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USE OF BIM FOR THE OPTIMAL MANAGEMENT OF EXISTING BUILDINGS

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ABSTRACT

This research concerns the use of the Building Information Modeling (BIM) for the optimal management of existing buildings, in particular social housing buildings. These buildings are characterized by aging, poor energy performances and tenant's low-income. The building managers suffer from lack of data concerning the buildings asset which could lead to poor operating decisions.

The thesis discusses how the BIM could help to meet existing building challenges by the creation of a user-friendly comprehensive system including information about the building and equipment as well as the maintenance. The benefits of the BIM model are illustrated through two case studies, which concern a social housing residence and a research building respectively.

This thesis is composed of four parts.

The first part includes a literature review concerning the current methods of facility management, and the role of BIM in improving this management.

The second part describes steps carried out to realize the BIM model of an existing social housing residence which includes 50 dwells.

The third part describes the use of BIM to optimize facilities management and building maintenance.

The last part describes the development of a dynamic BIM model using the as-built BIM and real time data collected with sensors to inform users and managers about energy consumption and abnormal events.

Keywords: Building information modeling (BIM), building management, Facility (FM) Management, social housing, building maintenance

RÉSUMÉ

Ce travail de thèse porte sur l'utilisation de la maquette numérique du bâtiment (BIM) pour l'optimisation de la gestion des bâtiments existants, en particulier le logement social. Ces bâtiments sont caractérisés par le vieillissement, les faibles performances énergétiques et le faible revenu des locataires dans le cas des logements sociaux. Les gestionnaires de ces bâtiments souffrent d'un manque de données concernant le patrimoine, ce qui peut entraîner des décisions inefficaces.

La thèse présente d'abord les défis de la gestion technique de patrimoine, puis elle explique comment le BIM pourrait aider à relever ces défis en créant une plate-forme comprenant les informations sur le bâtiment et ses équipements ainsi que l'historique et la maintenance. Les avantages du modèle BIM sont illustrés à travers deux cas études : une résidence de logement social comprenant 50 appartements et un bâtiment de recherche sur le campus scientifique de l'Université de Lille.

Le rapport de thèse est organisé en quatre parties.

La première partie comprend l'état de l'art concernant les méthodes actuelles de gestion technique de patrimoine et l'apport du BIM à cette gestion.

La deuxième partie décrit les étapes réalisées pour construire le modèle BIM d'une résidence de logement social.

La troisième partie décrit l'implémentation du BIM pour optimiser la gestion des installations et la maintenance des bâtiments.

La dernière partie décrit le développement d'un modèle BIM dynamique par la combinaison du model BIM et les données de confort et de consommations collectées avec des capteurs. Ce modèle sert à informer en temps réel les usagers et les gestionnaires.

Mots-clés: Modélisation des Données du Bâtiment (BIM), Gestion des bâtiments, Facility Management (FM), logement social, maintenance des bâtiments.

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List of abbreviations

AEC	**Architecture, Engineering, Construction**
BAS	**Building Automation System**
BEMS	**Building Energy Management Systems**
BIM	**Building Information Modeling**
BMS	**Building Management System**
CAD	**Computer Aided Design**
CAFM	**Computer-aided facility management**
CMMS	**Computer Maintenance Management system**
COBie	**Construction Operations Building Information Exchange**
CSS	**Cascading Style Sheets**
EMS	**Energy Management Systems**
FM	**Facility Management**
GIS	**Geographic information system**
HDMI	**High-Definition Multimedia Interface**
HTM	**Hypertext Markup Language**
HVAC	**Heating, Ventilation and Air Conditioning**
IFC	**Industry Foundation Classes**
M & R	**Maintenance and Repair**
MEP	**Mechanical, Electrical and Plumbing Engineering**
PHP	**Hypertext Preprocessor**
SQL	**Structured Query Language**

General introduction

The building sector is particularly concerned by city development. In France, the building sector accounts for 40% of CO_2 emissions, 37% of energy consumption and 40% of wastes.

These problems occur mainly during the operation phase which is the longest phase in the building lifecycle. With a service life between 30 and 50 years, the operation phase is about 10 to 15 times longer than the design and construction phases. It represents 80% of the overall cost.

An effective management of the operation phase is essential for the optimization of expenses, reduction of energy consumption and greenhouse gas emission, as well as for ensuring high quality services. In order to achieve these requirements, the facility managers need to be innovative in the management process.

Different solutions are used in Facility Management (FM), such as Computer-aided Maintenance Management (CMMS), Building Technical Management (GTB), Technical and Heritage Information System (SITP). However, these solutions are limited because of the lack of interoperability, which causes loss of data. Furthermore, these systems are mainly used for new buildings constructed after the numerical revolution.

Most of the buildings in cities are old with major challenges, such as aging and poor energy performances. Building managers suffer from lack of data concerning the buildings asset to take effective decisions in the operation phase.

Building information modeling (BIM) constitutes a big revolution in Architecture Engineering and Construction (AEC) sector. The benefits of BIM, especially in the design-construction phase, have been discussed in numerous studies. However, the application of BIM in facility management is rather new and requires further research. This thesis contributes to this issue. It aims to implement the BIM for the management of existing buildings, in particular social housing buildings.

This thesis is divided into four chapters:

The first chapter includes the state of art of facility management, as it describes systems used in buildings management. It discusses the major challenges in building management, such as lack of information, interoperability, difficulty to manage the existing buildings with valuable data and optimization of energy consumption. A literature review of the application of BIM on facility management is developed, explaining also the methods to create an as-built BIM model for existing buildings.

The second chapter discusses the implementation of BIM for existing buildings. It presents the creation of as-built BIM model of an existing social housing residence in Villeneuve d'Ascq, which includes 50 residences.

The third chapter details the implementation of BIM to optimize facilities management as well as building maintenance. It presents how BIM could be used in FM management. It also shows the advantages of the combination of BIM database with maintenance data, as well as the visualization of maintenance activities.

The fourth chapter describes the development of a dynamic BIM model for existing buildings using the as-built BIM and real time data collected with sensors. It allows to visualize comfort and consumption data and to inform users and managers about energy consumption and any abnormal event which may occur.

Chapter 1: State of the art

1.1 Introduction

This chapter presents the state of art in facility management. It discusses the challenges of the management of the operation phase, such as the lack of data, interoperability, energy optimization and quality of services to users. The building information modeling is proposed to meet these challenges. The chapter presents a literature review concerning the use of BIM for the management of existing buildings.

The last part presents the use of BIM and Smart Buildings concept to reduce energy consumption and to improve users comfort.

1.2 Facility management

The operation phase of buildings is the longest phase in its life cycle (Peng et al. 2017). It accounts for 74% of the total cost, including maintenance, renewal and energy (Beddiar and Imbault 2017). The design and construction phase costs do not exceed 29% of the total cost (Figure 1.1). The need for good management of buildings in the exploitation phase constitutes an important issue for both economic and environmental issues.

Information is very important and critical in the operation stage to support an effective maintenance of buildings and efficient daily operations. Nevertheless, facility management continues to suffer from bad information management, largely due to the fact that the information is fragmented (C. Eastman et al. 2011; Codinhoto et al. 2013). One of the essential prerequisites for an effective Facility management concerns the efficiency of communication and flow of information, widely understood as a practice that gathers m

ultiple disciplines related to building management (Araszkiewicz 2017). Furthermore, construction projects become more complex (Bryde, Broquetas, and Volm 2013) with huge volume and complex information during the building lifecycle (Pärn, Edwards, and Sing 2017).

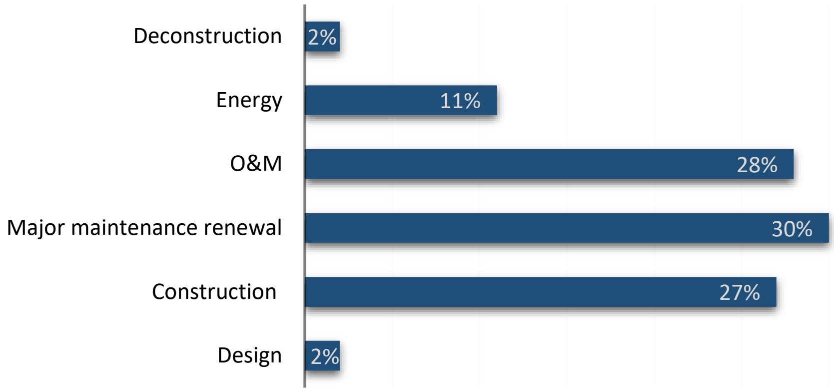


Figure 1.1 Distribution of the overall cost of a building over fifty years, case of a high school

Source (Beddiar and Imbault 2017)

Information collected during the design and construction stages is quickly outdated, and often incomplete. This makes Facility management the most disconnected phase of the building life cycle (Lucas 2012). Existing buildings that are constructed before the numerical revolution don't have enough documents for an effective management, or in the best cases, paper-based management system. All of these issues impact the effectiveness of facility management.

There are several definitions for Facility management or building management, which is commonly abbreviated as FM. Mignard (2012) defines it as an integrated approach to operate, update, improve and adapt the buildings and physical infrastructure of an organization. Alexander (2013) defines FM as "the process by which an organization delivers and sustains support services in a quality environment to meet strategic needs." The most recent definition of facility management is "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, places, processes and technology" (IFMA 2018). It is important to notice the importance given to the concept of technology, which was previously missing. In some cases, asset management is used instead of facility management and seams confusing. Roper and Payant (2014) suggests that the use of "asset management" should be reserved for major infrastructure assets such as federal, state, and local assets such as bridges, high ways and similar major infrastructure.

FM is in charge of conducting the operations and support actions for the occupants and the main activity of the organization present in the building (Chanter and Swallow 2008). It includes cleaning, waste management, energy management, environment management, estates management, purchase of equipment and consumables, fire safety, grounds maintenance, health security, human resources, office maintenance, relocation, renovation, adaptation, new construction, management of spaces and schedules. Roper et Payant (2014) provides the detailed functions of facility management in Table 1.1.

Table 1.1 Common functions of facility management

(Roper et Payant 2014)

Facility Planning and Forecasting	**Budgeting, Accounting**
• Business unit knowledge gathering • Strategic facility planning (three-to ten-years plans) • Space forecasting (macro-level, organization-wide) • Macro-level programming (organization-wide) • Financial forecasting and macro-level estimating (organization-wide) • Capital program development	• Programming (same period covered as for space planning unless otherwise specified by the company) • Work plan preparation • Budget preparation (one to two years) • Economic justification • Financial forecasting (one to two years) • Budget formulation • Budget execution
Workplace Planning, Allocation and Management	**Security and Life- safety Management**
• Workplace planning • Workplace design • Furniture specification • Furnishings specification • Estimating • "As Built" maintenance • Code compliance • Move, add change (MAC) management and record keeping	• Code compliance • Operations • Crime prevention through environmental design • Access control • Physical deterrents • Electronic security • Vulnerability assessment
Operations, Maintenance, and Repair	**Space Planning, Allocation, and Management**
• Exterior maintenance (roofs, shell, and window systems) • Preventive maintenance • Breakdown maintenance • Cyclic maintenance • Ground maintenance	• Space allocation • Space inventory • Space forecasting (micro-level, one location) Space management
	Management of the organization
	• Planning

• Road maintenance • Custodial maintenance • Trash removal • Hazardous waste management • Energy management • Inventory of systems and equipment • Maintenance projects • Repair projects • Correction of hazards (asbestos, bad air quality, radon, underground leaks, PCBs, ect...) • Disaster recovery • Procurement (operations, maintenance, and repair supplies and services	• Organizing • Staffing • Directing • Controlling • Evaluating
	Lease administration
	• Out leasing (as owner) • Lease administration/ audit (as owner or lessees) • Property management (as owner)

1.3 Methods and systems of facility management

1.3.1 Paper based facility management

2D floor plan graphics were predominate in construction. It was difficult to the staff without specific skills to understand the contents, which leaded to communication problems (Su, Lee, and Lin 2011). Furthermore, the use of paper based files for building and equipment information is quickly outdated and often inaccurate. When FM problems occur the research for an information is difficult to find; it takes time and produces extra cost (IFMA and Teicholz 2013). This mode has also has an impact on poorer building and equipment performance due to the lack of adequate data for preventive maintenance. Facility managers use paper sheets or flaps when visiting the equipment location and manage several types of information.

1.3.2 Current methods based on Computer Aided Facility management

Current methods of facility management are mainly based on Computer Aided Facility Management (CAFM) with technical data essentially based on CAD files and other types of numerical documents, such as different manuals and warranties in PDF.

CAFM is defined as a tool for organizing and managing various activities within the facilities assets, such as client contract whereby the client is aware of the equipment, its location and services catered for; the material used, stock, purchases and equipment replaced for repairs; procurement. The activities of CAFM can concern also the subcontractors service and management, the services rendered in accordance to service level agreement and other reactive maintenance; the work history carried out on equipment; and the strategy used to manage assets with the engineering instructions to do so at a schedule (Elmualim and Pelumi-Johnson 2009).

Several digital technologies facilitate the acquisition, processing, redundancy and compression of information for buildings. Different systems have been used to support facility management, such as Computer-Aided Facility Management (CAFM), Computerized Maintenance Management System (CMMS), Building Automation System (BAS) or Building Management system(BMS), Energy Management System (EMS) (Araszkiewicz 2017). The definition of these systems are given in Table 1.2

Table 1.2 Different systems used in building management

System	Definition	Author and date
CMMS	Computer Maintenance Management system is an application software used to provide for work and materials management of maintenance activities in a manufacturing organization	(Gartner 2018)
BMS **BAS**	Building Management Systems (BMS) also known as Building Automation Systems (BAS), is a control system that can be used to monitor and manage the mechanical, electrical and electromechanical services in a facility. Such services can include power, heating, ventilation, air-conditioning, and physical access control, pumping stations, elevators and lights.	(SearchDataCenter 2014)
EMS, **BEMS**	Building energy management systems (BEMS) are integrated building automation and energy management systems, utilizing IT or ICT, intelligent and interoperable digital communication technologies promoting a holistic approach to controls and providing adaptive operational optimization.	(Yang, Clements-Croome, and Marson 2017)

All of these systems have proved to be useful for buildings management, including their equipment as well as preventive maintenance. They are characterized by a lack of interoperability; the limits of their functionality are rapidly exceeded. As separate systems, the communication is limited. All of these factors lead to inefficient FM. It concerns also the integration of essential information, which can raise financial losses and sustainability issues.

1.4 Maintenance Management

Maintenance strategies are imperative to minimize the decline of building performance during their life cycle, by controlling the stages of degradation and preventing failure of building elements (Flores-Colen and de Brito 2010).

During the operation and maintenance (O&M) phase of buildings, large quantities of data are created. However, the complex and non-intuitive data records, as well as inaccurate manual inputs, lead to difficulties for an effective use of information in O&M (Peng et al. 2017). In building maintenance, the building systems and their components should always operate in a manner that supports the operation of the structure (Newton, Hampson, and Drogemuller 2009). If the maintenance plan is implemented in existing buildings it should be based on detailed evaluation of the service building's degradation (Madureira et al. 2017).

1.4.1 Corrective maintenance

Despite the inconvenience of the cost due to the consequences of unforeseen damage, corrective maintenance programs remain largely used in building maintenance operators and owners (Ets sollution Asia 2017). This means that they wait until equipment falters or fails completely before initiating corrective action. Corrective maintenance is the simplest type in the maintenance strategy. It includes activities, such as replacing or repairing a failing elements (Newton, Hampson, and Drogemuller 2009).

Corrective maintenance concerns instantaneous failures and problems or unplanned maintenance. It includes the location of the fault and its diagnosis, reconditioning with or without modification, and the control of the functioning quality (Network 2008). It can be expensive for two reasons: (i) the failure of one component can cause successive damage to other building elements (i.e., the failure of a roof waterproofing can impact the ceilings as well as the interior of the building), (ii) the failure of a component can occur at an inconvenient time for the user as well as the technical manager; it could make the manpower and the planning of the intervention extremely difficult.

Nevertheless, for equipment with low cost and low consequences of failures or when the cost of maintaining an asset is more costly than replacing it, this kind of maintenance is acceptable. For example, light bulbs have very limited impact on the critical operation of a facility and their cost is insignificant (Ets sollution Asia 2017).

1.4.2 Preventive maintenance

Preventive maintenance consists in acting before failure, deterioration, or significant physical or functional changes in the building elements (Madureira et al. 2017). It is carried out thanks to scheduled regular inspections, tests, repairs, replacements and other regular tasks designed. It was introduced to overcome the drawbacks of corrective maintenance concerning avoiding sudden failures and the occurrence of failures by identifying maintenance actions on major equipment and incorporating it in major maintenance programs.

Less than a third of building operators use preventive maintenance program, which involves performing regular rescheduled maintenance checks and repairs whether they are needed or not .(Ets sollution Asia 2017). This approach yields better results, but it is still not optimal (Ets sollution Asia 2017). This category of maintenance consists of scheduled maintenance tasks for building installations and components that sometimes are carried out without a prof of necessity. Moreover, it requires more agents because of the regular maintenance tasks which can engender human errors that can lead to degradation or failure of the equipment concerned and even lead to further damage. Figure 1.2 depicts the different approaches discussed in the proceeding section.

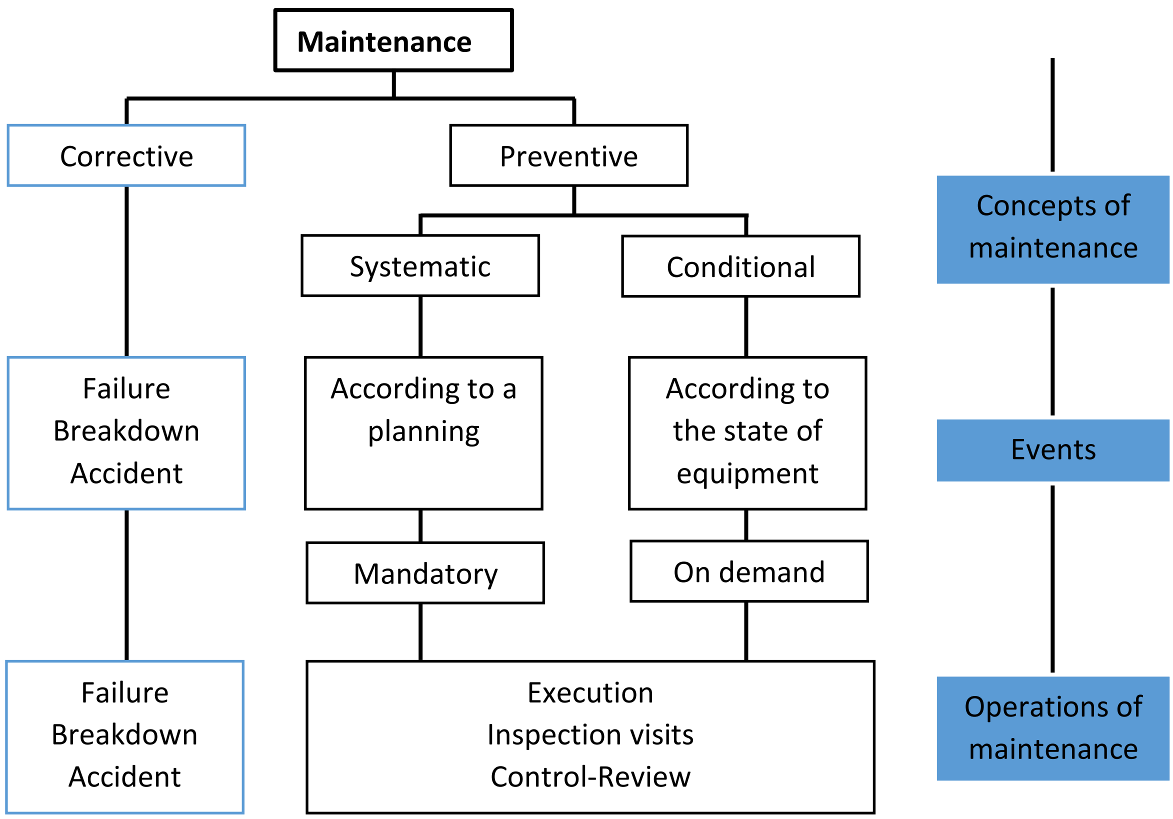


Figure 1.2 Diagram of the types and levels of maintenance to be defined in a maintenance contract

Source : (Cerema 2014)

1.4.3 Predictive maintenance

Predictive maintenance strategy is organized with a large amount of statistical and technical information on the behavior of building elements. It is based on inspection in order to establish the needs of maintenance for each element. These inspections are planned; maintenance is carried out according to inspection and the state of degradation of building's element (Madureira et al. 2017).

Facility management includes different information from several disciplines and stakeholders, (Peng et al. 2017). This generates an important quantity of data that can be stored in the history of maintenance and used for forecasting. Big Data allows to find latent patterns for prediction (Bilal et al. 2016)

Unlike preventive maintenance, predictive maintenance is based on current conditions or the actual condition of the equipment. This type of maintenance is conducted according to the performance status of the equipment. For example, the key operating parameters of a device are checked several times by the person responsible for maintenance or it is automatically managed by sensors. The results are analyzed to assess the state of the equipment and to predict future performance and failure probability (Hemmerdinger 2014).

A predictive approach can be used to prioritize repairs and maintenance. The most important systems are repaired first, and equipment is maintained continually rather than waiting for a failure. This ensures the most effective return on investment (ROI) (Ets sollution Asia 2017).

