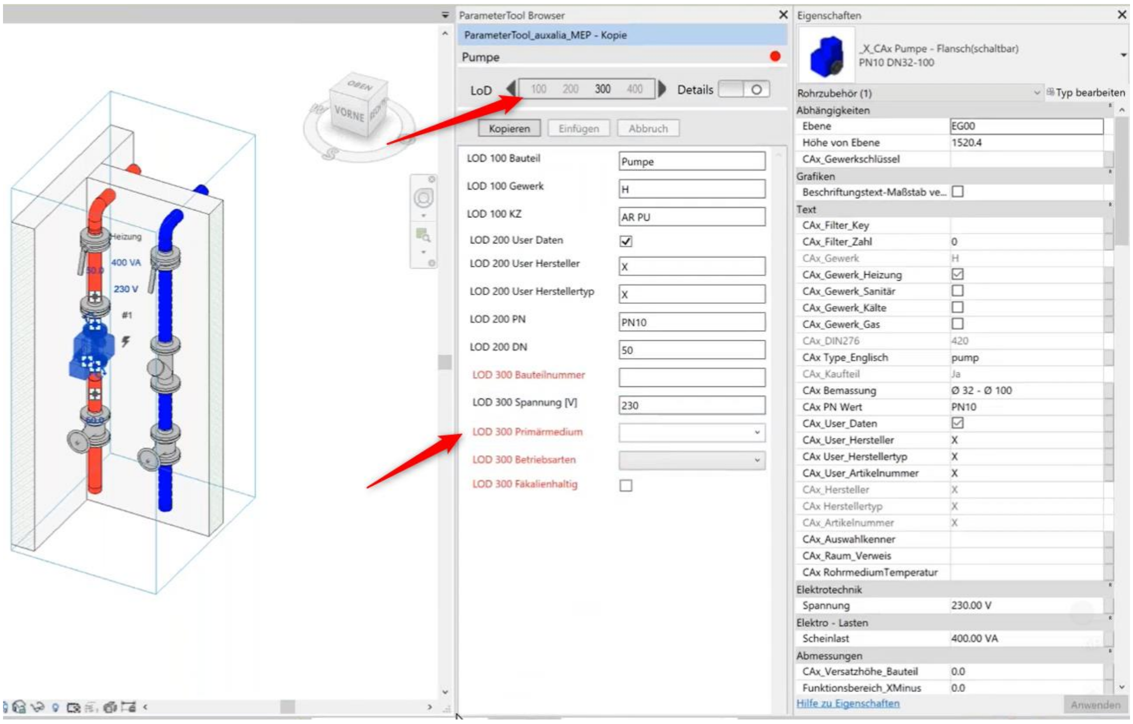


Figure 4. 9: Separating parameters according to LOD in Auxalia (Auxalia, 2021)

Additionally, this add-in can be used to adds the room number to the parameter element and the level as well. after choosing the level and the category the add-ins add the room number and the level to the parameter of the selected category (Auxalia, 2021).

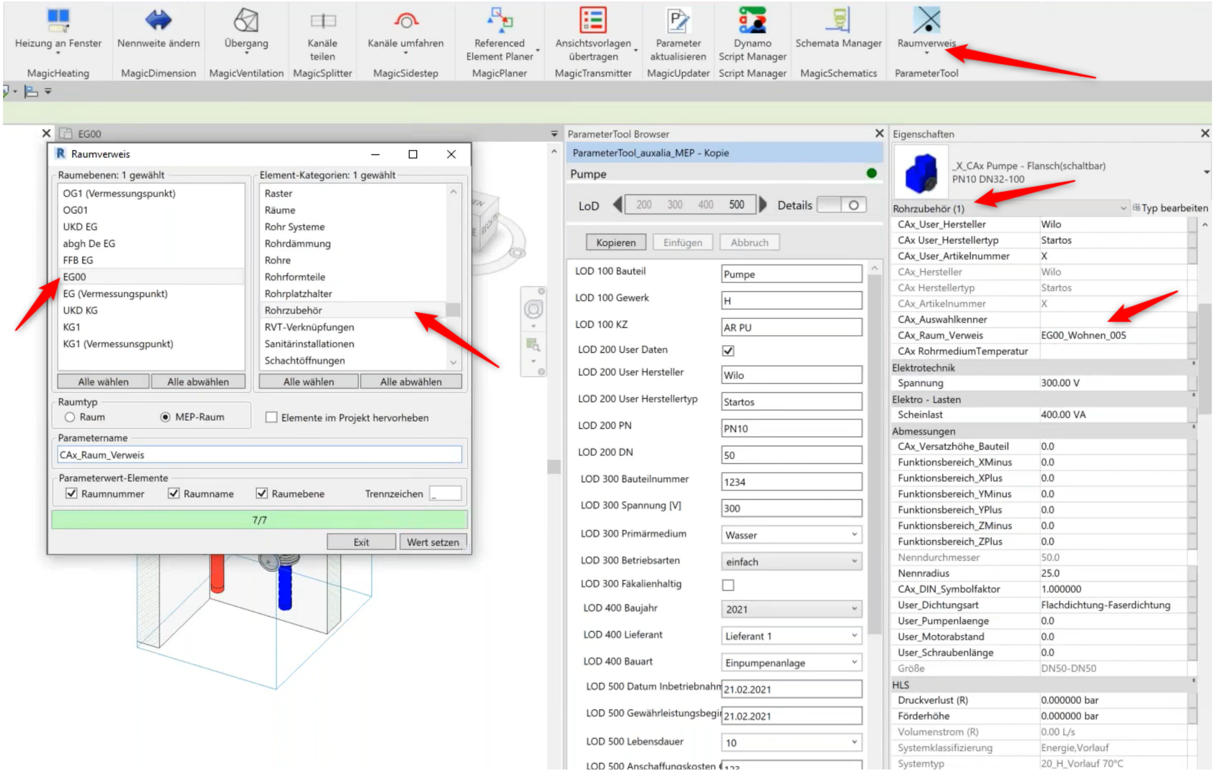


Figure 4. 10: Assign room number to elements with Auxalia (Auxalia, 2021)

The tool would be useful for the quality of the models because only required information is displayed in the selected properties window then it brings better overview. And create a key for define the location of the elements beside the easy way of creating the parameter.

5 Automated Tools for the QC and Case Study

In this chapter, a case study will be conducted to further validate the proposed solutions to ensure the quality of the BIM model in facility management. However, it is important to note that some items proposed in the main part of this thesis, particularly the involvement of facility management from the beginning of the project and the workflow for quality assurance, may not be feasible to fully cover in this case study as they should be implemented during the actual project. Nonetheless, the implementation part will focus on the third proposed solution which is the use of a checklist for quality control of the BIM model. In addition, some of the proposed tools will be used to address some items in the checklist, particularly the one related to the position of elements in the model. This case study will provide a practical application of the proposed solutions and tools in a real-world scenario and will demonstrate their effectiveness in ensuring a high level of quality in the BIM model. The results and findings of this case study will be presented in the following sections.