This approach is based on different methods, such as Markov-chain and factorial methods, which contain several factors that can impact the degradation of a building element. More than one technique could be used (Flores-Colen and de Brito 2010) to identify the deterioration or the most effective and appropriate maintenance strategy for existing facilities.

Research has shown that predictive maintenance increases the lifespan of buildings by several years, as well as provides a 25-30% reduction in maintenance costs (Hemmerdinger 2014). However, research related to this kind of maintenance is still limited and not implemented in large scale. Table 1.3 summarizes the methods used in building maintenance as well as their advantages and limits.

Table 1.3 Summary table comparing the different types of maintenance

Source (Hemmerdinger 2014)

type of maintenance	**Advantages**	**Limits**
Corrective or reactive	• minimal staff • lowest initial investment	• least efficient & cost-effective • increased cost of unplanned downtime, labor, repair • inefficient use of staff
Preventive	• more efficient & cost-effective: 12–18% savings over reactive • less equipment failure/ more uptime	• lack of prioritization • unnecessary maintenance

Predictive	• highly efficient & cost-effective: 8–12% savings over preventive • least equipment failure/ most uptime • improved safety, comfort, productivity, efficiency compliance • greater prioritization	• highest initial investment (staff, training, diagnostics) • savings potential not immediately seen by management
Predictive + analytics	• most efficient & cost-effective • greatest prioritization • streamlined operations • quantifiable ROI to show management	• requires a robust building management system BMS • special expertise

1.5 Building Information Modeling and facility management

1.5.1 Building information Modeling (BIM)

Building Information Modeling (BIM) is recognized as a technology and procedural change in the architectural, engineering and construction (AEC) sector (Wong and Yang 2010). IT allows CAD drawings to be processed, disrupting the production methods of the plans in the construction sector and saving considerable time and precision.

It is an evolution of the traditional processes, which is based mainly on computer aided CAD design. Figure 1.3 describes a building with 2D drawings such as plans, section and facades. A modification of one of these views requires modification of all other views manually. Furthermore, the data is only graphical (Yusuf Arayici 2008). The BIM contains geometry, spatial relationships, geographic information, quantities and properties of construction elements, cost estimates, material inventories and project schedule. (Azhar Salman 2011).

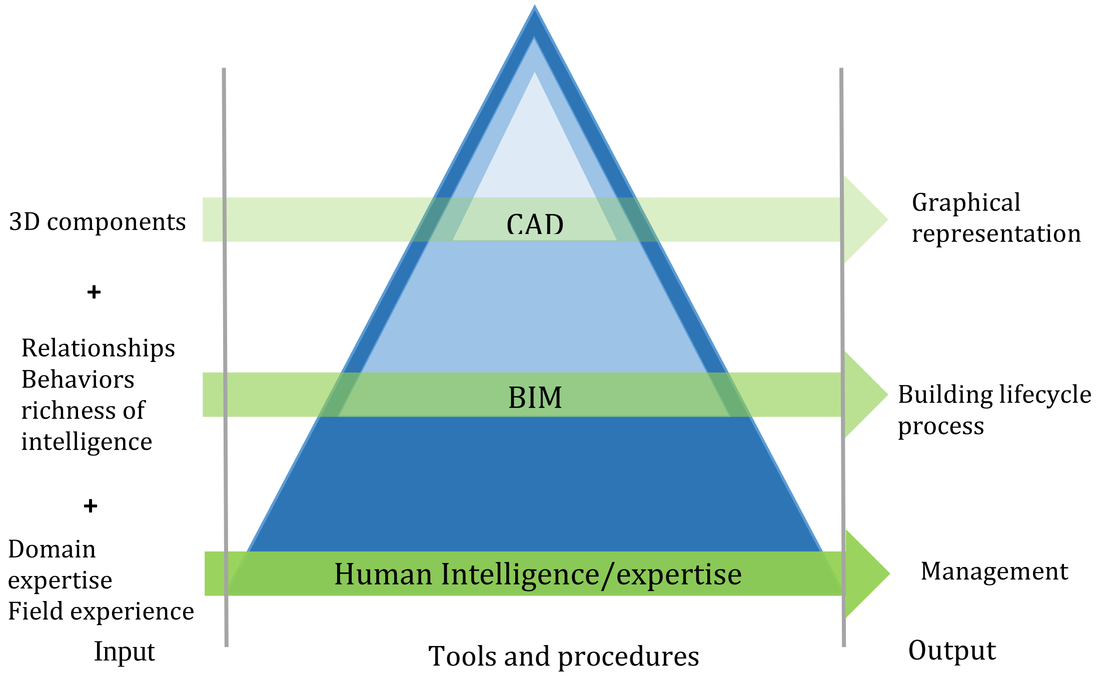


Figure 1.3 Information Application in the Building, Process and Tools

Source (Wong and Yang 2010)

BIM is a collaborative environment for the design, construction and management of construction projects. It allows the centralization of all project information in a digital model, forming a large database that allows the management of all elements of the project infrastructure throughout the life cycle (Troncoso-Pastoriza et al. 2018). BIM is used by design teams to design, analyze and develop the project, by the owner to understand the needs of the project, by the contractor to manage the project during the construction phase and by the asset manager during the project operating phase (Bryde, Broquetas, and Volm 2013).

The literature review of different definition of BIM highlights the following important characteristics (Celnik et Lebègue 2015; P. T. Eastman Rafael Sacks &. Kathleen Liston Chuck 2011):

• A process of integration, production, management and visualization of data.

• A unique model of the building or built structure (which can be contained in a digital file, which includes all the technical information necessary for its construction, maintenance, repairs, any modifications or expansions and deconstruction); The file is not a catalog of objects positioned in the space; it includes a description of the relationships between objects and their properties (eg: junctions of walls, type of opening or crossing of a wall or slab, thermal breaks). This single virtual model encompasses all aspects, disciplines (Architecture, Structure, MEP) and systems of a building, allowing the entire design team (owners, architects, engineers, contractor, subcontractor, suppliers) to collaborate in a more accurate and efficient way compared to using traditional processes (Azhar Salman 2011).

• Integration of software; The digital model provides for each modeled object information about it and on what reads it has other objects, which makes the digital model particularly effective for all kinds of simulations (thermal simulation, construction time, cost, etc.). The model is not just a simple visualization but a virtual avatar of construction, which would intervene throughout the life cycle of the building from its conception to its realization, from its exploitation to demolition. BIM is closely related to certain concepts such as levels of detail (LOD) and IFCs, which are discussed below.

1.5.1.1 LOD detail levels

There are five levels of detail based on the US Institute of Architects committee documents. The required level of detail (LOD) analysis is important for technical asset management (Lin et al. 2016a)

Based on interviews with BIM experts in Taiwan, Lin et al. (2016a) explained that most of them agree that not all BIM models need a maximum of LOD 500 as a FM requirement. The information identified concerns:

• Basic information, such as equipment name purchase information,
• Geometric information, such as equipment dimensions,
• Detailed information about equipment, such as supplier information
• Additional information, such as the user manual

Figure 1.4 Illustration of the different level of details

Source (BIM-Prozess 2016)

1.5.1.2 Interoperability and IFC

The world of engineering, architecture, and construction in general has undergone major changes in the way of designing projects thanks to the appearance of multiple software even for the same discipline. Each software develops its own standards and its own formats, making the communication between the multiple actors very difficult. It causes a considerable loss of data between the different phases, and reduces the effectiveness of facility management. Therefore, building SMART has developed a common data schema, called Industry Foundation Classes (IFC), that makes it possible to hold and exchange relevant data between different software applications, to increase the efficiency of BIM work and to ensure a consistent and high-quality output. It's a global standard, which is used to describe, share and exchange construction and facilities management information (Mc Portland 2018; "buildingSMART" 2018).

BIM concerns all phases of the construction, throughout its life cycle. Its applications in design and construction have outgrown the research stage and are now largely deployed. However, the BIM integration in FM is still in development. Its capability to deeply change the FM phase is not yet fully exploited (Pishdad-Bozorgi et al. 2018). There are still some limitations and shortcomings in software and management system in the assistance of managers to operate in an optimal way.

Martínez-Aires, López-Alonso, and Martínez-Rojas (2018) analyzed the repartition of publications in the field of BIM depicted in Figure 1.5. Research concerning the use of BIM in maintenance is very limited (1.37%), while 38% of the studies include the first stages and 60.27% in the construction phase.

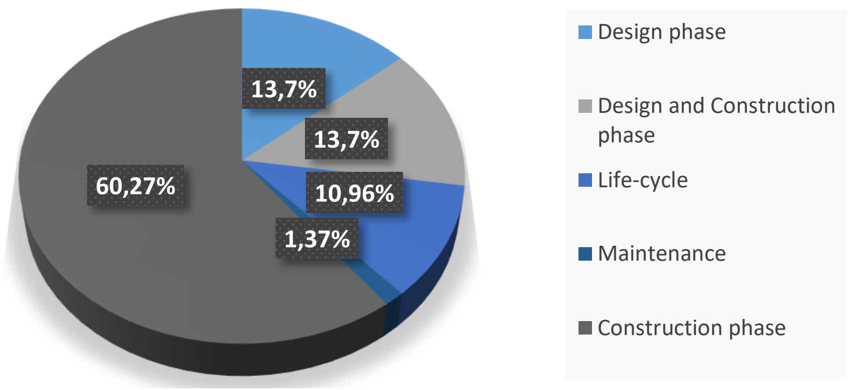


Figure 1.5 Percentage of BIM publications from the viewpoint of project life cycle

Source (Martínez-Aires, López-Alonso, and Martínez-Rojas 2018)

1.5.2 Use of BIM for existing buildings

Buildings can be classified into three categories according to their age: new buildings, existing buildings and heritage buildings. BIM applies to all phases of a building's life cycle, but still mainly is applied to new buildings. Most of the existing buildings do not have the information materials on the as-built building, no less than exploitable BIM models (Lu and Lee 2015). Furthermore, in most buildings, the information is fragmented, obsolete and incomplete (Becerik-Gerber Burcin et al. 2012). In the best case scenario, they are managed using computer aided design technology (CAD).

There are many challenges regarding the creation of a BIM model for existing buildings, due to a loss of documentation. The process of creating a BIM model for existing buildings needs further effort. It depends on the level of detail of the modeled project. The workers responsible for this task must have the required skills and successfully complete the process (Lu and Lee. 2015). Volk, Stengel, and Schultmann (2014) analyzed 180 recent publications on the use of BIM on existing facilities and reported the limited research in this field.

Creating a BIM model for existing buildings requires additional operations compared to new buildings. Whereas for new buildings designed with BIM, the digital model could be directly exploited for the technical management of heritage, for the existing buildings, it is necessary to reconstitute the information and go through several stages to create the model BIM of the building such that it exists (Figure 1.6).

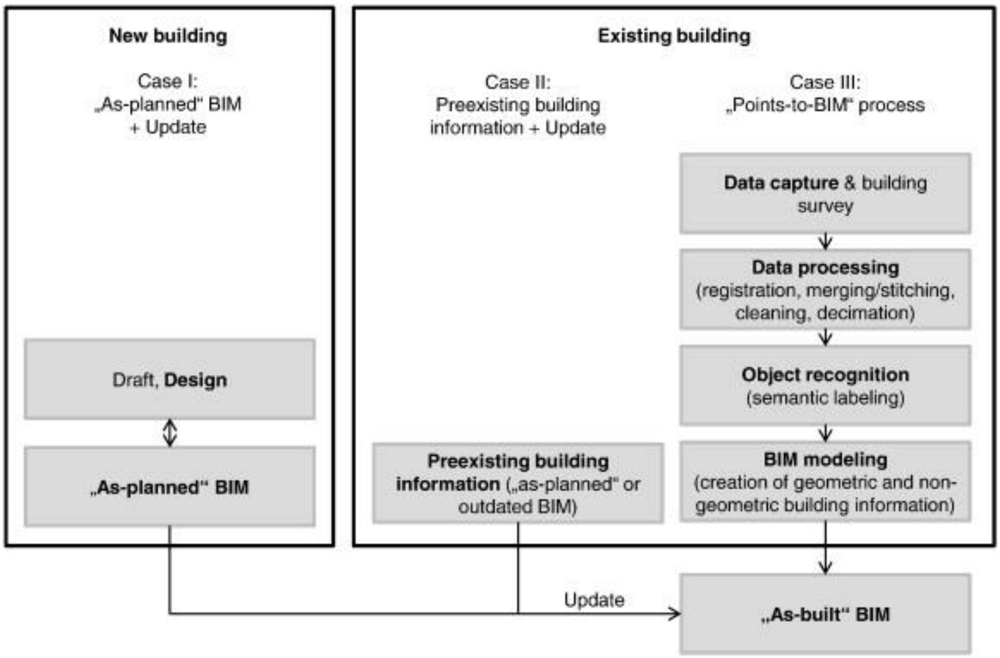


Figure 1.6 BIM creation process for new and existing buildings Source

Source (Huber et al. 2010)

The following sections describe how to create the BIM model for certain building categories.

1.5.2.1 Buildings with available documents

This could be a good starting point for creating the 3D model. Only a few checks should be made in advance, especially if renovations have been made to the structure, visiting the site and updating them if necessary. Then comes the step of scanning plans and importing BIM software. CAD drawings for the most recent buildings are usually accurate and contain all sorts of details, compared to plans made for maintenance purpose only. They must be taken carefully and checked on the site and then created. 2D model BIM, 2D plans will be used as support for the extrusion of the components that will constitute the future model BIM as-built. However, CAD plans or old paper plans may be outdated and may not correspond to the actual condition of the construction.

1.5.2.2 Buildings without graphic document or paper or CAD

a. Manual method

The creation of the as-built BIMs of existing buildings is often done with a manual process. The project can take up to several months depending on the complexity of the work and the requirements of the modeling (Matta 2009).

Several methods could be used to collect information to take measurements and reconstruct building plans. The first is the manual survey of the building. However, this method takes time. In order to collect the data on the dimensions of the building, the structure and the materials and to establish plans perfectly a model representative of the reality, several techniques can be used: traditional meter, laser rangefinders and station for GPS coordinates.

b. Laser scan 3D

The process of scanning an existing building with the 3D laser scanner requires four steps (Volk, Stengel, and Schultmann 2014) :

- ***Data collection:***

Laser scanners calculate distances from their sensors to nearby surfaces, so the x, y, z coordinates of spatial data are captured with thousands of spatial data points, with efficiency that makes it possible to create the as-built BIM model. The error is reduced to a maximum of one centimeter. This step generates millions of 3D points that form clouds of points (Figure 1.7).

- ***Information processing***

The BIM model is not generated instantly, but few steps are necessary. The point cloud created in the previous step will undergo data processing to enable BIM object recognition required for model functionality to generate the building's digital model with unmatched accuracy. The point clouds of each scanner are represented with its local coordinate system. The point cloud images are then aligned and merged into the same coordinate system as seen in Figure 1.7b (Tang et al. 2010).

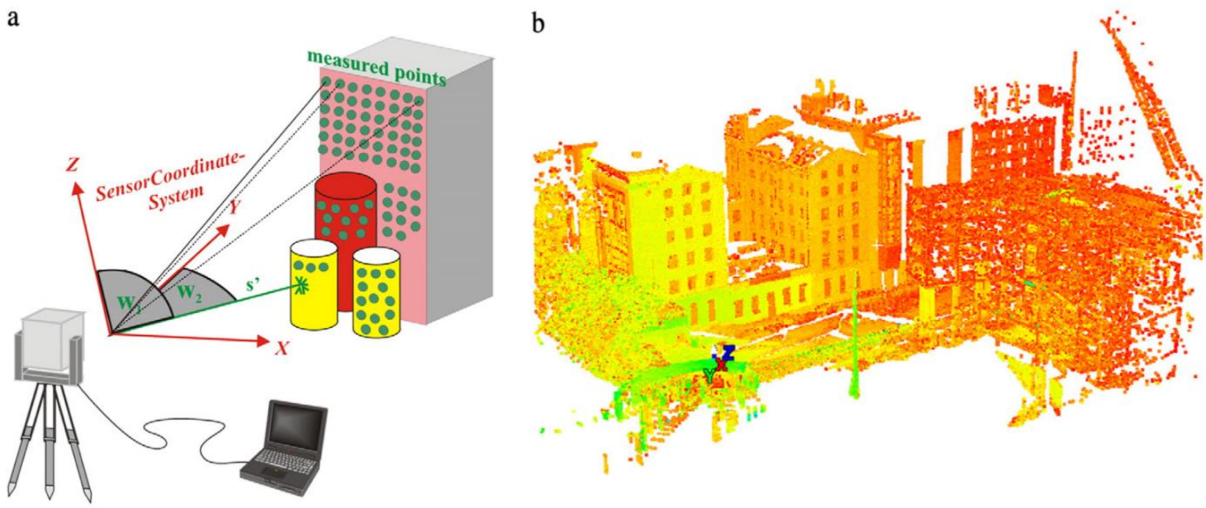


Figure 1.7 a) The laser scanning process used to measure 3D points. (b) An example of laser scanned data of a building under construction

Source (Tang et al. 2010)

- ***Recognition of objects***

Captured and processed building data is used to recognize building components and their relevant characteristics for their required functionality. Object recognition includes object identification, extraction of relational and semantic information, and concealment processing (Tang et al. 2010). To enable the functionality of the maintenance of technical equipment, such as HVAC or MEP systems, detailed information such as layers of materials, installation dates are necessary. These information are not automatically recognized in the model but requires intense manual intervention and user interaction (Dickinson et al. 2018)

- ***BIM Modeling***

The process of scanning to BIM requires three tasks. The first is the modeling of the components geometry, the assignment of a category of objects and property of the material to a component, and the establishment of relationship between components (Volk, Stengel, and Schultmann 2014). Modeling concerns geometric data and non-geometric attributes.

The current methods of the 3D scanner to the BIM remains largely manual and recognized as being also a method that requires a lot of time (Larsen et al. 2011; Tang et al. 2010).

Figure 1.8 depicts the process of creating the as-built BIM model with the laser scan method.

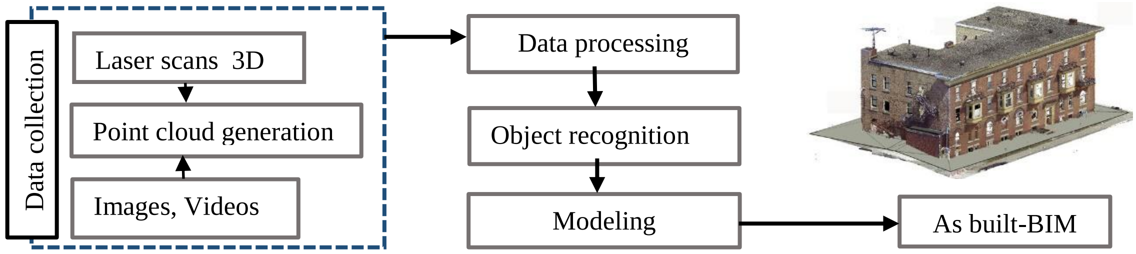


Figure 1.8 Workflow for 3D model-based BIM model creation

c. Combined methods, Automatic and semi-automatic

The use of a single technology is not sufficient to meet all the requirements, therefore the combination of different technologies is the most appropriate way to overcome the constraints and limitations of each separate technology (Volk, Stengel and Schultmann 2014). Several publications concerned semiautomatic methods for modeling surfaces of buildings. However, they is still a need for semantic information of property and attributes (Yusuf Arayici 2008; Klein, Li, et Becerik-Gerber 2012)

There are also automated methods to quickly create a BIM model. Lu, Lee (2015) explains that automatic as-built BIM creation means performing a rationalization, which stores entries (eg point clouds / images / video / others) and ends with the BIM model as-built. Brilakis et al. (2010) proposed a new framework for the automatic generation of parametric as-built BIMs in constructed facilities, creating a combination of laser scanning technologies and video capture. This framework uses spatial and visual data collected in the field to generate images and 3D surface represented as a cloud of points. Then, satisfactory relationship definitions and suitable object recognition algorithms reach the BIM construct as-built. The main contribution of this research is to automatically reduce redundant tasks and allow simultaneous modeling processes. Figure 1.9 summarizes the techniques used for creating a BIM model of an existing building.