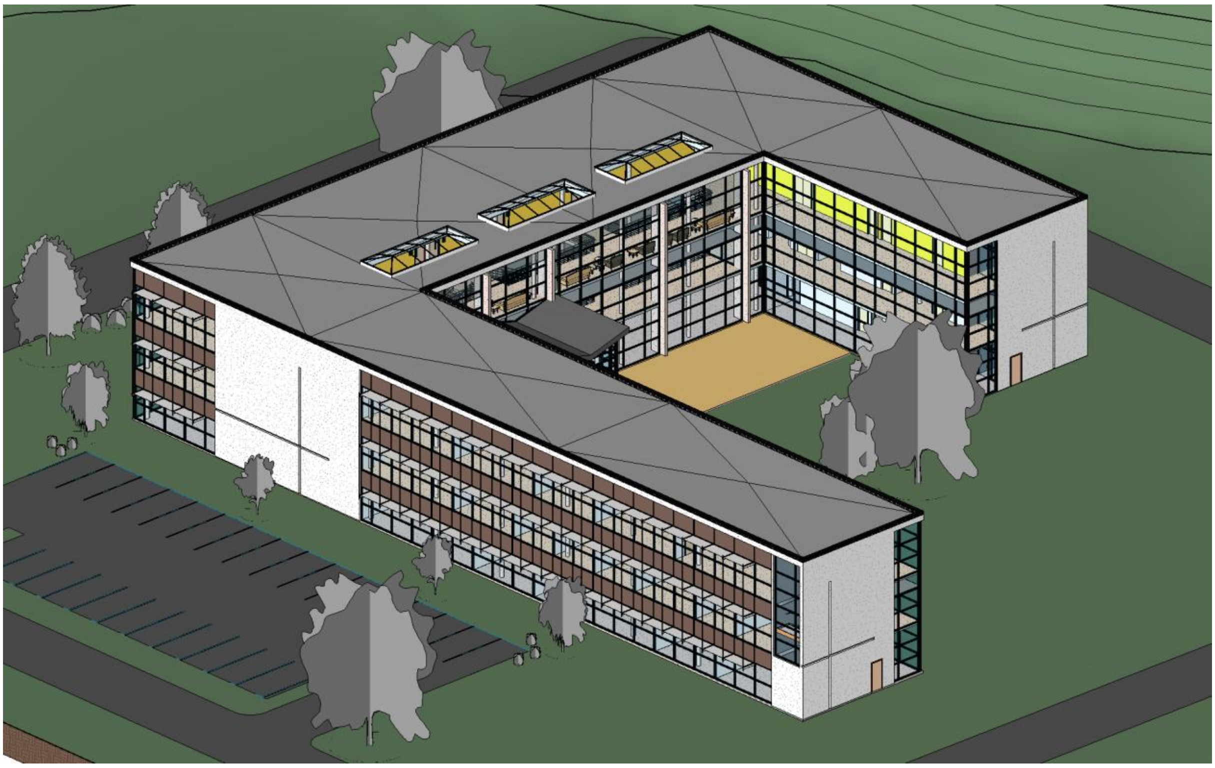


Figure 5. 1: The 3D Model of the case study project

The decision to continue the modelling process for the open-source BIM model was driven by the need to enhance the feasibility of implementing a rigorous quality control procedure. By refining and improving the model, the goal aims to increase model accuracy, completeness, and consistency, ensuring reliable results. This approach aligns with scientific principles of rigor and addresses potential shortcomings in the initial BIM model, ultimately improving its suitability for conducting a comprehensive quality control analysis.

5.1 Case Study Overview

The case study involves a school building that has already been modeled using Autodesk software, including the structural, architectural, and MEP files. The building is comprised of three floors, with a total area of 5010 m^2.

The scope of this case study is to evaluate the proposed checklist and tools for quality control by applying them to the existing BIM model of the school building. According to the BIM application areas in the facility management we can define the information requirement for the project. Assuming that the school project will be used on the main application areas such as locating building component, visualization and marketing, checking the maintenance, and space management. All these areas are based on the BIM model having correct location of the rooms, spaces and the components inside them having the correct height definition.

The objectives of the case study are to:

- Evaluate the effectiveness of the proposed solutions for quality control of the BIM model in facility management of the school project.
- Apply the checklist for quality control of the BIM model and verify the model's compliance with the requirements defined in the main part of the thesis.
- Test the Dynamo script developed for checking the position of the elements in the BIM model and assess its usefulness in reducing errors.
- Identify any potential issues or limitations in the proposed solutions and provide recommendations for improvement.

By achieving these objectives, the case study aims to demonstrate the practical application of the proposed solutions for quality control of the BIM model in facility management and provide insights into the challenges and benefits of using BIM in this context.

5.2 Application of Proposed Solutions

This Chapter aims to apply some of the proposed solutions from the previous chapter to the modeled school project. Specifically, the Dynamo scripts proposed to check the position of the elements and identify any deviations. Additionally, the Auxalia tool will be utilized to achieve several points in the checklist, such as ensuring that all elements have the correct attributes, structured naming system, and spatial assignment. Additionally, implement some items manually in different ways.

Table 5.2.1 defining the Checklist for the Spaces and the tools employed to check them:

	ROOMS AND SPACES	TOOL USED
Associated element	- All elements should be associated with specific story.	- Practice experience
Geometry and attributes specifications	- All spatial elements (Rooms and Spaces) must have a correct height definition.	- Dynamo Script
Naming System	- All rooms should be identified according to classification system.	- Practice experience.

Table 5.2.2 defining the Checklist for the Components and the tools employed to check them:

	Components	Tool used
Associated element	- All elements must be associated to their spaces.	Auxalia Paramer-Tool
Geometry and attributes specifications	- All elements' attributes should be filled according to LOD required. - All hosted elements should rest on its correct surface.	- Auxalia Parameter-Tools - Practice experience. - Dynamo Script

	- All elements should be in the correct position. - All hosted elements should be in the right workset.	- Practice experience.
Naming System	All elements should be identified according to classification system.	- Auxalia Parameter-Tool

All elements should be in the correct position:

This can be a difficult task to complete because it is difficult to monitor every project element, especially if the project is too large. The proposed dynamo script accomplishes this objective.

For the script to check the position of the elements, The user manually checked the location of the targeted elements on one floor. The script use this story as a reference to check the elements on other floors, and it extract the wrong elements into an Excel sheet containing the ID of the element and its room, as well as a column indicating whether the element is still in its room.