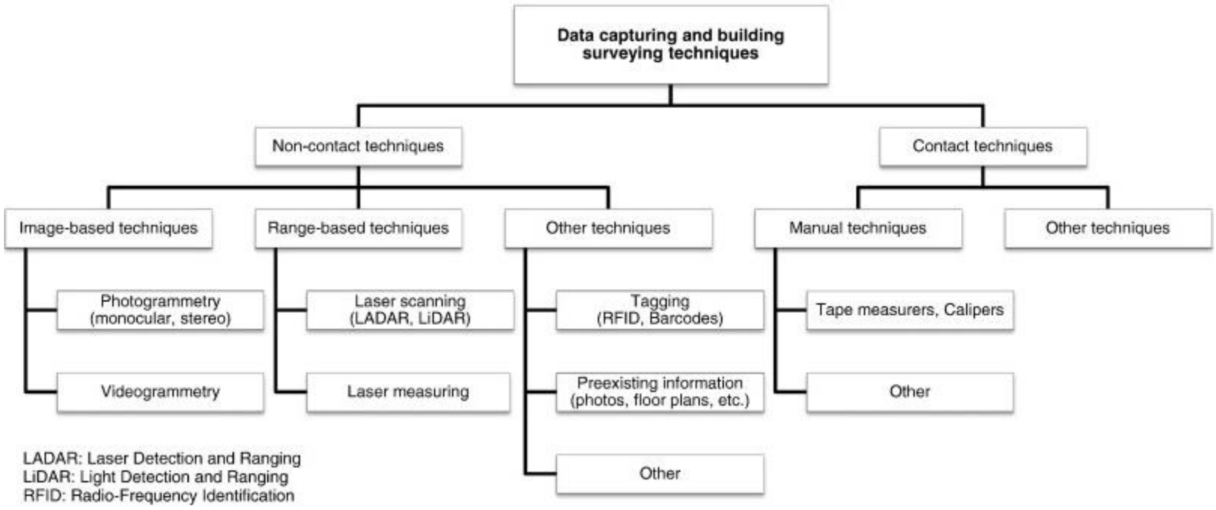


Figure 1.9 Systematic Overview of Data Entry and Survey Techniques to Collect Information on Existing Buildings

Source (Volk, Stengel, et Schultmann 2014)

1.6 Advantages of BIM for FM

The research carried out on the application of BIM for the technical management of buildings has identified advantages of BIM integration for FM. Firstly, the model provides necessary information to the FM, useful for the maintenance and repair, management of energy and commissioning of the building (C. M. Eastman 2008). The adoption of BIM in mainstream FM encompasses several disciplines to ensure greater functionality of the built environment by integrating people, place, processes and technology (Aziz, Nawawi, and Ariff 2016). The BIM management model contains all the data on the architecture, the MEP systems (Mechanical, Electrical, and Plumbing), such as the ventilation, plumbing system, etc.

Y. Arayici, Onyenobi, and Egbu (2012) categorized the benefits of BIM for building lifecycle FM in two main categories: (i) soft issues such as space management, cleaning, waste disposal and recycling, directing and planning essential central services which can be effectively managed, and (ii) hard issues such as maintenance of normal power systems, maintenance of building automation system (BAS), maintenance of mechanical and engineering, maintenance of windows and doors. Kensek (2015) has underlined four main advantages of using BIM for FM: space management, populating the database of assets from a building information model, effective preventative maintenance and retrofits, record building information model populated with data that makes it useful for continuing operations and maintenance.

Table 1.4 shows case studies where the BIM has been successfully implemented for technical asset management and highlights their benefits.

Table 1.4 FM related BIM application areas identified in the real-life case studies

Source (Volk, Stengel, et Schultmann 2014)

Application area \ Case study (ID nr)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Mobile localization of building resources							▪		▪	▪
Digital asset with real-time data access	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
Space management		▪	▪							▪
Renovation/retrofit planning and feasibility studies	▪	▪								▪
Maintainability studies	▪	▪	▪							▪
Energy analysis and control		▪	▪							
Safety/emergency management		▪			▪					

Legend:

(1) Sabol [26]; (2) Aryaici, Onyenobi and Egbu [2]; (3) Neelapala and Lockheed [21]; (4) Codinhoto and Kiviniemi [5]; (5) Wang et al. [31]; (6) Orr et al. [22]; (7) Lin, Su and Chen [12]; (8) Su, Lee and Lin [27]; (9) Costin et al. [6]; (10) Fillingham, Malone and Gulliver [10].

The main advantages of applying the BIM for the management-operation phase raised in the previous section are detailed below.

1.6.1 Space management

Space itself is a valuable and manageable asset. It has intrinsic value once the building is completed and is considered a major tangible asset. It can be rented or reassigned to other people and is often the key locator for other items like equipment, furniture, voice and data lines, lights, people, etc. (Kensek 2015)

The importance of BIM in the management of spaces concerns several points. It allows the manager to explore its visualization and coordination capabilities by streamlining the process of displacement, forecasting the needs of spaces and facilitating the analysis of spaces (Liu R. and Issa R. R. A. 2012)

1.6.2 Preventive Maintenance

BIM provides a template for storing all building information and thus allows for integrated views, it has the potential to support visualization and spatial analysis of various maintenance activities (Akcamete, Akinci, and Garrett 2010).

In current practice, reactive maintenance is more common and could even be four times more expensive than preventive maintenance for the same repair (Liu R. and Issa R. R. A.

2012), the implementation of BIM in FM can avoid this issue. Akcamete, Akinci, and Garrett (2010) propose an approach on a building of a university campus on maintenance data over a period of one year.

The intended approach is to support the capture of field information through maintenance manager work by generating custom templates for saving changes and automatically saving the installation change history in a BIM (Figure 1.10). This can allow visualization of M & R activities and spatial analyzes of building behavior that can support decisions about maintenance priority.

When previous M & R activities are spatially visualized, it would be possible to identify fault patterns for a particular wing or part of a building and to analyze the spatial relationships in the work orders for execution and performance for more efficient planning.

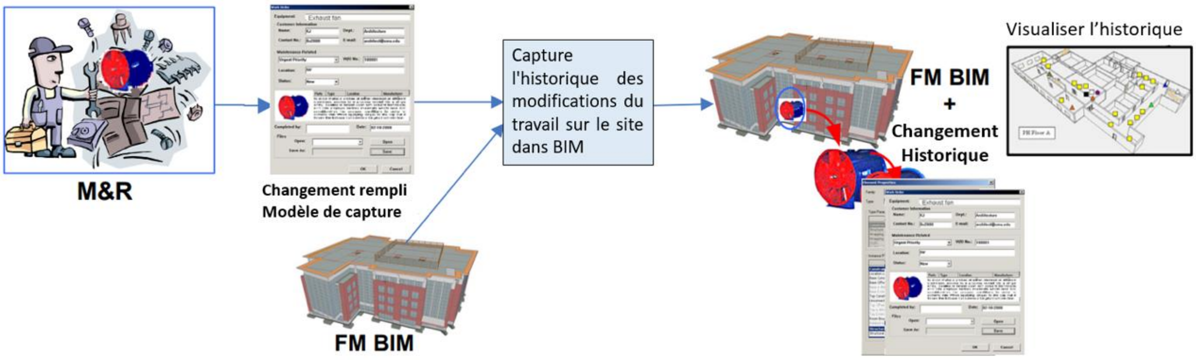


Figure 1.10 Visualization of the maintenance history

Source : (Akcamete, Akinci, and Garrett 2010)

1.6.3 Better documentation and visualization Registration Building information model

Facility managers face difficulties in building maintenance when their work is based on paper documents (Ani et al. 2015), the lack of updated documents and coordination between the different disciplines. BIM, in this case, has the potential to be a catalyst for improving efficiency by establishing relationships between FM and earlier phases (Yalcinkaya and Singh 2016). BIM also allows management personnel to link real components with their corresponding model in the BIM model. The BIM FM contains a virtual description of the building and associated data; 3D model, drawings and 2D drawings, components (furniture and equipment for example), maintenance manuals, warranties, and other information (Kensek 2015) all of this data is saved inside a single business model (Figure 1.11) where the data can be easily added, updated and viewed.

Figure 1.11 Visualization of a building and maintenance information in Ecodomus

(Virtual Building studios 2018)

1.6.4 Renovation / rehabilitation and feasibility study

BIM provides a complete database necessary for the technical and financial feasibility study of a project. It can be used for planning and feasibility studies with the historical database of existing building used as a reference for the estimation of expected labor costs (Nicał and Wodyński 2016). Different scenarios of rehabilitation and renovation can be developed on the BIM model upstream.

1.6.5 Management of security and emergencies

With the same principles as BAS, fire protection and alarm systems have integrated the computer-based systems, which include the emergency communication systems and fire detection as part of overall building operations during an emergency event (Kapis et al., 2013). Preece et al. (2014) explains that BIM is able to provide detailed information for an event, which requires for example, the evacuation of a building. The uncertainty in the emergency decision-making is therefore reduced. In case of fire in a commercial building, it will be useful to identify the nearest electrical panels, hydrants, floor plan and hazardous materials of the building. The BIM model is already used in the phase design to develop the most favorable scenarios in case of evacuation, and during the crisis management phase to identify secure and refuge spaces quickly. It is also used after the incident to assess damage and other planned interventions (Zhichong and Yaowu 2009).

1.6.6 Maintenance management with real time data

The usual equipment maintenance are carried out using plans, paper documents and a subjective judgment based on experience (William East et al. 2013). This approach is not effective and can often be dangerous (Nicał and Wodyński 2016). Failure to capture and use this information results in huge damage and costs due to inefficient decisions (Motawa and Almarshad 2013). Current BIM-based building maintenance systems can be expanded to capture and utilize real-time building component information to support appropriate maintenance decisions. BIM allows sensor data to be visualized in their context and allows maintenance departments to locate mechanical, electrical, plumbing and fire safety equipment, while displaying data to the operational context (Krukowski and Arsenijevic 2010). In addition, maintenance management personnel can opt for an object indication and collect the required information from the asset management system, indicating its location (Preece et al., 2014). The ability to access equipment status minimizes labor and intervention work and saves time and remedies inefficient decisions due to lack of information (Davtalab 2017).

1.6.7 BIM management of MEP systems

MEP Engineering (Mechanical, Electrical, and Plumbing) is a general term that refers to the non-structural management of the building. It concerns the management of plumbing, heating, ventilation and air conditioning (HVAC), electricity, energy conservation and maintenance of elevators, etc. (Hu et al. 2018).

MEP system constitutes an important part of the construction cost. It should be effectively monitored. In current practice, management information of MEP systems are received in the form of various unstructured documents varying between hard and soft copies (Bosché Frédéric et al. 2014). The application of BIM for the management of the MEP system is mainly a process of optimization of its systems and subsystems. Approaches have been developed for the integration of BIM for the management of MEP systems, beginning by the creation of the model of the existing based on the laser scanner. Bosché et al. (2015) have developed a new approach for the recognition and identification of cylindrical objects in the 3D point cloud allowing to easily recognize the piping system. Once the MEP model created or received from construction and design phases, it is used for the technical management of the building.

(Hu et al. 2018) have developed a BIM application for intelligent management of MEP systems. Citing the example of pipes, where thousands of components are logically related to each other forming a complex set. In the case of a leak, the upstream valve should be closed as soon as possible. So they propose to create a clear picture showing the logical chains connecting the components and incorporated into the as-built BIM model and have an enriched model to effectively respond to emergencies and daily maintenance tasks.

The principle of this work is explained in Figure 1.12, where frame 1 proposes a method for automatically establishing a logic chain for a given MEP subsystem. Section 2 shows a scheme of components based on specific areas, to form groups with parts, part 3 introduces an algorithm created to automatically generate from the GIS map.

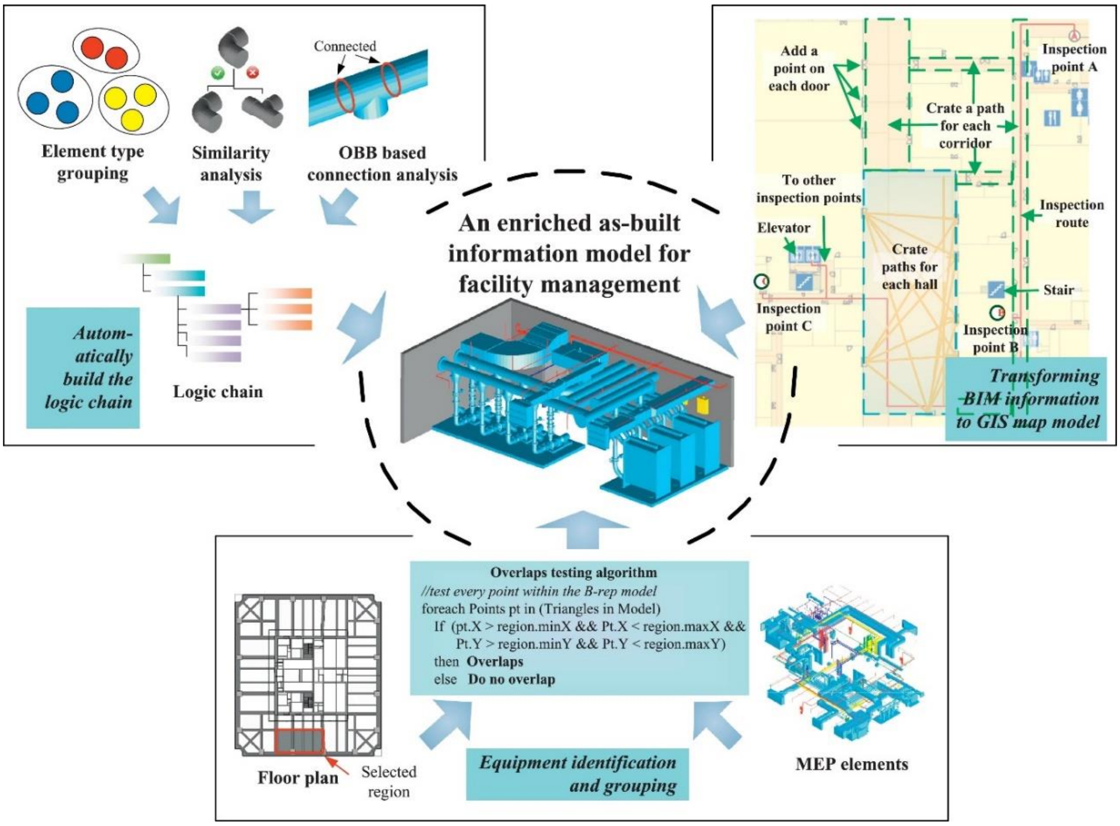


Figure 1.12 Diagram of BIM Generation as Built and Delivery Method

Source (Hu et al. 2018)

1.7 Case study: Application of BIM for maintenance of a building of the Carnegie campus Mellon University, USA

Akcamete et al. (2010) conducted a study of a building including three levels in the university campus to illustrate the potential benefits in implementing BIM in maintenance management over a period of one year. All maintenance activities were analyzed (corrective maintenance, breakdowns, daily maintenance, repaired equipment, etc.) and categorized. Those associated with a specific component or location in the building were manually integrated into the BIM.

A manual map was carried out as a first step in order to illustrate the immediate advantages of viewing the types of incidents recorded in their precise location over time, with a color code for each type of component concerned.

The second is the spatiotemporal analysis that has provided the tendencies of repairs for components or spaces, which can be correlated with the context of the building. It shows that 85% of the replacement of lighting is done in rooms without windows, and 90% of ceiling tile replacements were conducted on the 2nd floor, which is directly below the roof.

The result of this work revealed relations and correlations between maintenance activities and their locations in the BIM model, which could not be conducted with traditional management systems.

1.8 BIM and energy efficiency in operation phase

The increase in energy consumption is one of the major problems of this century (Volkov and Batov 2015). Energy accounts for 30% to 43% of the annual operating costs associated with building operation (Araszkiewicz 2017; Beddiar and Imbault 2017). Other studies showed that around 90% of the energy consumption in buildings lifecycle occurs during the operation and maintenance phase (Martínez-Rocamora et al., 2017), the potential for energy savings through systematic building management is known to be significant: between 5% and 30% (Costa et al. 2013). Sustainability should be considered throughout the post-construction building lifecycle (GhaffarianHoseini et al. 2017). Several approaches have been developed for the reduction and control of energy consumption based on IT solutions such as: smart buildings, innovative energy management systems, use of BIM or the combination of several concepts. However the current methods of facility management systems and energy management systems are characterized with a grand complexity, due to the heterogeneous data, devices and system protocols (Tomašević et al. 2015). The integration of the building information modeling with these technologies is not been fully explored.

1.8.1 Smart building concept

The concept of smart building is often identified with modern building automation systems (BAS). Literature review shows different definitions of the smart building concept, but it does not have a standard definition (Araszkiewicz 2017). According to Cook (2012), the concept of a Smart Home is "a computer software playing the role of an intelligent agent perceives the state of the physical environment and residents using sensors and then takes actions to achieve specified goals, such as maximizing comfort of the residents, minimizing the consumption of resources, and maintaining the health and safety of the home and residents".

Buckman, Mayfield, and Beck (2014) considered that Smart Homes are closely linked to smart sensors, smart materials and smart meters. In Smart Building, devices are used to control the energy consumption by control of the ventilation, heating, cooling, production of hot water, lighting and sealing, etc. The objective is to reduce the energy consumption while maintaining high comfort conditions (Figure 1.13).

The Smart Building uses the smart grids technology to improve the energy management as well as quality life (Beddiar and Lemale 2016). Ciribini et al. (2017) argue that the design of smart buildings should not be sufficient, it should include interactions with users.

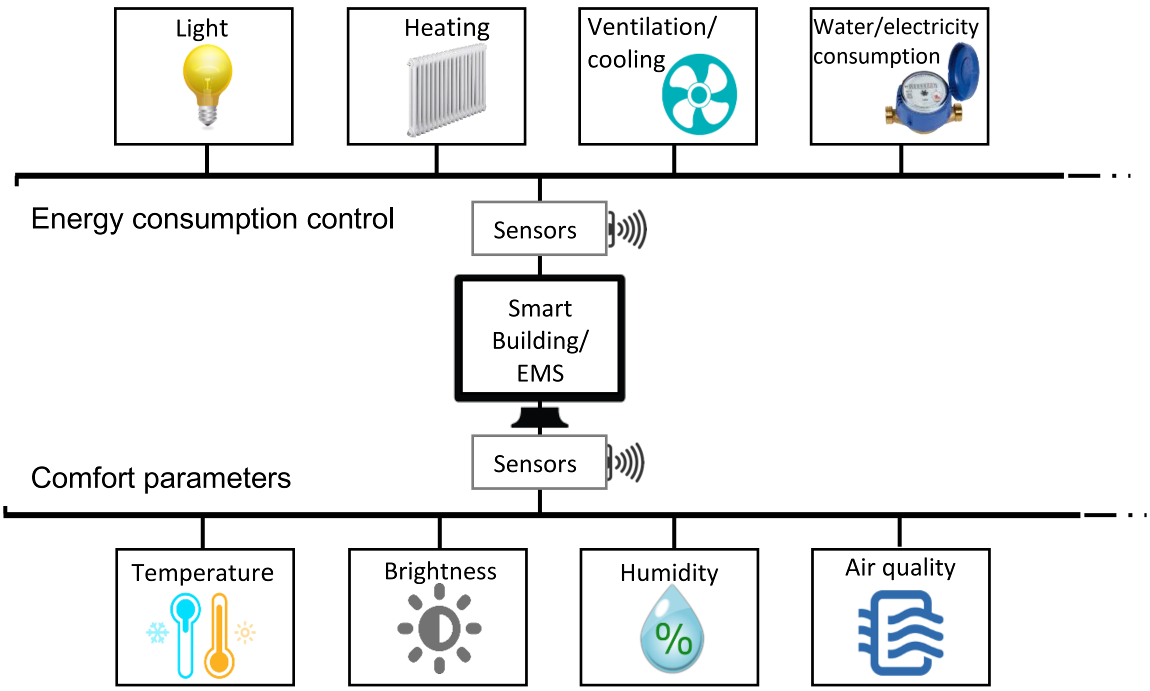


Figure 1.13 Smart home system

1.8.2 BIM and smart building integrations

The BIM-based models used in the operation phase include only the as-built data due to their static nature (Volkov and Batov 2015). It means that they show only physical building properties without showing processes in the building. However, research has been made about the integration of BIM and smart building concept or with a building management system through a dynamic extension of BIM.

Cahill, Menzel, and Flynn (2012) explained how integrating sensors data can support a dynamic BIM. Chen Jianli et al. (2014) developed an approach in order to connect the data captured with sensors in the real facility to the IFC-based BIM.

Ciribini et al. (2017) conducted an implementation of Building Management System (BMS) into BIM environment. By connecting data collected by sensors to a BIM database, they showed how the integration of smart technology for data acquisition the storage an analysis could improve users' awareness.

Volkov and Batov (2015) explored the application of BIM to smart buildings through a dynamic extension of the Building Information Model. The model builder contains the static data, including geometrical topological data of the building, to pass to the dynamic data proprieties the model accepts information related to the resident's activities and environmental changes, and real time monitoring in the operation stage, which is valuable to facility managers.

In order to analyze the energy behavior of a building, a BIM model can be used to simulate the energy systems based on different building arrangements and to discover efficient energy solutions based on BIM, the environment visualization, energy consumption and integration of presence sensors can be easily controlled (Preece, Hedayati, and Mohandes 2014). It is also possible to integrate energy analysis tool into a single module with BIM or BMS. The interfaces of the BIM environment facilitates the visualization and makes possible the comprehension for non-experts including the users which could influence on their behavior (Attar et al. 2010).

1.9 Drivers and barriers of wider implementation of BIM

Application of BIM for building performance has been studied by Gerrish et al. (2017). They summarized the BIM integration into operational information environment. The main barriers of this integration are: (i) the absence of clear guidance to utilize the BIM to support the ongoing building performance optimization, (ii) a lack of real cases where BIM application is demonstrated in a replicable form and (iii) limited coordination in the design and operation. The ineffective handover can lead to an increase in energy consumption and occupant dissatisfaction (McGraw 2014). To maintain the as-built BIM model reflecting the real state of the building, data updates are necessary to ensure that the recent asset history data is readily available in a relevant sematic format (Pärn, Edwards, and Sing 2017).

There are also some limitations between BIM and CAFM systems integration, moreover the question of the level of information which is not standardized and clearly established. Although BIM enables greater data integration between the stage of design and construction information with the facility management, this data is not especially well presented into FM (Shen et al. 2010). Figure 1.14 presents a comparison of the traditional modes of facility management with the current IBM based FM.

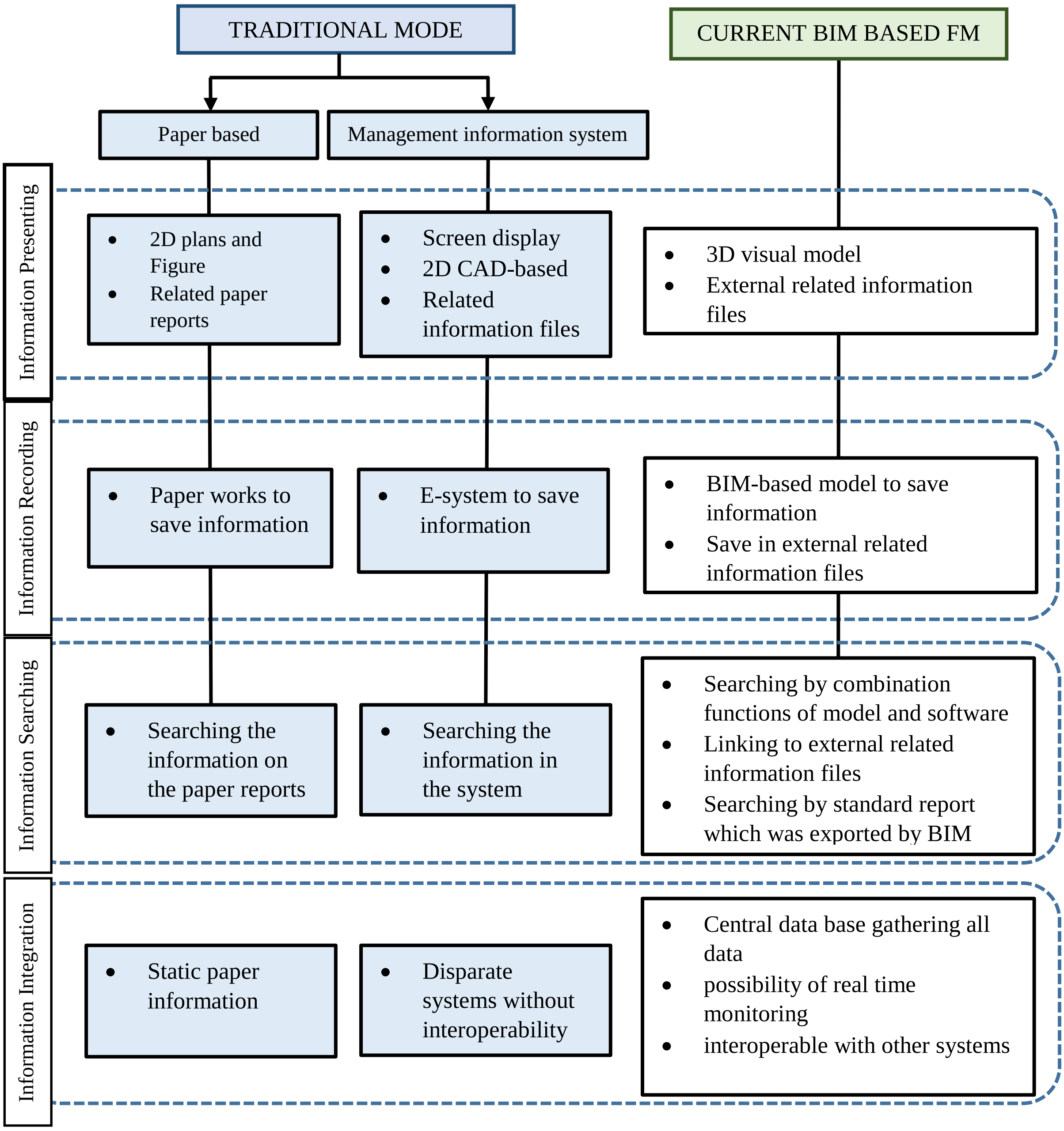


Figure 1.14 Comparison of the BIM-based method and traditional facility management

Based partially by the research of (Su et al., 2011)

1.10 Conclusion

Since the exploitation phase is the longest and most expensive during buildings lifecycle, great care should be paid for the management of this phase to reduce the exploitation expenses, improve the security of both the asset and users, reduce energy consumption and provide high quality of life for users.

Considering the important development in the field of digital technology in the construction industry (2D and 3D computer-aided design, BIM, Smart Building,), it is of major concern to explore how these developments could significantly improve facility management. The thesis concerns this issue with a focus on the use of BIM in the optimization of facility management.

The following chapters present successively how BIM could be used in Facility Management and then its application to the social housing sector as well as to an academic building.

Chapter 2: Methodology of creating as built BIM

This chapter discusses the implementation of the BIM technology for existing buildings. The creation of as-built BIM model is carried out for a social housing residence in Villeneuve d'Ascq, which includes 50 dwells. The chapter describes steps carried out to realize the BIM model, which includes architecture and MEP systems (Plumbing system, ventilation system, elevators, and solar panels, boiling room).

2.1 Introduction

The social housing sector in France faces major challenges, such as aging and poor energy performances. Building managers and social landlords suffer from lack of data concerning building assets, maintenance and efficient use of energy. The BIM could help in meeting these challenges. This work concerns the creation of a BIM model for the Tennis residence in Villeneuve d'Ascq in the North of France. The first step concerned collection of existing technical data, and then to establish necessary information and level of data necessary for an efficient facility management.

The creation of BIM includes three main steps:

- **Step 1:** Modeling the architectural model based on existing plans and survey in the physical building.
- **Step 2:** Creation of MEP systems, respectively; plumbing systems (Hot water pipe system, cold water pipes, and waste water, ventilation systems and some equipment (elevators, boiling room, solar panels, fire protection system).
- **Step 3:** Model organization for each discipline, clash detection to find out error or interference in the systems, validation of the final BIM.

2.2 Methodology

This section describes the workflow used to create the BIM model for the Tennis residence. First, we analyzed conditions and problems of current maintenance work and management of the building, and the expectations of the operator. During analysis, the specificities of the social housing sector for the facility managers and for users were taken into account. All the parameters were used to define the appropriate level of details of the numerical model for both geometrical information and data for maintenance. The software Revit was employed to create the BIM model of the residence. Models were integrated for checking and validation using Navisworks. Figure 2.1 details the methodology followed for the construction of the BIM model.

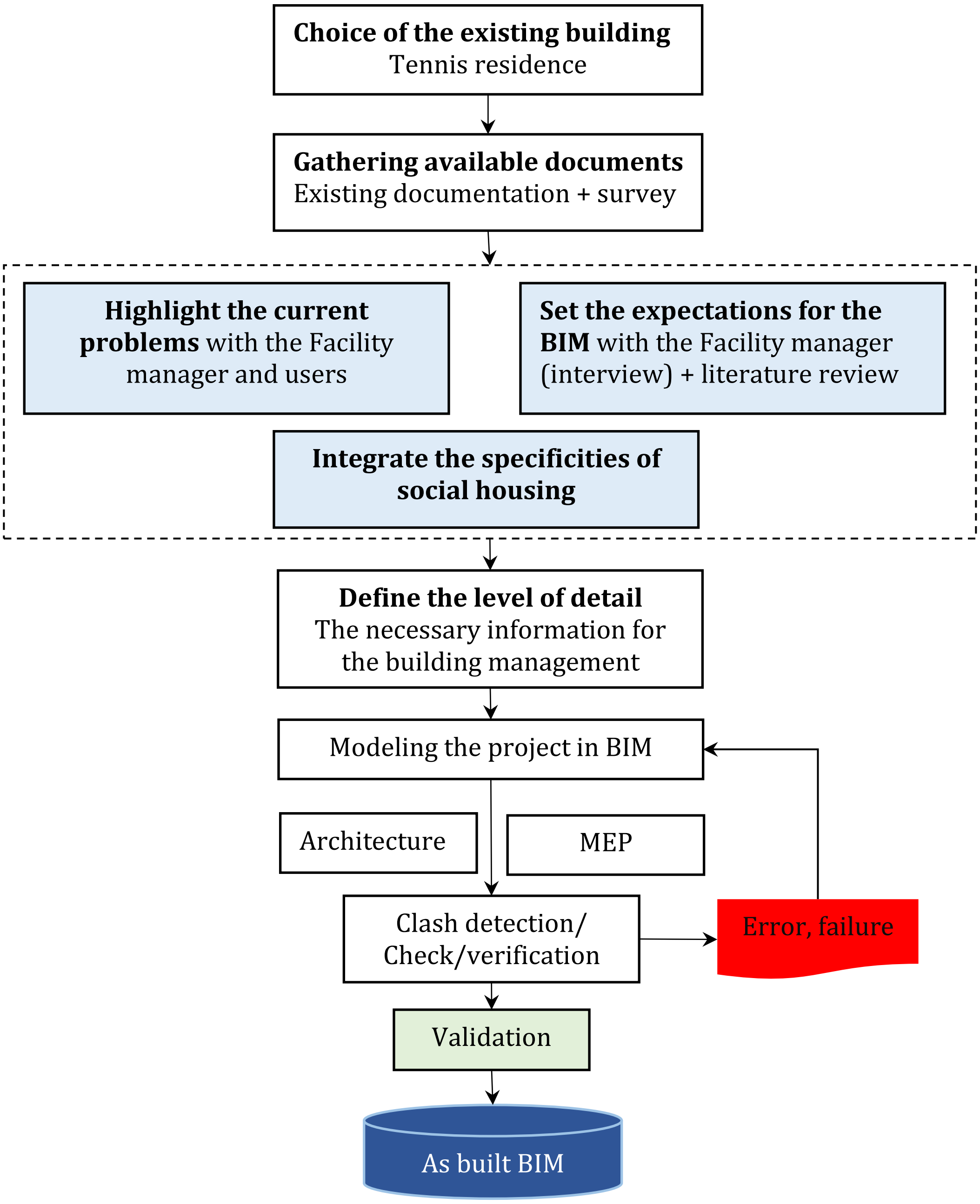


Figure 2.1 Methodology used for BIM creating of a social housing residence

2.3 Description of Triolo Residence

This social housing residence is located in Villeneuve d'Ascq. It was built in 1973 and rehabilitated in 2012. It is composed of two parts with simple geometric shapes (Figure 2.2). It contains 50 dwellings with different types T2, T3 T4. The north part includes 9 levels and 35 dwellings, while the south part includes 4 levels and 15 dwellings. The principal facades are oriented to the east and west as shown in ground plan and the facade cladding is made of Trespa meteon panels with thickness 8mm of three different colors (white, Trespa pastel gray, and orange red) as shown in figure 2.2.

Figure 2.2 View of the residence Tennis Data provided by the building operator

The residence manager provided the following documents:

- The architectural plans in paper format, which were realized for the building rehabilitation with details about the materials of the facade and the external walls.
- Technical documents and maintenance manuals for some equipment, such as the ventilation system, extractors and the boiler.
- Maintenance documents, which concern corrective and preventive maintenance of some building equipment.

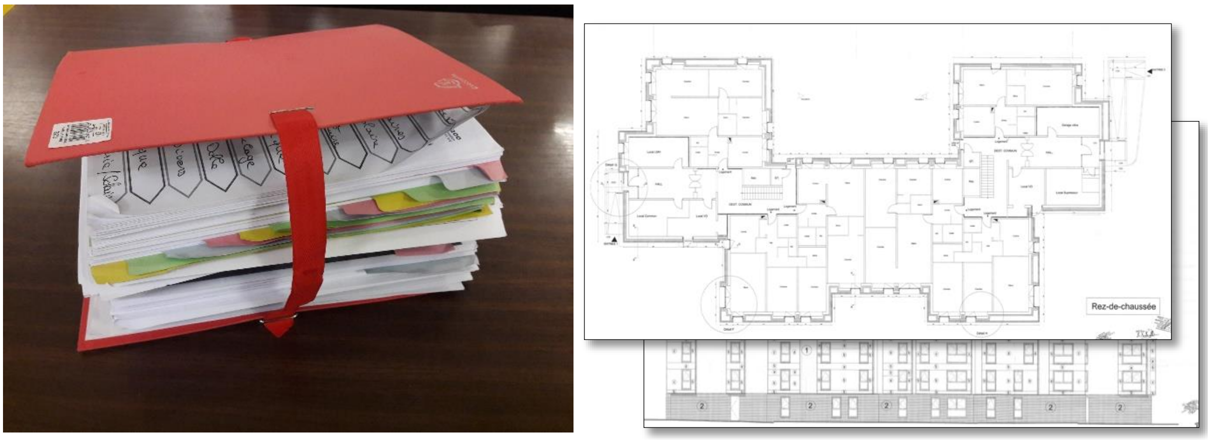


Figure 2.3 Documents provided by the building operator LMH

2.4 Level of data for the BIM model

Defining and formalizing the required FM information is an essential step in BIM implementation. There are five levels of detail (LOD) based on the American institute of architects (AIA). These are LOD 100, 200, 300, 400, and 500. Most of FM projects use up to LOD 500. It's very important to identify the required LOD for the building management and its equipment. The identified information are:

- Equipment name and purchasing data
- Geometric information, such as length and width of the equipment
- Detailed information of the equipment (equipment supplier information)
- Related supplementary information, such as maintenance manual

Based on literature review, all the information and details for the design and construction phases are not required for the exploitation phase. BIM for the Tennis residence was constructed for architecture and MEP systems. Table 2.1 shows the required information of the BIM model for facility management according to facility manager expectation and needs (interview) and the literature review (Lin et al. 2016b).

Table 2.1 The required information of BIM for facility management

The detailed required information of BIM for Facility management				
Type of data	Date: 2017		Parameters	
Identification of the facility	Basic information		Type of the building	Social housing
			Equipment name	Tennis
			Building operator	LMH
			Developing BIM model of equipment	
			Appearance description(word)	
			Appearance example(picture)	
Model parameters	Geometric information		Size (Length、Width、Height)	
			Material	
			Elevation	
			Special detail of model (word / picture)	
	Information for Each discipline	Architecture	Wall properties	
			Joinery	
			Space details	
			Apartment identifications	
		Structure	Structural system	
			Other structural details	
		MEP systems	Plumbing system	
			Ventilation system	
			Fire protection system	
			Elevators	
			Solar panels	
	Equipment detail information		Equipment number	
			Omni class coding	
			Brand / Manufacturer	
			Manufacturing company	
			Location (area / floor)	
			Price	
			Purchase date	
			Installation date	
			Responsible unit / person	
			Equipment specifications	
			Equipment type	
			Equipment functions	
			Equipment units	
			Equipment professional information	
External links information	Supplementary information		Warranty	
			Assembly process	
			Operating manual	
			2D CAD	
			Equipment performance table	
			Manufacturer information	
			Maintenance manual	

	Maintenance records	Equipment resume	
		History maintenance records	
		Checklist	
		Record book of maintenance staff	

2.5 Analysis of available documents

Documents and plans of the renovation phase constitute a good base for creating the as-built BIM model for the Tennis residence. Some documents are not accurate, or some parts are missing, or events do not exist for some building elements. This situation differs from a discipline to another. A deep analysis of these documents is required to determine the missing information for each discipline.

2.5.1 Architectural plans

The architectural plans were realized during the residence renovation in 2012. Details concern the external envelope of the building with details concerning the different layers and materials composing the external wall which is going to facilitate the modeling of the façade. Such details are addressed here:

- Exact location of the joinery and the corresponding type are often missing
- Details of the stairs and railings
- The available sections allow to have the height for almost all the levels

Survey served to complete the internal side of the plans. The figure 2.4 shows the plan of the ground floor with highlighted apartments.

Figure 2.4 Plan of the ground floor with highlighted apartment

2.5.2 MEP Systems

2.5.2.1 Plumbing system

The model of the plumbing system concerned hot water, cold water and waste water. Since data were not available, a direct survey was conducted to collect information concerning diameter of piping system and location of vertical pipes.

2.5.2.2 Ventilation system

For the ventilation system, we have a number of plans of system containing information about air ventilation ducts, the maintenance manuals, and information about the type of extractors. A survey was necessary to locate the position of the system.

2.5.2.3 Fire security system

Since the information related to the fire security system was not available, a survey was necessary to determine the type and the position of the fire extinguisher in all the common spaces and corridors and emergency issues.

2.6 Conducting the survey

The survey of this residence was realized using basic tools, such as the Laser measure which is simple to use, accurate and saves time. The camera was used to photograph facades, also typical doors or windows or details which are too complicated to draw, such as decorative carvings or interesting ironwork and other details important for creating the model.

Table 2.2 Components of the BIM model for architecture

Discipline	Method	Concerned components	Level of details/ information
Architectural model	Plans+ Survey	External walls Internal walls Joinery (doors, windows) Floors Flats Name of the spaces (private and common spaces)	Type, dimensions, materials, colors

Considering the size and the architecture of the residence, we decided to organize it into two sections. The building is composed of two main parts, so each page holds a section because it is easier to draw at a large enough scale to add the measurements/dimensions. The survey was conducted in two steps.

2.7 Modeling tools

Tools used for the development of the BIM model are described in Table 2.3 which include Autodesk AutoCAD, Revit and Dynamo.

Table 2.3 Software used during the development of the BIM

Software	Function
Autodesk AutoCAD	AutoCAD was used to scale up the scanned plans, and to prepare for the importation to Revit
Autodesk Revit	Autodesk Revit is a building information modeling software for architects, landscape architects, structural engineers, MEP engineers, designers and contractors developed by Autodesk. In this work, the software was used to develop the architectural and MEP models for BIM
Dynamo	In this work it was used to create a script to automatically generate the as-built walls based on the imported plans

2.8 Creation of the BIM model

The BIM creation included 2 steps:

- Creation of the architectural model
- Creation of the different MEP systems

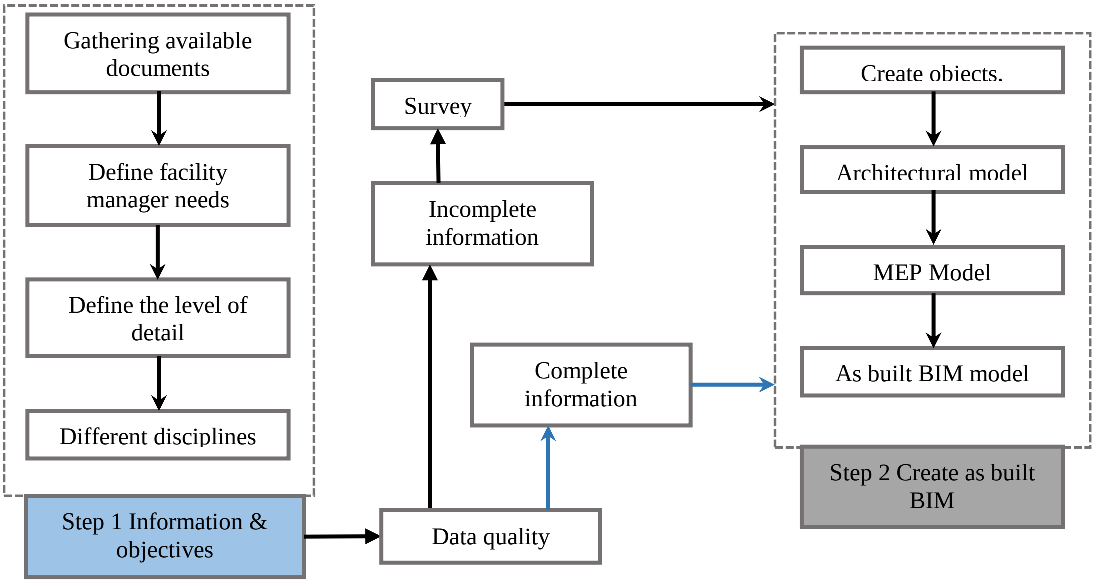


Figure 2.5 Work process of the BIM

2.8.1 Architectural model

It is imperative to create all the typologies of the components corresponding to the residence before proceeding with the import of the plans and the modeling of the project. Therefore, the data on the objects and composing of the building can be available during the modeling in Revit.

Creation of the component types concerned the creation of the model components, such as the type of walls including the different layer, material type and the joinery (type of windows and doors) as illustrated in Figure 2.6.