All elements should be identified according to classification system. And contain the right naming system:

Using Auxalia Tool, achieved to solve these quality control inventory items. including ensuring that all elements have the appropriate attributes and are assigned to the appropriate spatial element. Auxalia can also be used to automate certain duties, which can save time and reduce the likelihood of making mistakes. Using Auxalia in conjunction with other proposed solutions can aid facility managers in ensuring that their BIM models are of the highest quality and precision.

All hosted elements should rest on their correct surface and on their correct worksets:

To check some items of the checklist, the functionality of Revit can be used. With some practice experience can achieve a result as much as efficient as automated tools.

Hosted Elements:

one of the most frequent modelling mistakes has been found, the hosted elements. Ceiling elements is hosted on flooring or the opposite. Those kinds of mistake are also challenging to catch when the majority of the time is spent looking at floor plan views. This problem can be solved by Filter option in Revit and with some family planning.

In order to achieve that, all hosted elements must be included with the Host surface name like Ceiling or floor or Wall. MEP elements were tested using this method. Change the color of ceiling-mounted items to differentiate them from floor- or wall-mounted ones. Turn off non-MEP model categories to reduce the QC view to only what must be inspected. Levels should be displayed, but in halftone to make the MEP elements "pop." Depending on the number of placed items, you may wish to mix the QC for ceiling-mounted and floor-mounted elements and modify the color of floor-mounted elements to a different hue than ceiling-mounted ones. Elements on the incorrect host will still be readily identifiable.

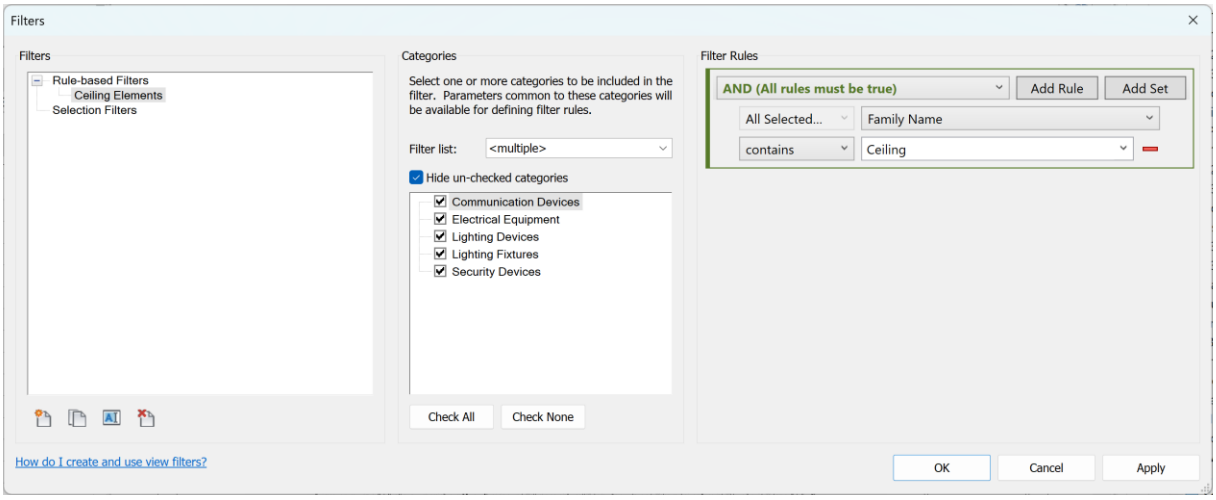


Figure 5. 2: Filtering the ceiling elements in Revit.

Elements assigned to wrong worksets:

With the same concepts, the workset problems can be solved. Usually, the workset are used to visual checking a specific discipline such as MEP. There for it is important to check all elements in the right workset.

In order to do so, a filter of the targeted elements by workset has been done. For example, the MEP elements must check with all other workset which MEP elements should not be there. If any elements in these worksets have been found there, it is easy to move them to the right worksets.