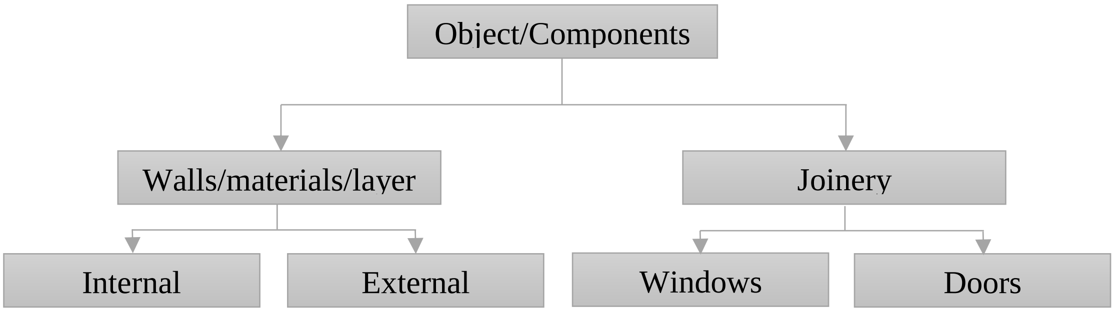
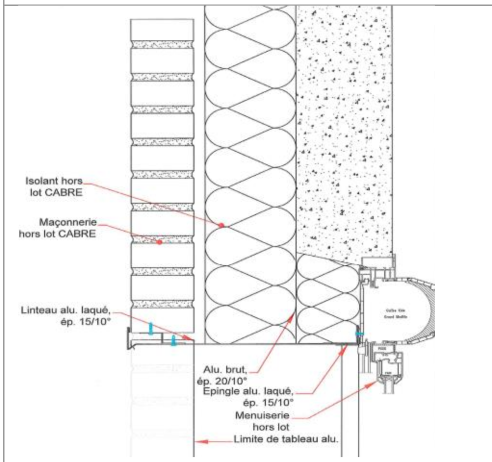
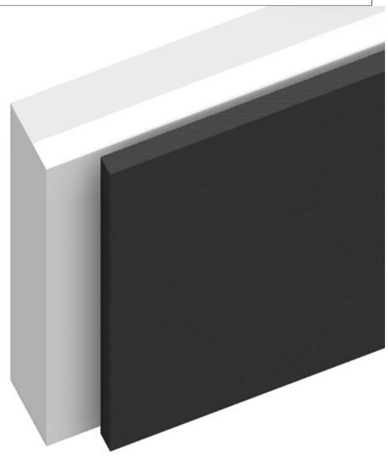
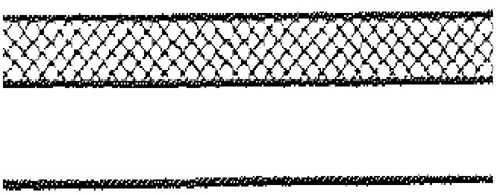
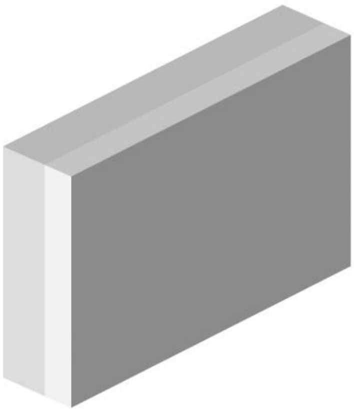


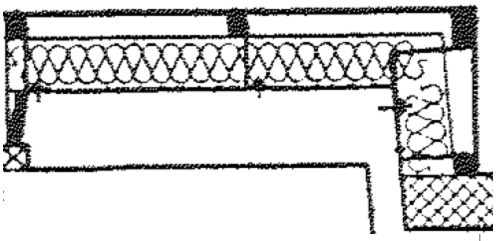
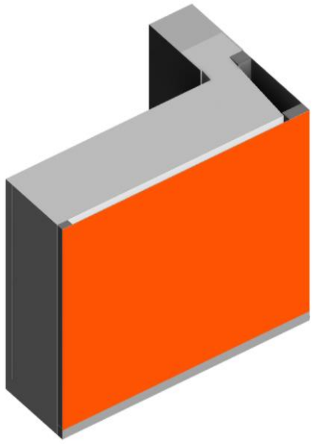
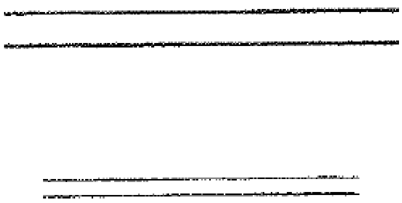
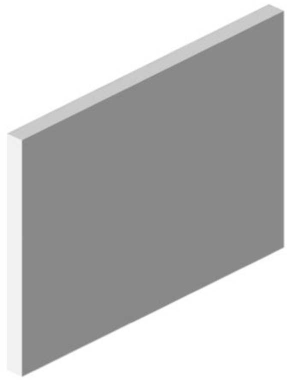
Figure 2.6 Type of components of the residence

2.8.1.1 Walls

Exterior walls were renovated in 2012. The documentation provided all the details concerning the composition of the walls including type of materials with their thicknesses and their cleanliness. There are three main categories of walls in the Tennis residence; the exterior wall of the ground level, the exterior walls of the other floors, and the interior walls. The external walls contain insulation of 160 mm made of Rockwool (λ = $0.036W/m^2K$) which gives a resistance of R = 4.44 $m^2.K/W$

Table 2.4 Wall categories created by Revit

2D drawings	BIM object
External wall Type 1	
	
Brick 0.11 Insulation, Rockwhool 0.16 Masonery 0.25	
External wall type 2	
	
Insulation, Rockwhool 0.16 Masonery 0.25	
External wall type 3	

	
Trespa panels Insulation, Rockwhool 0.16 Masonery 0.25	
Interior walls	
	
Masonery 0.16 0.06	

2.8.1.2 Joinery Doors, windows

Joinery were categorized according to the documentation and survey. The accuracy of these information is very important, because the data will be used during the operation and maintenance. In case of failure, the facility manager has access directly to the type and the dimensions of the concerned door or window. The residence uses two types of windows.

2.8.2 Process of modeling the residence

First, the plans of the residence were scanned and used as a background in the levels of Revit. Then a manual work was conducted to add the heights and construction details, such as stairs, entrance and the room of the boiler located on the terrace.
The software Revit was used to create the BIM model. Modeling started with the walls with the respect of the thickness and type of materials for both internal and external walls.

Then doors and windows models created with survey are positioned in their corresponding location.

Since the internal distribution of the apartments changes every three floors, a model was created for each category and then duplicated other floors. The creation of the architectural model included: (i) scaling of the plans with updating of the missing data made with the statement, (ii) plans were imported into the Revit software to serve as a support for the creation of the BIM model. Other information was introduced beforehand such as the ceiling height and the thickness of the floors.

This model is therefore based on the creation of a precise geometry of the building as it is constructed, and reproduces exactly the existing plans, for the current floors, the model of a floor is simply duplicated at the other levels when the plans are similar (Figure 2.8). The facade is also modeled with precision, using the types of wall created in the previous step, morphology, colors and materials are scrupulously respected.

The residence contains three typologies of apartment, whose surface varies between 58 m^2 and 110 m^2. All categories of these dwellings are created in the BIM model, with the numbering of the apartments of the residence, differentiated just by a letter A for the north part in nine floors and B for the southern part in quarter floors. In this way all equipment and installations and fixed furniture contained inside an apartment will be automatically identified in this dwelling. The housing identification will also be necessary for the housing instrumentation with sensors.

Figure 2.7 Architectural BIM model view in Enscape

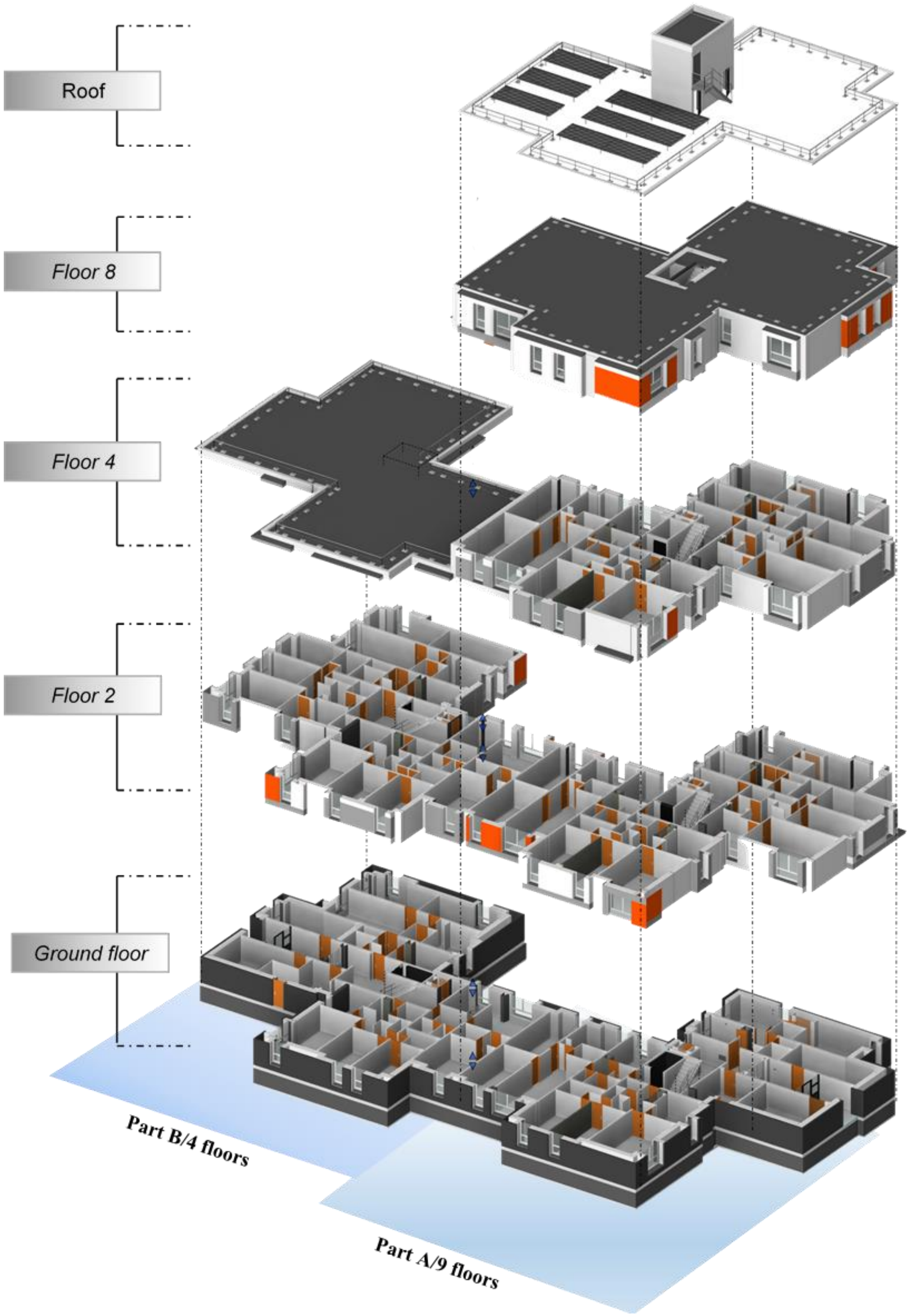


Figure 2.8 Architectural BIM model by levels

2.8.3 Mechanical, Electrical and Plumbing (MEP) Model

A MEP (Mechanical, Electrical and Plumbing) system includes HVAC, fire protection, electrical system and security. It plays a key role in social housing. Information concerning the exploitation and maintenance of the MEP systems comes from heterogeneous documents understructure copies and paper documents of hard copies.

The MEP system of residence Triolo concerned plumbing, ventilation, elevators, boiler, and fire protection system. The residence operator did not use any system of information management. The HVAC systems included technical documentation, such the type of extractors and plans of the system. This was not the case for the plumbing system.

The table 2.5 summarizes the different systems concerned by the modeling, methods used and the level of information.

Table 2.5 Components of the BIM model MEP systems

system	Method	Concerned components	Level of details/ information
Plumbing system	Survey	Hot water pipes Cold water pipes Waste water pipes Categories; washbasin, bathtub, faucet	Dimensions, diameter, materials, constructor
Ventilation system	Technical documents + Survey	Conducts Ventilation extractor Air vent	Dimensions, types, power, constructor
Fire protection	Survey	Fire extinguisher	Type, location
Smart sensors	Survey	Temperature Humidity Brightness Energy consumption; water, electricity	
Elevators	Survey	Mechanism	Type , location
Solar panels	survey	Panels	Type, location

2.8.3.1 Plumbing system

The plumbing system was entirely realized after the residence survey. More specifically, the identification was attributed to vertical and secondary pipes as well as the sanitation equipment and kitchen. Information was integrated in the BIM model.

Figure 2.9 View plumbing pipes inside an apartment

Survey was carried out on current floors to identify first the vertical pipes on the two parts of the building, then the distribution of the pipes inside the dwellings, by identifying the types of pipes and their diameters.

Also, a survey on the types of sanitary equipment to find their equivalent in BIM. This type of information is necessary for maintenance and management of the building. If we take the pipeline as an example, there are hundreds or more components logically linked with each other in a logical way. In case of water leak, upstream valve should be closed as soon as possible. Therefore, a clear picture showing logic chains liking proper building components should be generated and embodied in the as-built model for exploitation and maintenance staffs to conduct maintenance and emergency procedures.

There are ducts and risers in common areas and private areas, distributed to ensure distribution / evacuation in the most balanced way. Most vertical pipes are in common parts. Each riser of the hot and cold-water pipes leads to the common part of the floor. Boxes at each level host water meters.

Furthermore, models corresponding to water meters in BIM are used in the model. Parameters are created for each model BIM counter with identifiers concerning the apartment to facilitate the real-time monitoring with the BIM model.

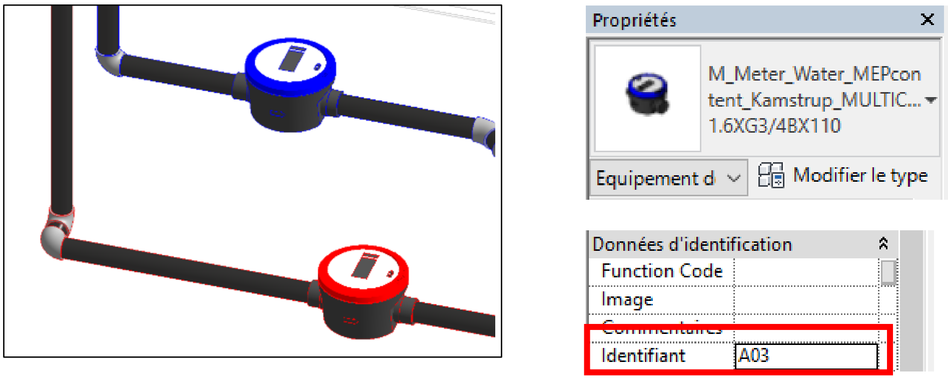


Figure 2.10 Models of water meters of the residence

2.8.3.2 Ventilation system

This system was introduced according to technical plans and operating manuals for the extractors, completed with a survey in the building. The ventilation system is composed of twelve ventilation galvanized steel, circular duct with diameters varying between 125 mm and 355 mm, whereas each duct deserves aligned vertical apartments.

The BIM model of the extractors was obtained from website of the constructor. It concerns an adjustable extraction group type (fan box) category 4 (according to fire regulations in the collective housing) low consumption type micro-watt (engine power consumed is as needed), mounted on anti-vibration pads having a filtering rate of at least 85% with continuous power supply (Figure 2.11).

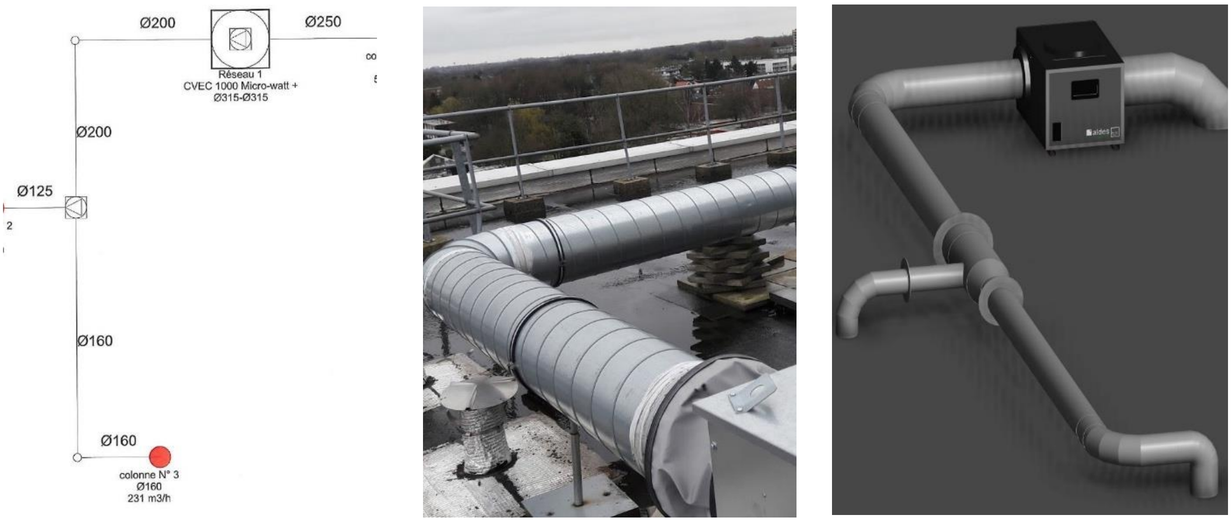


Figure 2.11 Partial view on ventilation system and its model in BIM

2.8.3.3 Fire protection system

Fire risk assessment system is important to prevent fires and ensure safety for people. This should be inspected and updated periodically. Prevention systems similar to gas safety, contractor management and hot work should be applied. Regular inspection & maintenance should be conducted for extinguishers and fire detectors.

The following elements were integrated in the BIM model: emergency exits, fire alarm and fire extinguishers (Figure 2.12).

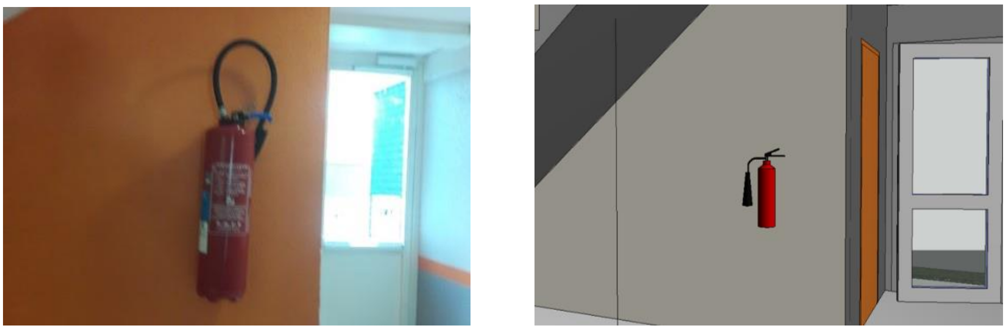


Figure 2.12 Fire extinguisher in the residence

2.8.3.4 Solar panels

Solar panels VITSOL 200-T are used for the supply of the hot water boiler. They are placed on the roof, each panel has these dimensions (2043mm height, 1418mm width, and 143mm depth). The solar productivity in the residence according to the design office is 554kWh / m^2.year. The corresponding BIM model was downloaded and integrated in the BIM model.

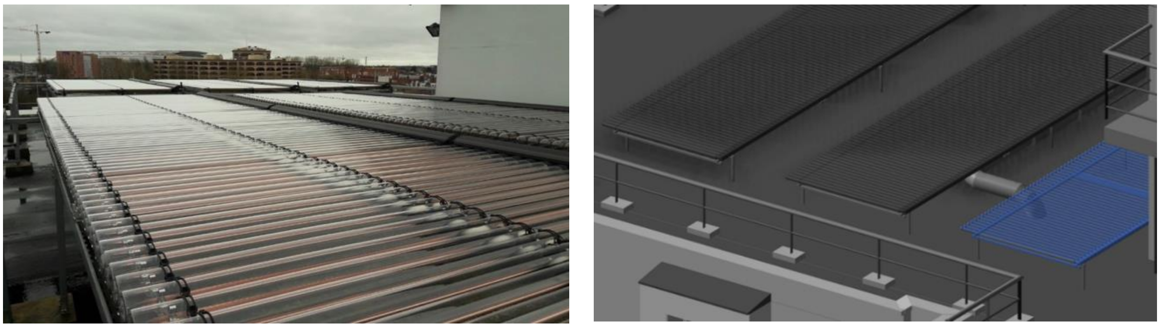


Figure 2.13 Solar panels model

2.8.3.5 Boiler room

The heating system includes a heating room was integrated in the BIM model for inspection and maintenance purposes.

2.8.4 Assembling disciplines models

The models of disciplines presented in the previous sections were assembled using Revit. It includes the architectural model, plumbing system, VMC system, fire protection system, elevators, solar panels and the boiler room. Figure 2.14 shows the incorporation of the different systems and equipment in the residence built BIM model.

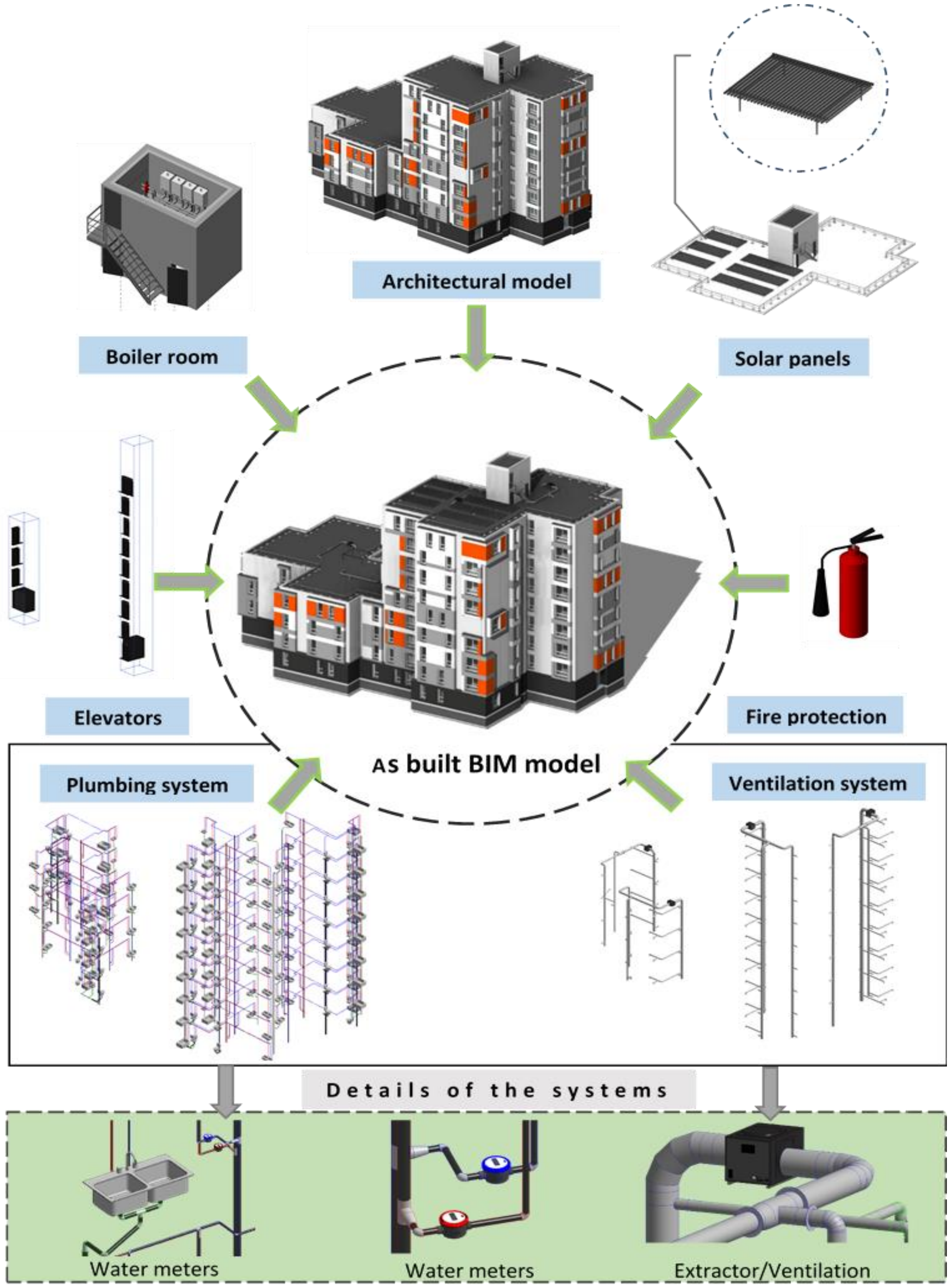


Figure 2.14 Gathering all the disciplines for the as built BIM model

2.9 Clash detection and validation of the model

BIM Clash detection designates automating collision found prior to construction issues. It is often used during the phase of design and preconstruction to avoid issues which could lead to difficulties. It could be used also in creating BIM model for an existing building to check the validity of the model through detection of clashes between the system components.

Two types of clashes are known in the BIM process. Soft clashes, which refer to objects that demand certain special or geometric tolerances or buffers having objects within their buffer zone for access, insulation, maintenance or safety. Hard clashes refer to objects occupying the same space. Clash detection can be realized using software such as Solibri Model checker, Tekla BIM sight. In this work we used Autodesk Navisworks.

The first step included exporting from Revit to Navisworks the architectural model, plumbing system and ventilation system. The value of the tolerance used is 0.0 to detect only hard clashes. A clash detection was then carried to find the collision between the plumbing and ventilation system (figure 2.15).

The clash detection gave 69 clashes, which concern mainly collisions between the pipes of water of the plumbing system and the ventilation ducts, the results are shown in Figure 2.16.

The clash detection shows that there are errors in the modeling. After checking the different clashes reported on the model, we see that each error is reproduced on each floor, as it is the same plane that is repetitive in several floors, so running a clash detection scan or report will typically bring many duplicated instances of the same issue. So there are in all about ten different errors, if we take into account the number of floors, a single run of pipework clashes with eight beams, it will show eight clashes.

Collisions were rectified in Revit.

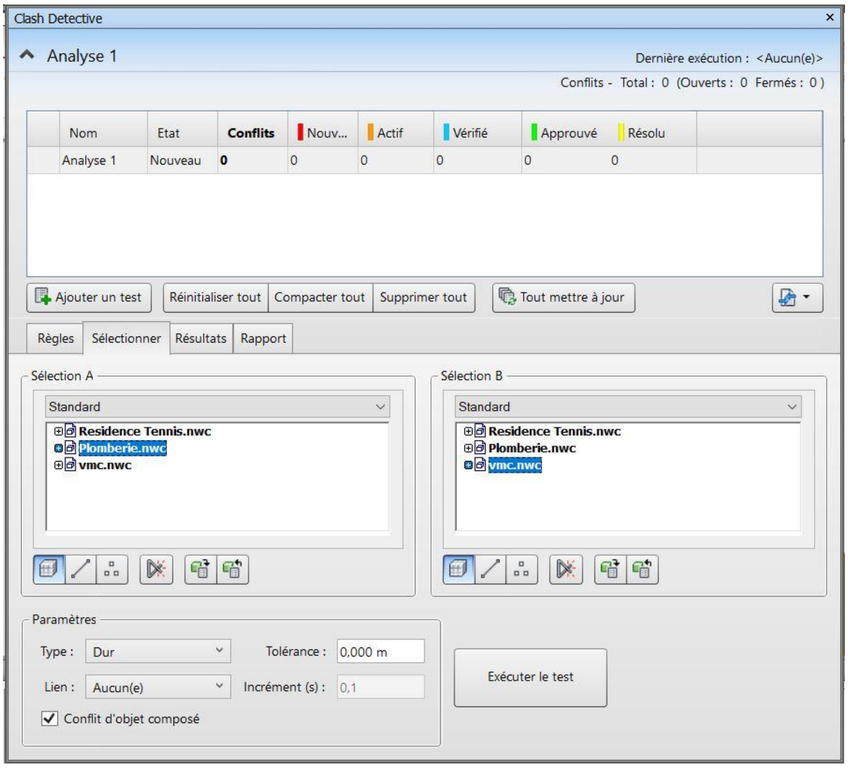


Figure 2.15 Systems used for the clash detection and initial parameters

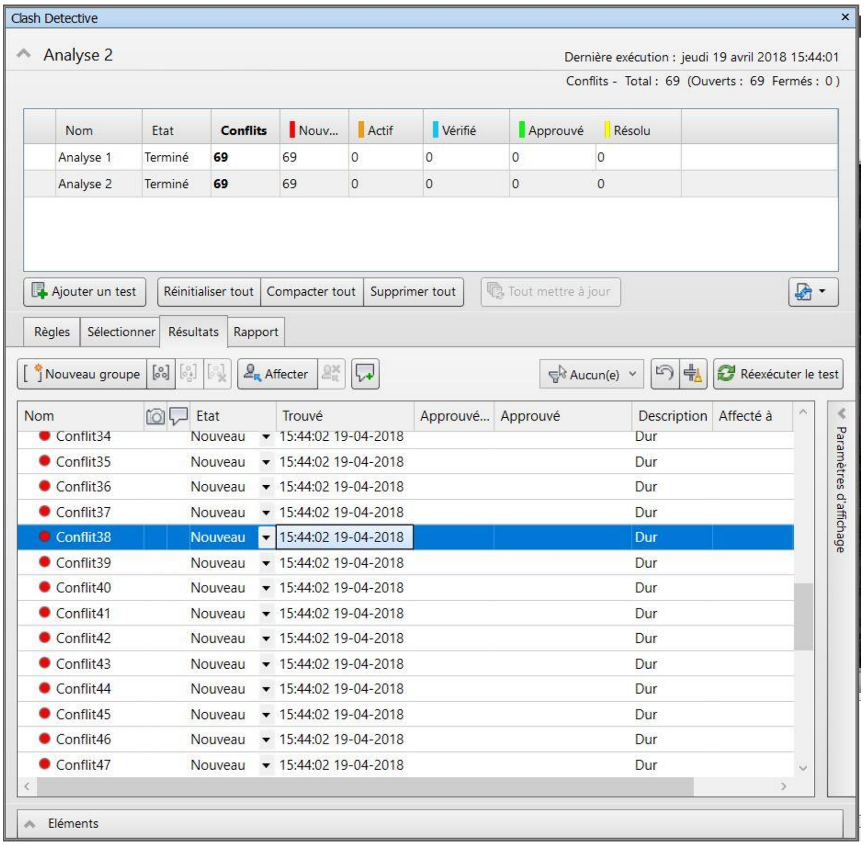


Figure 2.16 Result of the clash detection plumbing vs ventilation system

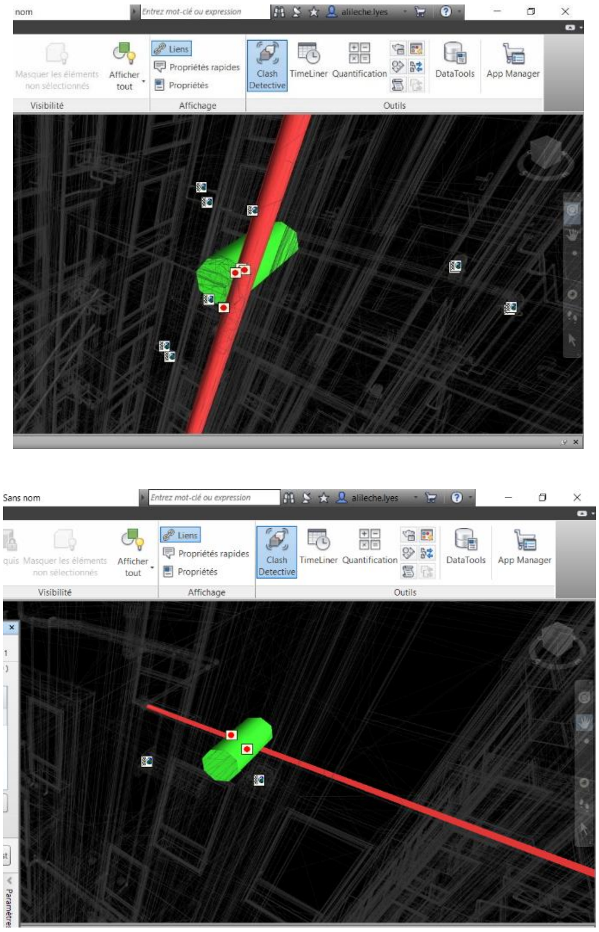


Figure 2.17 View of clash detection results

2.10 Limitation and Barriers

This case study revealed the following limitations:

1) The architectural model constructed manually using plans and survey can be limited in some situations; some details could be forgotten. Some detail were not accessible, such as the layers of the roof with the material used for the slops and insulation.

2) Impossibility of modeling MEP system perfectly, because the system is very complex and contains a lot of small components, which can sometimes be inaccessible for the survey.

3) The balance between the level of detail of the geometry and information for the creation of the as-built BIM model is not clearly defined.

2.11 Conclusion

The BIM model for facility management allows an efficient integration of available data in a system that could be easily used, shared and updated. The construction of this model for an existing building is laborious, because of lack and absence of data and the necessity to conduct important survey work. However, this construction presents important advantages in facility management. This chapter presented the methodology followed for the construction of as built BIM model for an existing social housing residence. Thanks to this work, the final as-built BIM model is obtained, including the architectural model, plumbing system, VMC system, fire protection system, elevators, solar panels and the boiler room.

In the following chapters we will present the use of this model in building management.

Chapter 3: Use of BIM for facility management optimization

This chapter concerns the use of BIM to optimize facilities management, as well as building maintenance using the model created in the previous chapter. It presents how BIM could be used as a platform for supplementing FM practices. It presents first the model of the residence and then the organization of the BIM data in the operation phase including space management as well as conventional and preventive maintenances. It shows the high advantage of combination of BIM database with historical data of maintenance and the visualization of maintenance activities in social housing buildings.

3.1 Introduction

In the park of social housing residences, most of maintenance activities are corrective. This practice is not effective, because its cost can reach up to three or four times preventive maintenance. Therefore, it is necessary to implement planned preventive or predictive maintenance. This work discusses the use of BIM for building exploitation and maintenance. It includes three sections.

The first section presents BIM based FM workflow and the handover to the facility management platform.

The second section concerns the organization of the FM information based on the BIM model, including the social housing sector, space management and planning effective maintenance activities. The objective is to reduce the reactive maintenance using BIM to support advanced visualization as well as analysis of maintenance activities.

The third section concerns the use of BIM database of the asbuilt residence and the exploitation data for maintenance optimization.

3.2 BIM based facility management workflow

This research concerns the use of BIM to improve buildings management, with a particular focus on:

- Space management
- Facilities maintenance
- Effective energy use
- Optimized and economic renovation
- Life cycle management

Figure 3.1 summarizes the workflow of lifecycle management based on BIM. Details about each phase are given below.

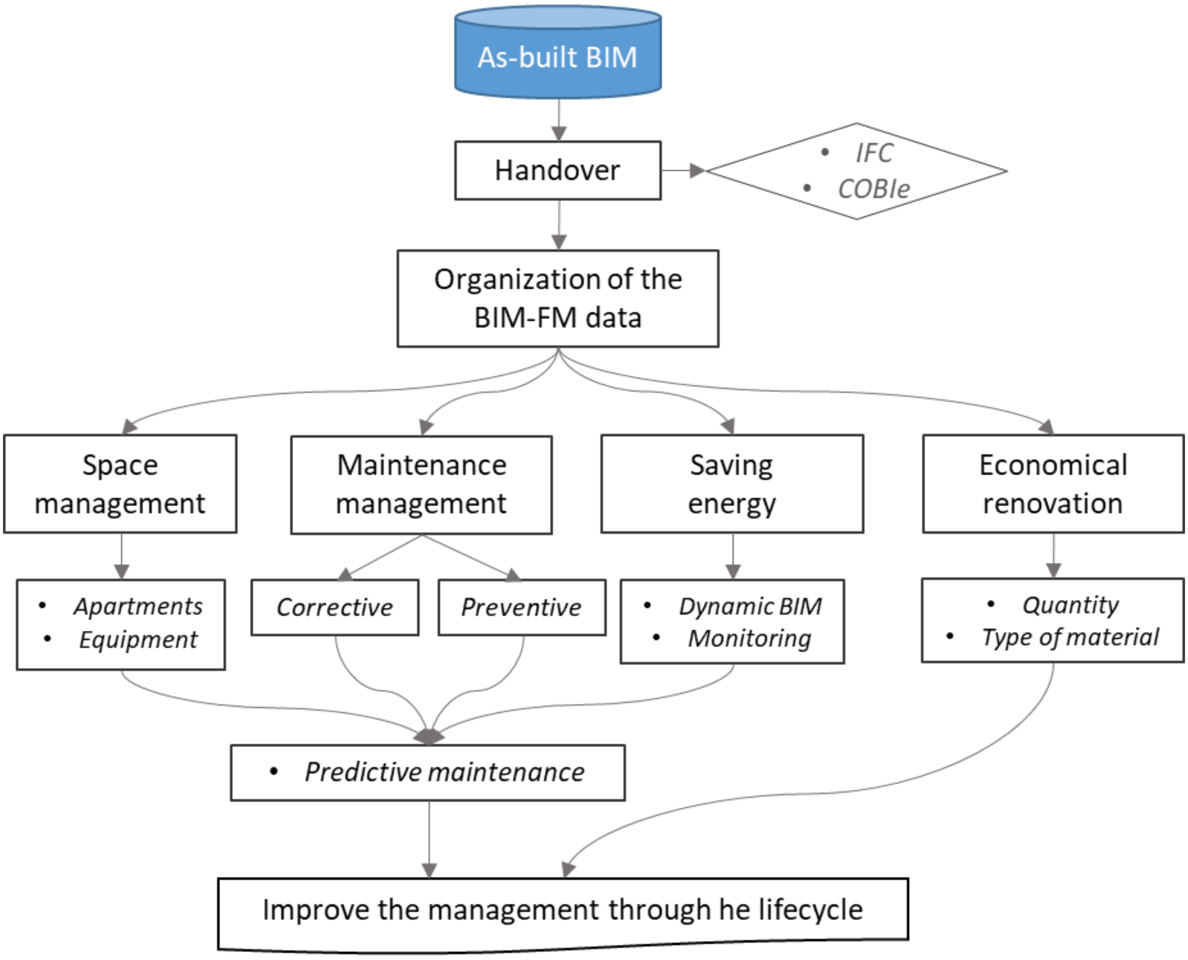


Figure 3.1 Proposed workflow of FM based on BIM

3.3 Integration of as built BIM to FM platform

In order to build the BIM model of existing buildings, data and documentations are required from the owner, managers and other parties concerned by the building. It requires connection of BIM software to facility management software.

In order to use the BIM model of the Tennis residence created using Revit, it is necessary to transfer this model to management software. The Ecodomus solution was adopted for this issue. The main advantage of this solution concerns the capacity to integrate in the BIM model systems used for building management, such as building automation system (BAS), computerized maintenance management system (CMMS), computer aided facility management (CAFM), and geographic information system (GIS).

Ecodomus PM ("Project Management") software solution is dedicated to use BIM and Lean processes to manage data concerning the construction and renovation as well as other available data. Ecodomus is a cloud-based solution, which offers the possibility to access the model from anywhere with an internet connection. It allows to edit the COBie (Construction Operations Building Information Exchange) data in a collaborative mode environment.

3.3.1 Challenges of the handover to FM platform

Limited empirical research has been conducted to determine how BIM FM can be developed in the later stages of the building life cycle, just after implementation in the operation phase. This section shows the development of BIM FM in a pilot project concerning an existing social housing residence.

3.3.2 Test with COBie format

COBie is an exchange format, based on IFC definitions, which focuses on the transmission of mostly non-graphic building information. It is used at well-defined stages of design as well as for handing the book as built to the customer. It contains necessary information for using and maintaining the book. COBie, which can be compared to a giant Excel sheet, can be shared in Excel and XML formats.

The only outstanding issue was used to the COBie toolbox to automate BIM data exchange to the computerized maintenance management system Ecodomus. The original plan was to export the COBie spreadsheet from the Revit model as built with the COBie extension, and then import the COBie spreadsheet into the Ecodomus system, but the errors automatically interrupted the import process (Figure 3.2).

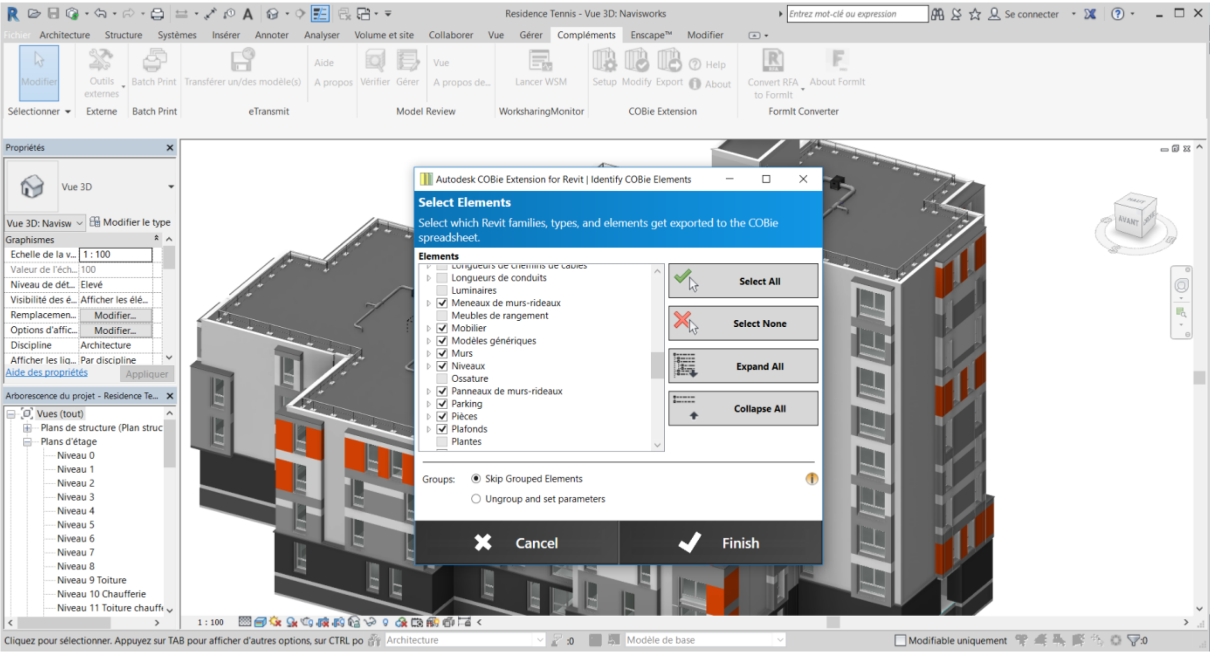


Figure 3.2. COBie export of the residence in Revit

If the data format imported from the COBie spreadsheet is not 100% compliant with the Ecodomus system, the import will be automatically stopped. Even if, theoretically, the data format exported by COBie Extension for Revit was COBie 2.4, Ecodomus system being respected, it is confronted with errors during the attempt of importation. Some of the errors were caused by an "invalid value for some attribute" in the COBie spreadsheet.

The interoperability problem has delayed the transfer of FM information into the Ecodomus platform. We therefore believe that in order to avoid these problems of interoperability and data transfer, it is necessary to first determine the data format requirements of the installations and the computer support of the CMMS.

This process, however, involved additional work and a manual process which took a relatively longer time because only a small amount of data could be imported at one time and some extra data had to be deleted.

The COBie format therefore allows us to export the data of the residence with the information selected for the technical management of the building in excel spreadsheets. This data can be easily utilized by the facility management services. Nevertheless, this format is completely detached from the graphic and visualization side of the BIM which considerably reduces its efficiency. So we think that this method should be used for specific and punctual data, not for the overall management of the building. Also standards for data exchange still need to be developed. IFC and COBie, two OpenBIM formats, could offer a solution.