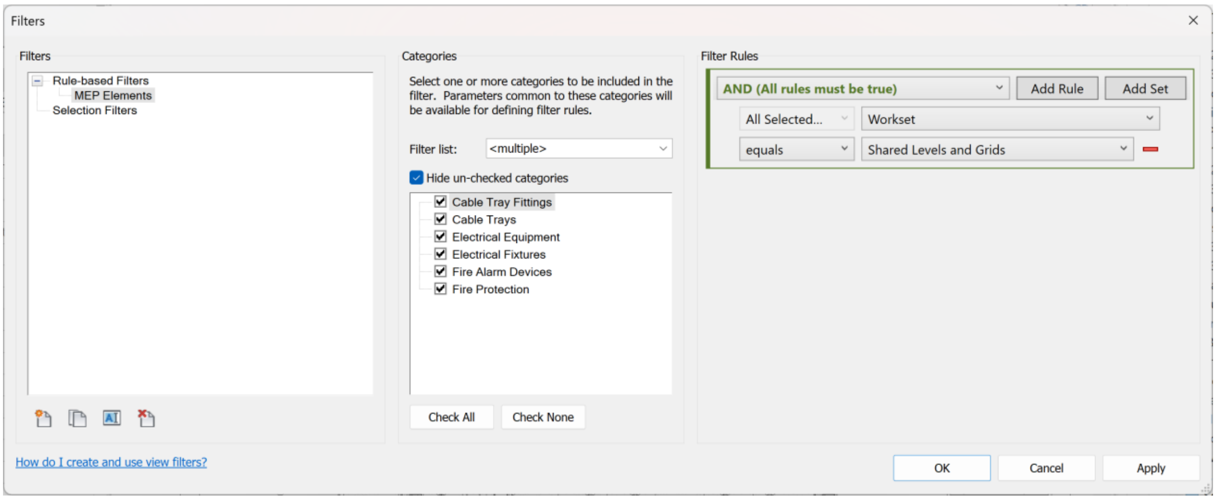


Figure 5. 3: Filtering the elements according to the worksets inside Revit.

5.3 Analyzing the Project and defining the quality control checklist

Based on the BIM application areas in facility management, the information requirements for the project can be defined. Assuming that this school project will be utilized in key application areas such as locating building components, visualization and marketing, maintenance checks, and space management, it is crucial to ensure the BIM model accurately represents the room locations, spaces, and components with correct height definitions. Consequently, the proposed tools will be utilized in this part to accomplish specific items from the checklist based on the IFC schema, and the tools will be provided in Revit, the industry's most widely used program. However, the same concept can be applied to other software as well.

5.4 Evaluation of Results

In the evaluation of results section, a detailed analysis conducted on the data collected during the implementation of the proposed solutions. The effectiveness of each solution in meeting the checklist requirements will be thoroughly examined, and a comparison will be made between results obtained through manual and automated methods represented in Table (5.1). The accuracy and reliability of the automated tools utilized in the project will be evaluated, with a focus on identifying their strengths and weaknesses. To facilitate a comparison between manual and automated methods, the time consumed for each checklist item will be measured in minutes, and the number of missed mistakes in the manual approach will be documented. Furthermore, the effectiveness of the proposed solutions in enhancing the quality of the BIM model and achieving project goals will be assessed. Moreover, the practicality of employing automated tools versus manual methods in various scenarios will be assessed. This assessment encompass an evaluation of the cost-effectiveness associated with implementing the proposed solutions and the benefits derived from their usage. The challenges encountered during the implementation of the proposed solutions will be discussed, and potential areas for improvement in future projects will be identified. Overall, the evaluation of results section provide a comprehensive analysis of the data collected, shedding light on the effectiveness of the proposed solutions, the advantages and limitations of automated tools, and the practical implications of their implementation.

Table 5. 1: The comparison between the automated and manual way

Items checked from the checklist	**Time takes for checking**		**Number of the issues missed**	
	Manual (min)	**Automated (min)**	**Manual (mistake)**	**Automated (mistake)**
- All rooms should be identified according to classification system	10:00	02:00	9	3
- All elements' attributes should be filled according to LOD required.	18:00	1:00	5	0
- All hosted elements should rest on its correct surface.	12:00	00:45	6	0
All Elements should be located in the right positions.	40:00	00:45	25	0

- All hosted elements should be in the right workset.	10:00	02:00	3	0
All elements should be identified according to classification system.	15:00	03:00	6	2

Overall, the evaluation of results section provided a comprehensive assessment of the effectiveness of the proposed solutions in improving the quality of the BIM model and achieving the project goals. It also provided valuable insights into the practicality of using automated tools versus manual methods in different scenarios and identify potential areas for improvement in future projects.

5.5 Conclusion and Lessons Learned

In conclusion, the implementation of the proposed solutions proved to be effective in improving the quality assurance process and achieving the project goals. The use of automated tools such as Dynamo scripts and Auxalia helped in reducing the time consumed and minimizing mistakes in meeting the checklist requirements. However, the practical experience and manual approach also proved to be valuable in achieving a similar outcome.