3.3.3 Exportation to Ecodomus

Ecodomus PM provides a unique way to extract and edit COBie data from Autodesk Revit and other BIM tools, and re-insert data into the model. It integrates quality control reports to analyze and improve the quality of BIM data. The transfer of the model is conducted through a plugin allowing the use of Revit file in its native format (Figure 3.3). It greatly reduces the loss of information via software. Since both Revit and Ecodomus are based on databases, it is essential to provide accurate table and parameter matching to ensure bidirectional communication.

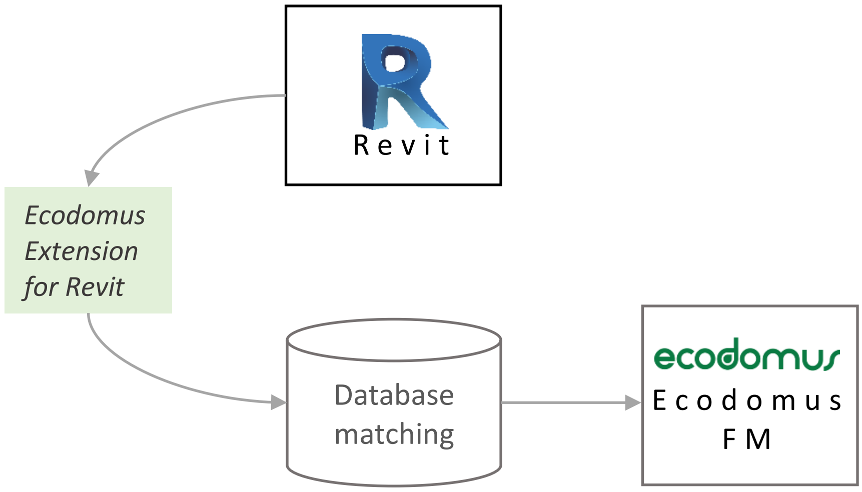


Figure 3.3. Revit Ecodomus interoperability process

3.4 Space management

The space management is an important task in buildings management in the operation phase. The digital model is primarily an information system, for which it is necessary to structure the data to get the most benefit from it. For the Tennis residence, we proposed a specific method to meet the needs of social housing managers. We have to prioritize the

space and create links between the objects and space. Each equipment should have an identifier.
The space management is organized in five categories (Figure 3.4): (1) Space, (2) room, (3) identification (4) attributes and (5) the list of equipment contained in each space.

The category space includes three types: apartments, common spaces and technical area. A precise knowledge of managed spaces is essential for FM, BIM to facilitate this in the sense that it provides an assembly of spatial and geometric information with the 3D model. The residence includes 50 dwellings. Each dwelling includes rooms with a relative identifier on the floor and the side of the building (A or B). To have a good configuration of the BIM model, additional parameters are necessary to characterize the residence spaces. The apartment is categorized by the following attributes: surface, volume, type (type 2, type 3, etc.).

The object identifier is important for managers since it allows the identification of the concerned equipment, as well as their status and needs.

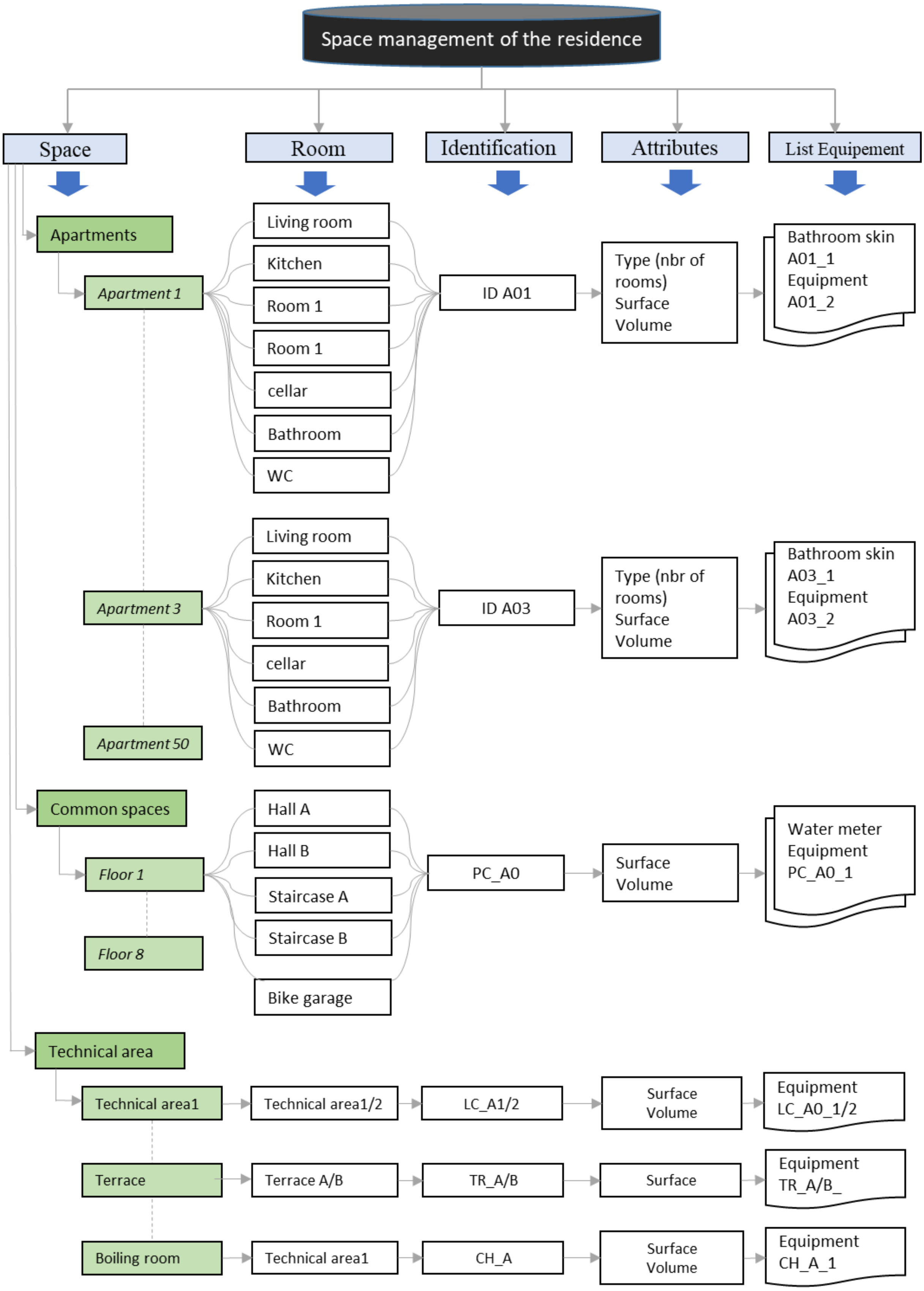


Figure 3.4 Proposed space management of the residence

The database can be enhanced with other parameters such as the space use. Table 3.1 summarizes the parameters used for the dwellings.

Table 3.1 Shared parameters

Parameter	Type
ID	Text
Type	Text
Surface	Number
Occupation	yes/no
Tenant	Text

This information can be visualized using dynamic floor with different colors according to the parameter selected. BIM provides an effective support to highlight the sate of a parameter in the residence.

Figures 3.5 to 3.7 illustrate three types of visualization: apartment's occupation, ID and type of apartment.

The BIM database is extensible; other shared parameters can be added for rental management and maintenance.

This database can be exploited also for the management of spaces in the form of tables, and exported to answer to specific needs.

Figure 3.5. Visualization of apartment occupation

Figure 3.6. Visualization of apartment ID

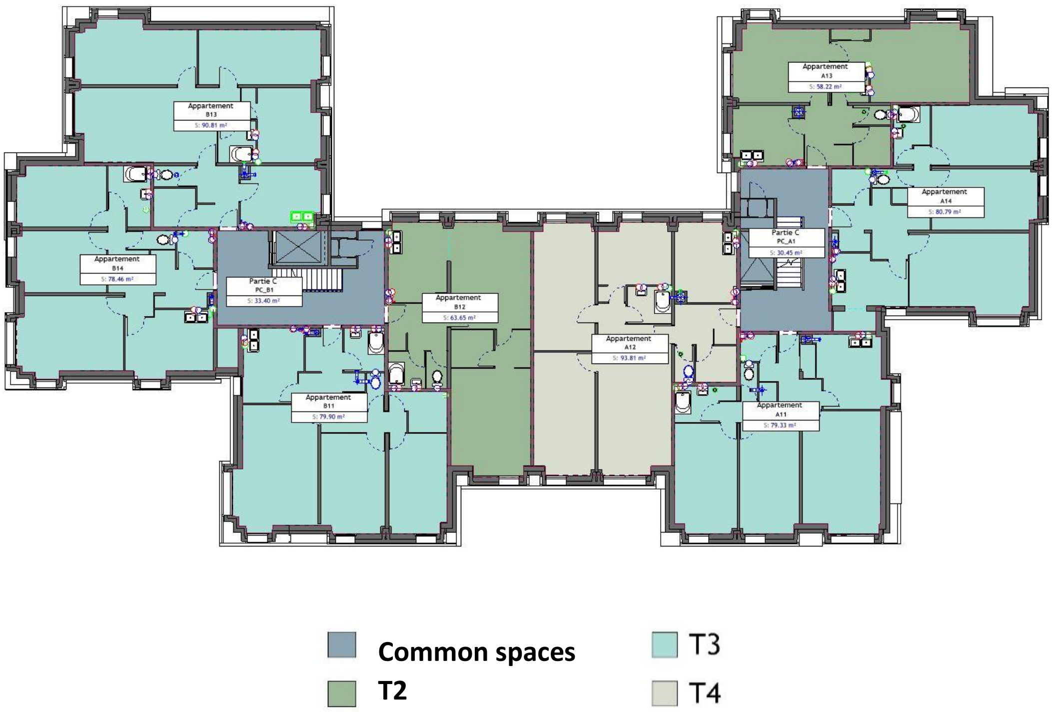


Figure 3.7 Visualization of apartment type

Table 3.2 displays a Revit schedule of the spaces that includes the apartments, common spaces and technical areas for the levels 0 and 1. It contains predefined parameters such as levels and area, as well as additional parameters (shared parameters) created for the management purposes: apartment IDs or apartment numbers, the type of apartments, as well as the column occupation which allow to know directly whether the apartment is occupied or not.

Table 3.2 Schedule of apartments of the residence on floor 0 and floor 1

<Nomenclature des surfaces (Appartement)>				
A	B	C	D	E
ID_logement	Niveau	Type de logement	Surface	Location
LC_A0	Niveau 0	Local technique	38.46 m²	☑
A01	Niveau 0	T3	78.37 m²	☑
A02	Niveau 0	T3	105.56 m²	☑
B02	Niveau 0	T2	67.82 m²	☑
B01	Niveau 0	T3	80.64 m²	☑
LC_B0	Niveau 0	Local technique	37.72 m²	☑
B03	Niveau 0	T3	90.93 m²	☑
PC_B0	Niveau 0	Partie commune	55.78 m²	☑
PC_A0	Niveau 0	Partie commune	53.94 m²	☑
A03	Niveau 0	T2	57.69 m²	☑
LC_BO	Niveau 0	Local technique	17.87 m²	☑
LC_A0	Niveau 0	Local technique	17.48 m²	☑
A13	Niveau 1	T2	58.22 m²	☑
A14	Niveau 1	T3	80.79 m²	☑
A11	Niveau 1	T3	79.33 m²	☑
A12	Niveau 1	T4	93.81 m²	☑
B12	Niveau 1	T2	63.65 m²	☑
B11	Niveau 1	T3	79.90 m²	☑
B13	Niveau 1	T4	90.81 m²	☑
B14	Niveau 1	T3	78.46 m²	☑
PC_A1	Niveau 1	Partie commune	30.45 m²	☑
PC_B1	Niveau 1	Partie commune	33.40 m²	☑

3.5 Use of BIM for maintenance

Effective maintenance requires information concerning the design and construction stages as well as the exploitation phase.

For preventive maintenance, it is essential to collect necessary information according to steps depicted in Figure 3.8. It concerns maintenance manuals, technical documents and warranties, which should be attached to corresponding equipment. It concerns also historical data of the residence, such as thermal camera scans. For preventive maintenance, a maintenance schedule should be added for each equipment.

The BIM based management process implemented in this residence uses a global information system, which includes two types of information: (i) static data obtained from the Revit project about the building, manuals and the technical documents and (ii) maintenance data provide by the building operator.

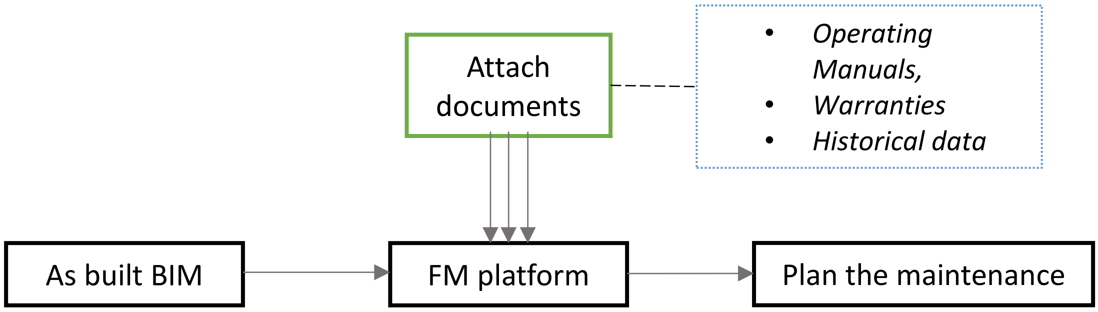


Figure 3.8. Workflow of BIM based maintenance

3.5.1Maintenance documents integration

Documents provided by the social housing manager and maintenance operators are stored in PDF format with specifications concerning the equipment and document type. Four documents types are used:

- Maintenance manuals (extractors, boiler room, etc.)
- Descriptive technical documents
- Guarantees
- Other documents such as thermal camera output (Fig 3.9).

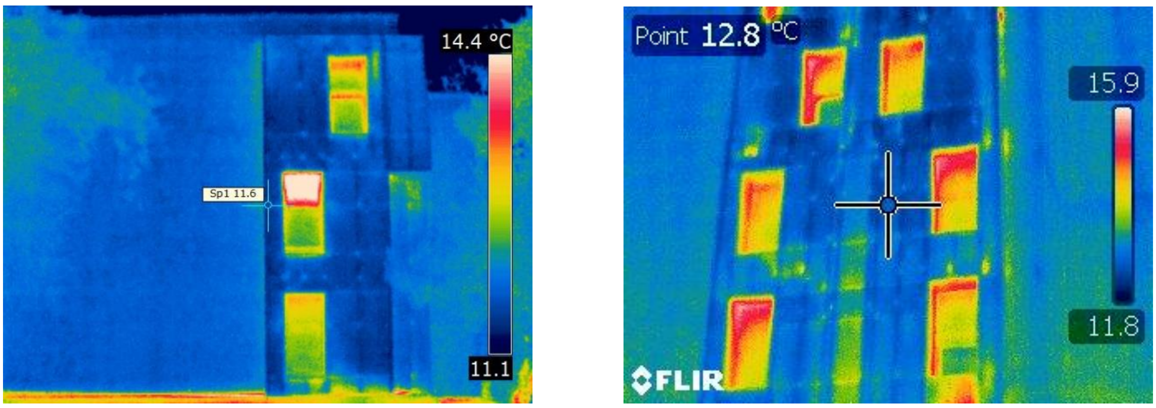


Figure 3.9. Photos of facades of the residence with thermal camera

Figure 3.10 provides the 3D visualization of the final as-built BIM model of the Tennis residence containing both of architecture data and MEP systems. It shows the ventilation extractor with information concerning the maintenance and warranty.

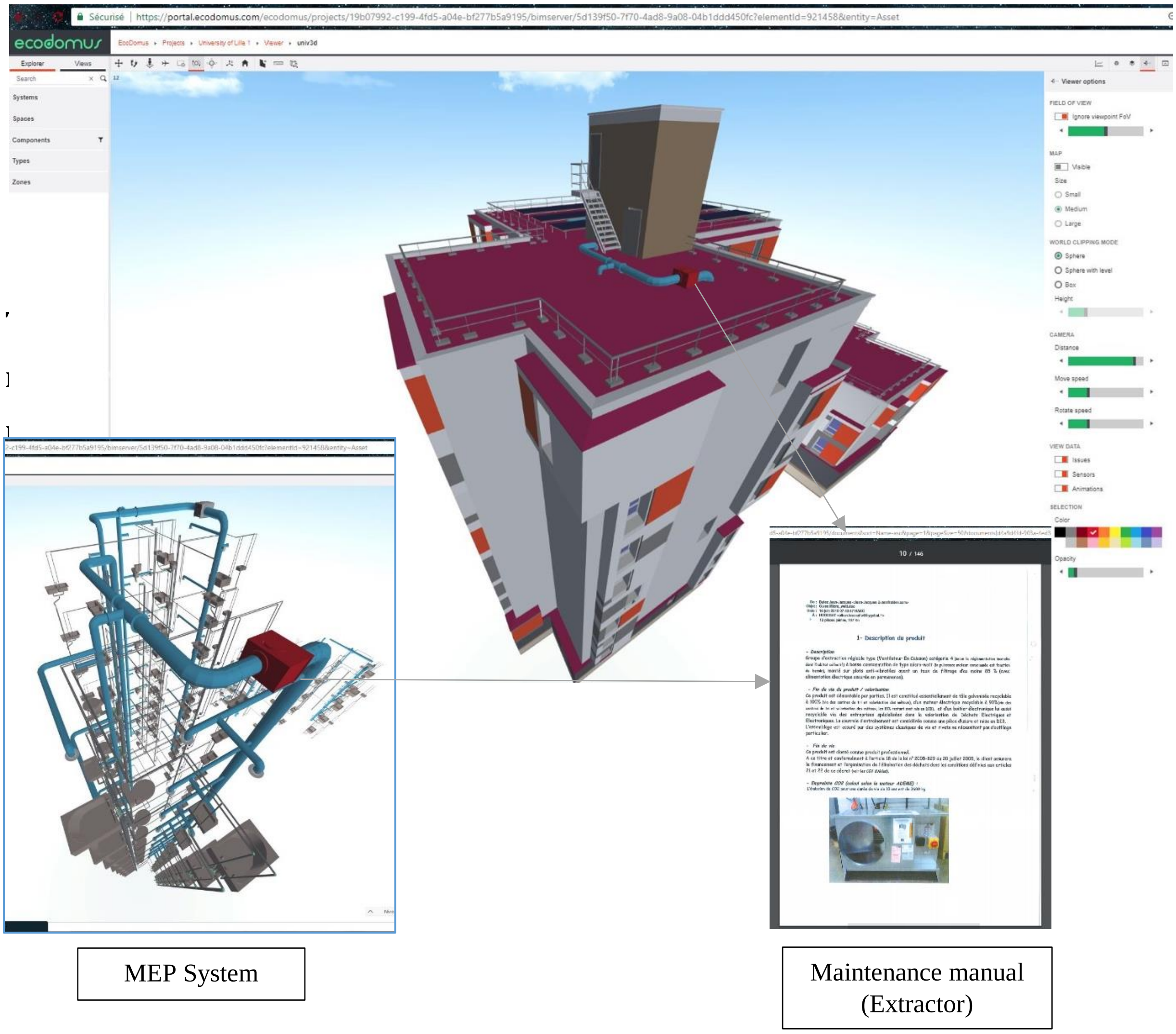


Figure 3.10. BIM model for the building management - Ecodomus

3.5.2 Approach for BIM based maintenance

Different systems such as, the management Computer Assisted Maintenance Management (CMMS), Technical Building Management (GTB) and Technical and Heritage Information System (SITP) already exist.

The method used for the construction of BIM maintenance model is presented in Figure 3.11. It includes a combination of BIM and maintenance information with the objective to optimize corrective maintenance as well as to develop preventive maintenance strategy using a 3D dynamic visualization. The corrective maintenance is performed when a deficiency is fixed by sensors, technical staff or users. The facility manager sets up the preventive maintenance process in the digital model. Maintenance information are recorded as historical data (date, description, location, type of intervention, etc). The visualization of the equipment state using colors allows to rapidly fix the maintenance requirements.