Through the evaluation of results, The Paper found that the automated tools were effective in achieving most of the checklist requirements and reducing the time consumed. However, in some cases, the manual approach proved to be more accurate and reliable, highlighting the importance of balancing automated tools with practical experience.

The lessons learned from this case study emphasize the importance of developing a good workflow and integrating quality assurance into every milestone of the project. It is also essential to identify the most suitable automated tools for the project and balance them with practical experience to achieve optimal results. Finally, the importance of teamwork and collaboration in ensuring the success of the quality assurance process cannot be overstated.

Overall, the case study demonstrates that the integration of quality assurance into the project workflow and the use of automated tools can significantly improve the project's outcome and meet the project's goals while minimizing errors and saving time.

6 Conclusion

This research investigated methods to improve the quality of the BIM-Model based facility management (FM). The in-depth analysis on how to resolve the individual issues within the BIM-based facility management imposed the development of a framework as the most comprehensive solution. In addition to the framework, a checklist for measuring the quality of the BIM model to be used in facility management is recognized as a very efficient step in minimizing initial errors and ensuring high-quality throughout the process.

The framework developed in this research succeeds to avoid the quality issues that often happen in BIM-based FM by proposing a project delivery method that ensures participation of the facility manager in the earlier phases of the project. Moreover, it proposes an improvement of the current Exchange Information Requirement (EIR) through collaboration between the client and the facility manager since the studies analyzed show a high lack of knowledge from the client's side to establish sufficiently detailed information requirements for facility management.

Furthermore, a more intensive participation of the facility manager in the quality control process is proposed, in order to improve the quality assurance. A constant reevaluation and improvement of the quality control checklist throughout the construction process, performed by the facility manager, is what is expected to ensure better quality in the facility management.

The paper also categorizes different pieces of information according to how they are utilized for the facility management from relevant (high importance) information to irrelevant (excessive) information. From this categorization, a primary checklist is generated that can be used as a foundation for other checklists that are further developed based on the information requirements of every individual project.

Finally, the paper introduces automated and semi-automated tools for BIM-based FM that facilitate a more effective implementation of the quality control checklist. The proposed tools have been applied on the example of an existing BIM project in form of a case study that shows the efficiency of using the quality control checklist in BIM-based FM.

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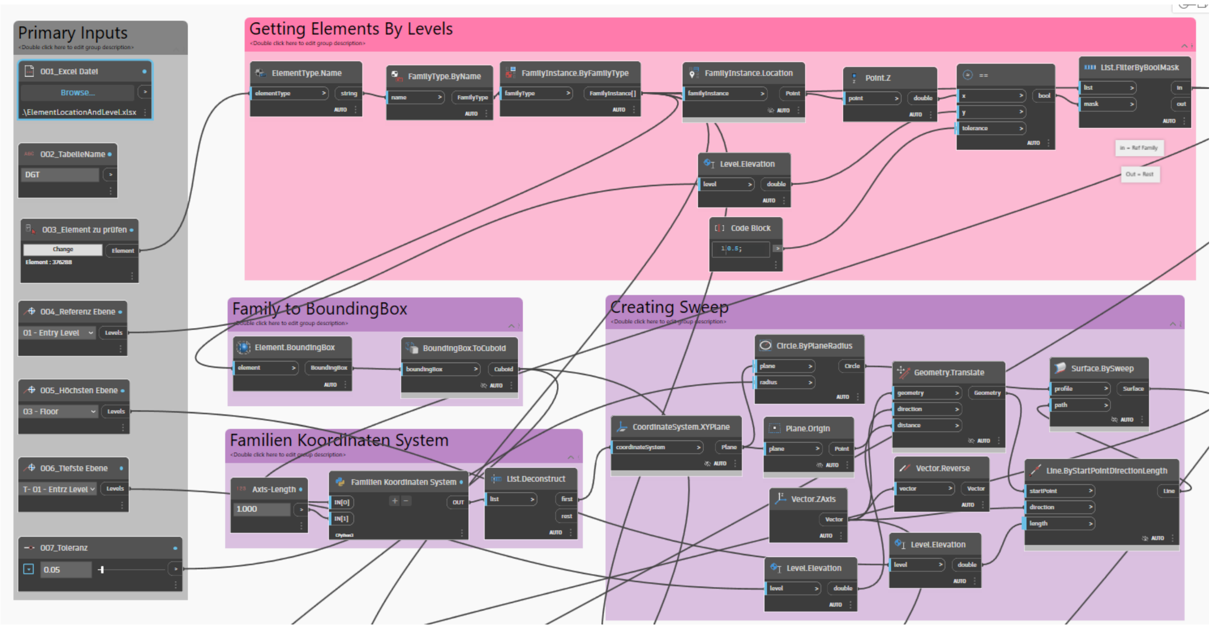
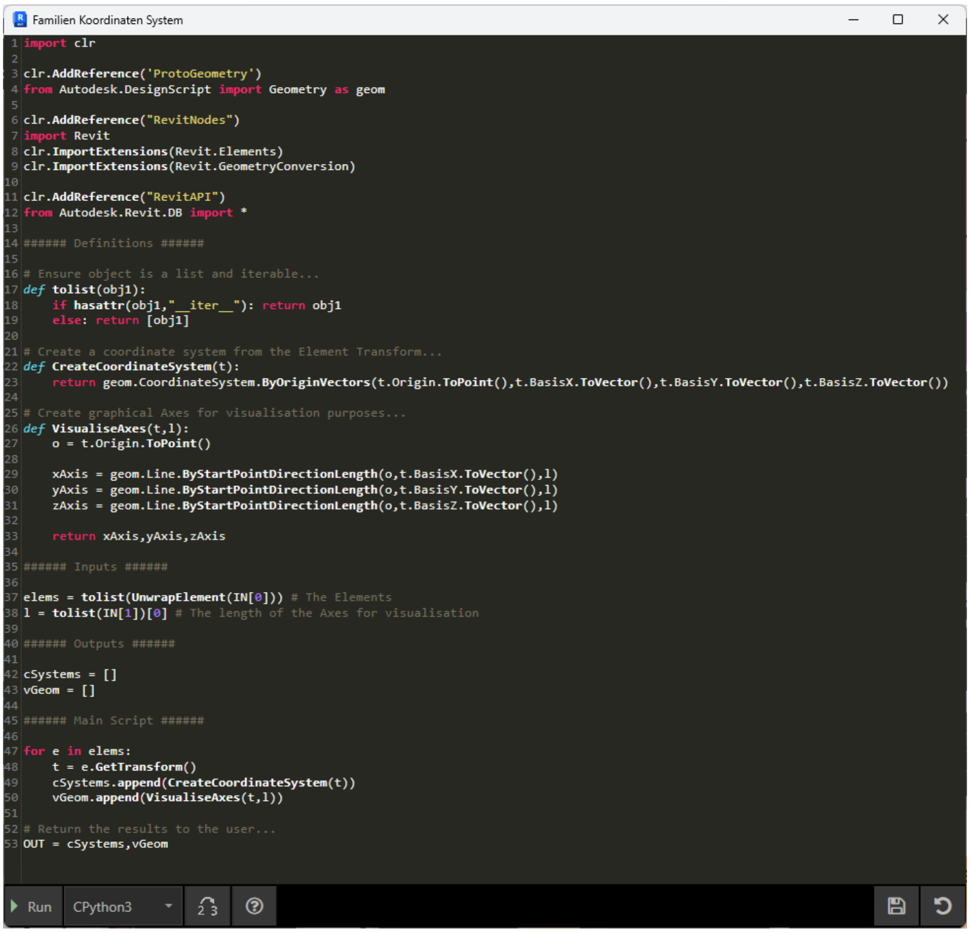
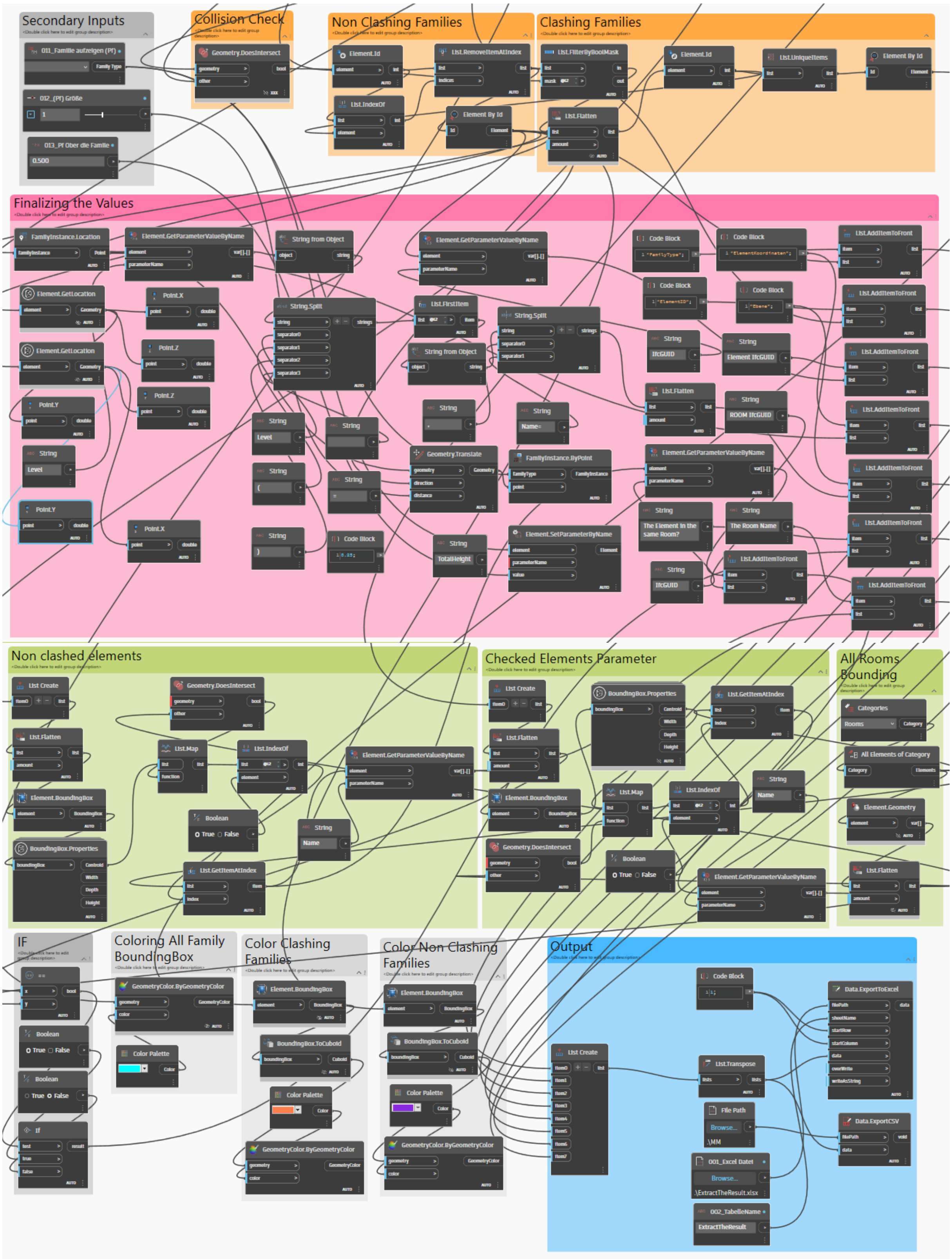
Appendix A

Dynamo Script to check the position of the elements.






```
import clr

clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript import Geometry as geom

clr.AddReference("RevitNodes")
import Revit
clr.ImportExtensions(Revit.Elements)
clr.ImportExtensions(Revit.GeometryConversion)

clr.AddReference("RevitAPI")
from Autodesk.Revit.DB import *

###### Definitions ######

# Ensure object is a list and iterable...
def tolist(obj1):
    if hasattr(obj1,"__iter__"): return obj1
    else: return [obj1]

# Create a coordinate system from the Element Transform...
def CreateCoordinateSystem(t):
    return geom.CoordinateSystem.ByOriginVectors(t.Origin.ToPoint(),t.BasisX.ToVector(),t.BasisY.ToVector(),t.BasisZ.ToVector())

# Create graphical Axes for visualisation purposes...
def VisualiseAxes(t,l):
    o = t.Origin.ToPoint()

    xAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisX.ToVector(),l)
    yAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisY.ToVector(),l)
    zAxis = geom.Line.ByStartPointDirectionLength(o,t.BasisZ.ToVector(),l)

    return xAxis,yAxis,zAxis

###### Inputs ######

elems = tolist(UnwrapElement(IN[0])) # The Elements
l = tolist(IN[1])[0] # The length of the Axes for visualisation

###### Outputs ######

cSystems = []
vGeom = []

###### Main Script ######

for e in elems:
    t = e.GetTransform()
    cSystems.append(CreateCoordinateSystem(t))
    vGeom.append(VisualiseAxes(t,l))

# Return the results to the user...
OUT = cSystems,vGeom
```


Secondary Inputs
Collision Check
Non Clashing Families
Clashing Families
Finalizing the Values
Non clashed elements
Checked Elements Parameter
All Rooms Bounding
IF
Coloring All Family BoundingBox
Color Clashing Families
Color Non Clashing Families
Output

Erklärung

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, 30. May 2023

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