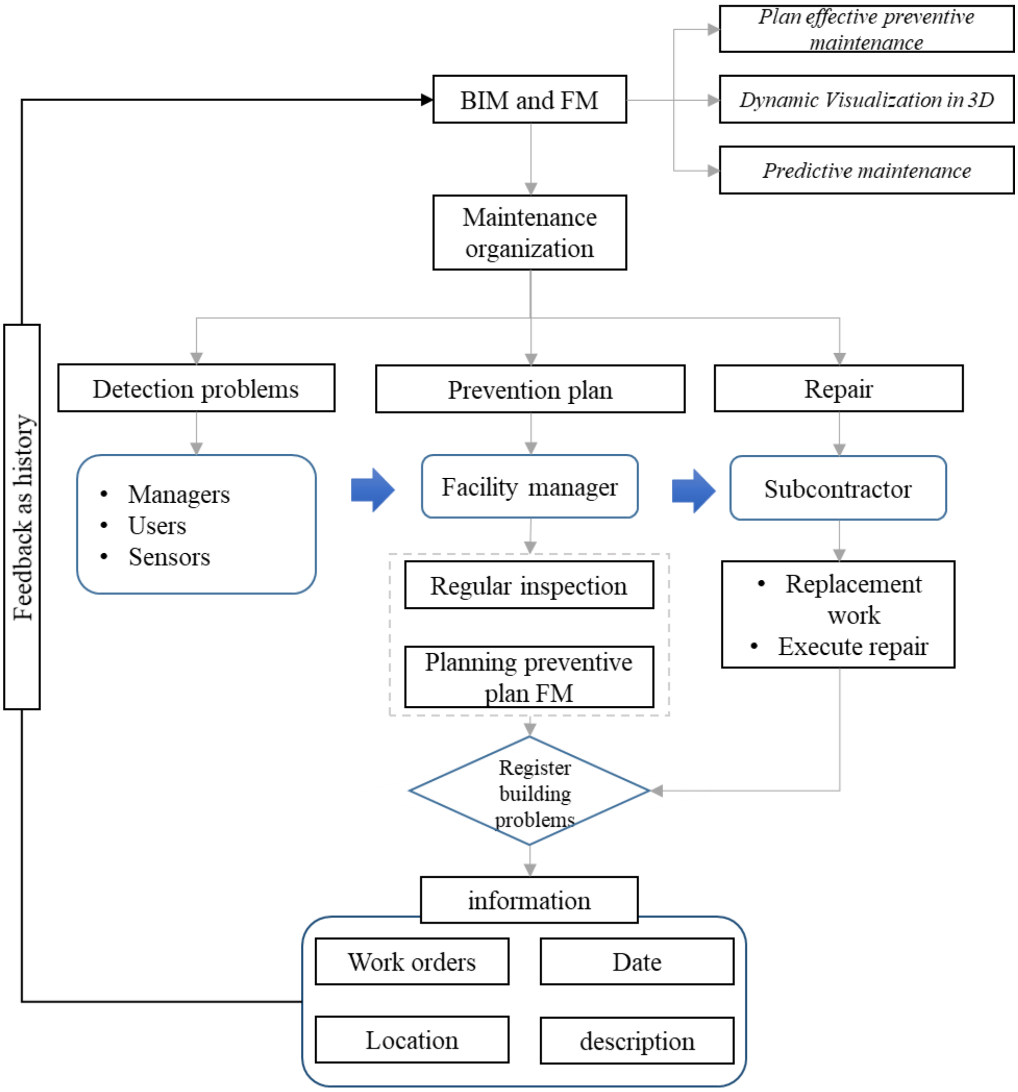


Figure 3.11. Proposed approach for BIM based maintenance

3.6 Categorization of maintenance activities

Regular equipment monitoring should be implemented at adapted time-intervals. In the following, we present the maintenance monitoring strategy.

3.6.1 Low regular monitoring components

The following components require long time interval maintenance:

- **Roof:** its maintenance consists in drains cleaning the cracks repairing.
- **Windows and doors:** damage repair, wood paint.
- **Exterior walls:** repair of mortar between bricks, coatings.

3.6.2 High regular monitoring components

Systems such as elevators, heating and ventilation require regular maintenance. To organize this maintenance, it is necessary to analyze and record the most performed tasks in the maintenance history and also the maintenance requirements in the equipment manuals.

3.7 Boiler room and fire protection maintenance

The boiler room is used to illustrate the proposed methodology.

Information contained in each device is divided into (Table 3.3):

- Geometrical information and the attributes
- Additional information concerning the equipment
- Maintenance information

Table 3.3 table of maintenance information

Model parameters	**Supplementary information**
Geometric data	Identification
Size (length, width, height)	Equipment ID
Material	Category
Elevation	Location (common space Apartment, Floor)
Colors	
Pictures	

Attributes/ equipment detail	**Linked information**
Equipment number	Warranty
Manufacturing company	Assembly process
Price	Operating manual
Purchase date	2D CAD
Installation date	PDF/ schema
Responsible unit/ person	Equipment performance
Equipment specifications	table
Equipment type	Manufacturer information
Equipment functions	Maintenance manual
Equipment units	
Equipment professional information	

In order to store the maintenance historical data of the boiling room, 13 parameters are used. Table 3.4 summarizes these parameters.

Table 3.4. Boiler maintenance parameters

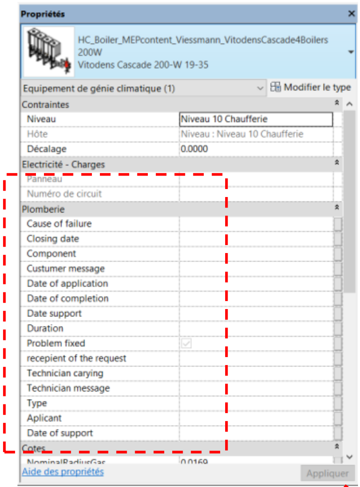
Maintenance parameter	Detail
Date of application	*Date*
Applicant,	*User or technician*
Message,	*Customer or user*
Problem fixed	*if the problem is fixed or not, yes/no*
Duration	*Time*
Recipient of the request	*Name*
Date of support	*Date*
Technician carrying	*Name*
Date of completion	*Date*
Cause of failure	*The detected cause*
Component	*The exact component concerned*
Technician message	*Short description of the repair*
Closing date	*Date*

A maintenance table is created for maintenance management. Table 3.5 shows an example with data provided by the subcontractor. Names are deleted for confidentiality reasons. The information is organized via "Create Table" and can be checked / entered / modified in the Revit program as well as in other FM solutions. This maintenance information is related to the object or equipment concerned with its geometry and attributes. This can be extracted to Microsoft Excel through the function "Export table".

Table 3.5. Table of maintenance data of the boiling room

<Boiling room Maintenance data>

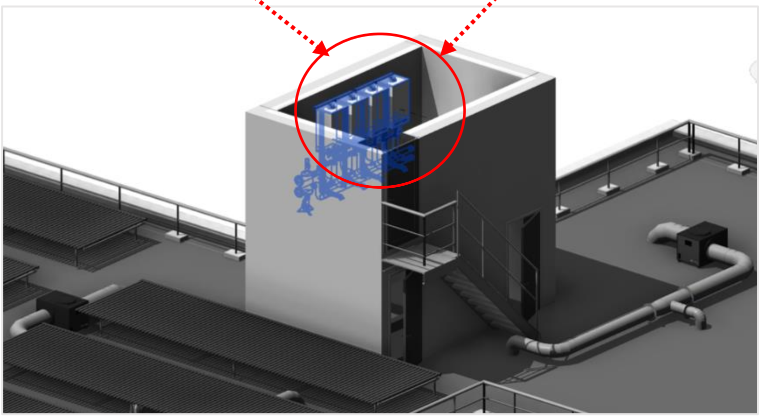
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Nom	ID_logement	Date of application	Applicant	Custumer message	Problem	Duration	Date of support	recepient of the requ	Technician c	Date of completion	Cause of failure	Component	Technician message	Closing date
Chaufferie	CH10		User	By this, I ask the shutd	☑		05/22/2017 4:33 p.	Contact M De TRAIN	Name				customer absent	22/05/2017 16:17
Chaufferie	CH10	05.04.2017 9:55	Manager	PRESSURE NO COLD	☑		05.04.2017 9:07	Contact M De TRAIN	Name		Other	Other	customer absent	05/04/2017 9:04
Chaufferie	CH10	05/12/2017 4:33 p.	Subcontractor	V. D'ASCQ - TRIOLO 5	☐	02h-41mn	05/02/2017 11:12	Contact M De TRAIN	Name		Lack of water or drai	Ball, DHW	Water shortage	05/02/2017 10:47
Chaufferie	CH10	01/05/2017 5:25 p.	Subcontractor	DECS NOT FAULT GE	☑	46mn	01/05/2017 2:15 p.	Contact M De TRAIN	Name	01/05/2017 2:43 p.	electrical malfunctio	Regulation servomo	Actuator 3WV always alimenté	05/01/2017 10:39:
Chaufferie	CH10	30/04/2017 12:54	Manager	The ECS IS BOILING.	☑		30/04/2017 11:11	Contact M De TRAIN	Name	30/04/2017 11:34:0	electrical malfunctio	Regulation servomo	Observed engine 3WV ECS ex	28.04.2017 8:32
Chaufferie	CH10	05/09/2017 3:08 p.	User	1 and 3 went tennis NO	☑	02h-55mn	28.04.2017 8:47	Contact M De TRAIN	Name		Setting-Regulation	Ball, DHW	Observed engine 3WV ECS ex	04/19/2017 5:09 p.
Chaufferie	CH10	26/04/2017 11:08	User	prevent disconnection of	☑		04/25/2017 4:57 p.	Contact M De TRAIN	Name	04/25/2017 5:07 p.	Setting-Regulation	Other	Fault burner	04/16/2017 7:35 p.
Chaufferie	CH10	04/21/2017 4:47 p.	Subcontractor	Failure ECS collectively	☑	00	20.04.2017 9:14	Contact M De TRAIN	Name		Ignition / stop	Ball, DHW	General cut cold water and DH	04/16/2017 7:27 p.
Chaufferie	CH10	04/16/2017 9:19 p.	Subcontractor	1allée tennis: no more c	☑	39mn	04/16/2017 8:15 p.	Contact M De TRAIN	Name	04/16/2017 8:38 p.	hydraulic malfunctio	Ball, DHW	Default secondary pump and v	16/01/2017 11:14
Chaufferie	CH10	04/16/2017 9:19 p.	Manager	building 6 trudaine Stree	☑		04/16/2017 7:28 p.	Contact M De TRAIN	Name	04/16/2017 8:38 p.	hydraulic malfunctio	Ball, DHW	Default secondary pump and v	01/11/2017 3:41 p.
Chaufferie	CH10	17/01/2017 10:18	Manager	NOT BY ECS intermitte	☑	01mn	16/01/2017 11:21	Contact M De TRAIN	Name		hydraulic malfunctio	Radiators, radiator	hydraulic problem column	06/01/2017 12:59
Chaufferie	CH10	01/11/2017 5:54 p.	Manager	ALLEY OF TENNIS EC	☑	01h-30mn	01/11/2017 3:46 p.	Contact M De TRAIN	Name	01/11/2017 3:56 p.	hydraulic malfunctio	Ball, DHW	Purge	01/05/2017 1:16 p.
Chaufferie	CH10	07.01.2017 7:37	Manager	leak on the thermostatic	☑		01/06/2017 2:22 p.	Contact M De TRAIN	Name	01/06/2017 3:30 p.	Lack of water or drai	Ball, DHW	Bleeding bouglage circuit DHW	12/22/2016 10:06
Chaufferie	CH10	01/05/2017 4:28 p.	Manager	Kitchen radiator valve do	☑				Name					12/14/2016 11:09
Chaufferie	CH10	12/27/2016 11:19	Manager	RADIATOR COOLING I	☑		12/22/2016 1:56 p.	Contact M De TRAIN	Name		hydraulic malfunctio	Fittings, piping	Radiator valve blocked	14.12.2016 7:12
Chaufferie	CH10	12/19/2016 7:42 p.	Subcontractor	gnérale failure DHW and	☑	05h-57mn	12/15/2016 11:44	Contact M De TRAIN	Name		hydraulic malfunctio	Radiators, radiator	farm setting T	14/11/2016 12:48
Chaufferie	CH10	12/14/2016 3:10 p.	User	NO ECS OR HEATING	☑	00mn	14.12.2016 7:13	Contact M De TRAIN	Name	14.12.2016 9:12	Lack of water or drai	Fittings, piping	Lack of water because of leaka	31/10/2016 9:44
Chaufferie	CH10	11/14/2016 2:08 p.	Manager	PROGRAMMING HEAT	☑		11/14/2016 2:08 p.	Contact M De TRAIN	Name	14/11/2016 12:48	Requests that do no	Other	DIRECT CALL TENANT	10.09.2016 8:48
Chaufferie	CH10	31/10/2016 4:19 p.	Manager	blackout ECS General	☑	00mn	31/10/2016 10:14	Contact M De TRAIN	Name		Other	Boiler	Control regulation	10/08/2016 11:11
Chaufferie	CH10	10/10/2016 12:56	Subcontractor	MORE ECS AND WHE	☑	59mn	09/10/2016 10:01 p.	Contact M De TRAIN	Name	10/10/2016 12:54	already performed In	exchanger		10.07.2016 8:20
Chaufferie	CH10		User	Hereby, I ask you LMH	☑	01h-00mn	10/08/2016 11:38	Contact M De TRAIN	Name	08/10/2016 1:31 p.	Lack of water or drai	exchanger	Tapering exchanger. Make-up	10/08/2016 11:34
Chaufferie	CH10	07/10/2016 1:51 p.	User	MORE PRESSURE IRR	☑		10/07/2016 10:41	Contact M De TRAIN	Name	10/07/2016 12:50	Ignition / stop	Other	Commissioning	08.03.2016 9:27
Chaufferie	CH10	08/10/2016 7:01 p.	Manager	CUT THE APPLICATIO	☑		10/08/2016 11:40	Contact M De TRAIN	Name		Setting-Regulation	electrical cabinet	Setting suppreseur + reinflate v	08/01/2016 11:09
Chaufferie	CH10	08/29/2016 3:55 p.	Manager	GUARDIAN M SAYS R	☑		08.03.2016 9:34	Contact M De TRAIN	Name		Edf cut / GDF / Wat	Ball, DHW		13.06.2016 7:49
Chaufferie	CH10	02/08/2016 4:04 p.	Manager	TURN THE WATER LE	☑	01h-00mn	08/01/2016 11:16	Contact M De TRAIN	Name		hydraulic malfunctio	Other	control system	05/20/2016 2:13 p.
Chaufferie	CH10	14/06/2016 11:50	Subcontractor	Request Ignition / Off: D	☑		13.06.2016 8:57	Contact M De TRAIN	Name	14/06/2016 10:41	Edf cut / GDF / Wat	Ball, DHW	ef cut and DHW	06/01/2017 12:59
Chaufferie	CH10	24.05.2016 8:18	Manager	heating pipe has ceded	☑		05/20/2016 3:11 p.	Contact M De TRAIN	Name		Ignition / stop	Other		08.03.2016 9:27
Chaufferie	CH10	04/15/2016 5:10 p.	Manager	come cut the hot water f	☑		15/04/2016 11:55	Contact M De TRAIN	Name		Lack of water or drai	Radiators, radiator	Leak passage	08/01/2016 11:09
Chaufferie	CH10	04/11/2016 1:51 p.	Manager	no heating General 1 all	☑		05.04.2016 8:59	Contact M De TRAIN	Name		Out-Troubleshooting	Ball, DHW		10.07.2016 8:20
Chaufferie	CH10	04/05/2016 10:24	Manager	no heating in genera	☑	00mn	05/04/2019 9:01	Contact M De TRAIN	Name		Setting-Regulation	Regulation servomo	Problem on the control back in	10.09.2016 8:48
Chaufferie	CH10	15/02/2016 12:33	User	NO ECS OR HEATING	☑	00mn	29/02/2016 9:10	Contact M De TRAIN	Name	02.29.2016 9:23	Lack of water or drai	Boiler	Lack of water has extra 1,5bar	10/08/2016 11:11
Chaufferie	CH10	11/02/2016 11:58	Manager	must be a water cut on	☑		15/22/2016 10:16	Contact M De TRAIN	Name	15/02/2016 11:00	Call not based contr	Ball, DHW	flush when I was	10.07.2016 8:20



Equipment model supplementary information

Maintenance parameter	Detail
Date of application	*Date*
Applicant,	*User or technician*
Message,	*Customer or user*
Problem fixed	*if the problem is fixed or not, yes/no*
Duration	*Time*
Recipient of the request	*Name*
Date of support	*Date*
Technician carrying	*Name*
Date of completion	*Date*
Cause of failure	*The detected cause*
Component	*The exact component concerned*
Technician message	*Short description of the repair*
Closing date	*Date*

The detailed required maintenance data sheet



Boiling room model

Figure 3.12 Use of maintenance information

3.7.2 Fire protection system

The maintenance of the fire protection system includes various tasks, such as checking smoke detectors and replacing batteries every year, checking the state of extinguishers and their replacement if necessary. Table 3.6 shows the maintenance schedule of the fire extinguishers in the Tennis residence.

Table 3.6. Table of maintenance of the extinguishers in Tennis residence

Tableau d'entretien des extincteurs									
A	B	C	D	E	F	G	H	I	J
Famille et type	Type	Commentaires	Fabricant	Pièce: Niveau	Pièce: ID_logement	Pièce: Nom	Nombre	Date de la derniére m	Date d'expiration
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 0	PC_A0	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 0	PC_B0	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 2	PC_A2	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 4	PC_A4	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 6	PC_A6	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 8	PC_A8	Partie c	1	15/04/2018	14/09/2018
Extincteur C02: Rouge	Rouge		Fabicant x	Niveau 2	PC_B2	Partie c	1	15/04/2018	14/09/2018

3.8 Maintenance organization and priorities

Building maintenance is a complex process. It requires large amounts of information. As presented in the previous chapter, the MEP system for the Tennis residence concerns the ventilation system, plumping system, solar panels and elevators. These systems require preventive maintenance. Figure 3.13 outlines the maintenance prioritizing.

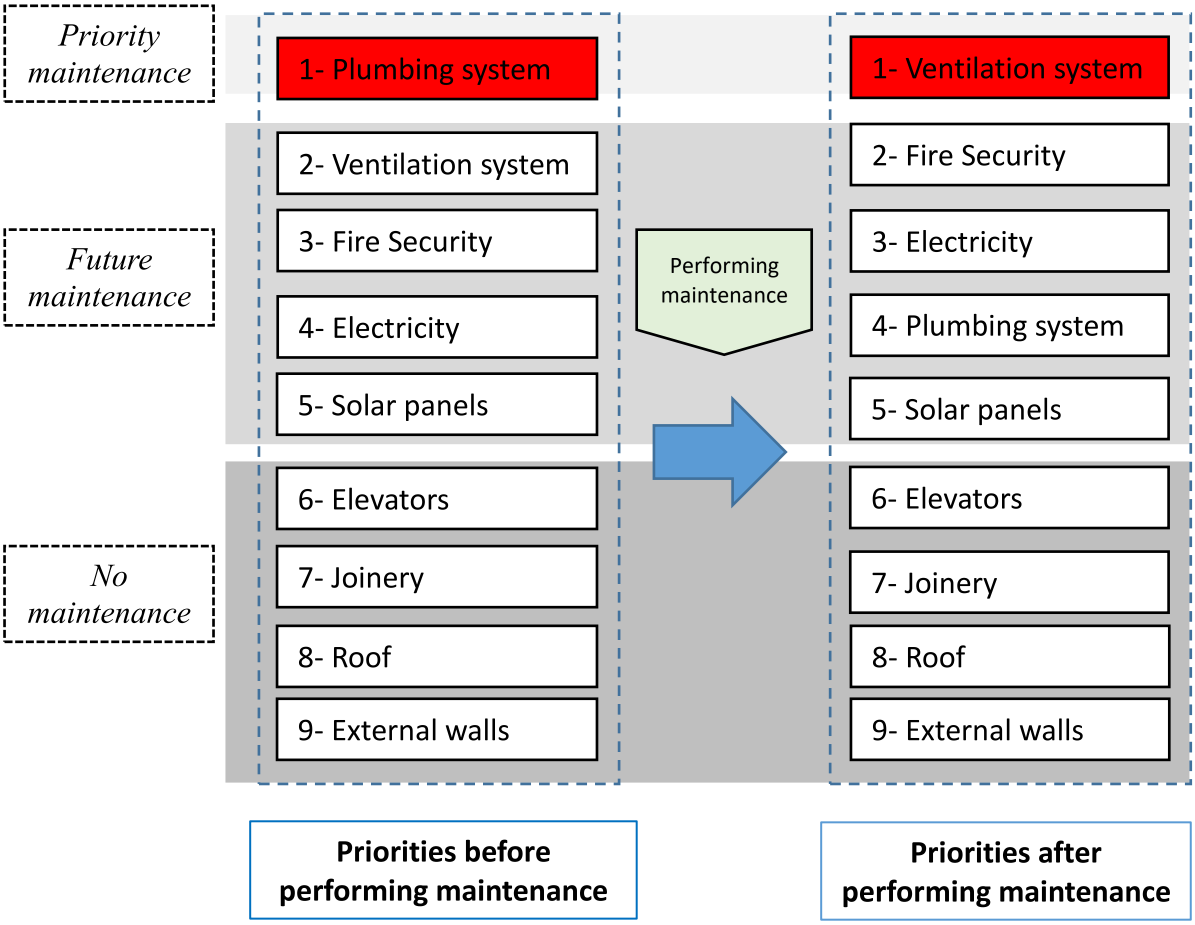


Figure 3.13. Proposed method prioritizing maintenance

Since all maintenance data are collected, the BIM database becomes weighted with information; therefore it is necessary to develop tools to help managers access prioritized information. Priorities are determined by managers. The script created for this issues is given in appendix A.

Figure 3.14 shows the result of maintenance simulation of some equipment in the Tennis residence. The classification of maintenance is done according to the order of propriety.

The first equipment that should be maintained before 10/06/2018 is the solar evacuated tube, then the HC boiler (18/06/2018).

Figure 3.14. Maintenance priorities visualization

We have developed a program that exports the maintenance priorities and facilitates data sharing among concerned services and stakeholders. Figure 3.15 shows an excel export file.

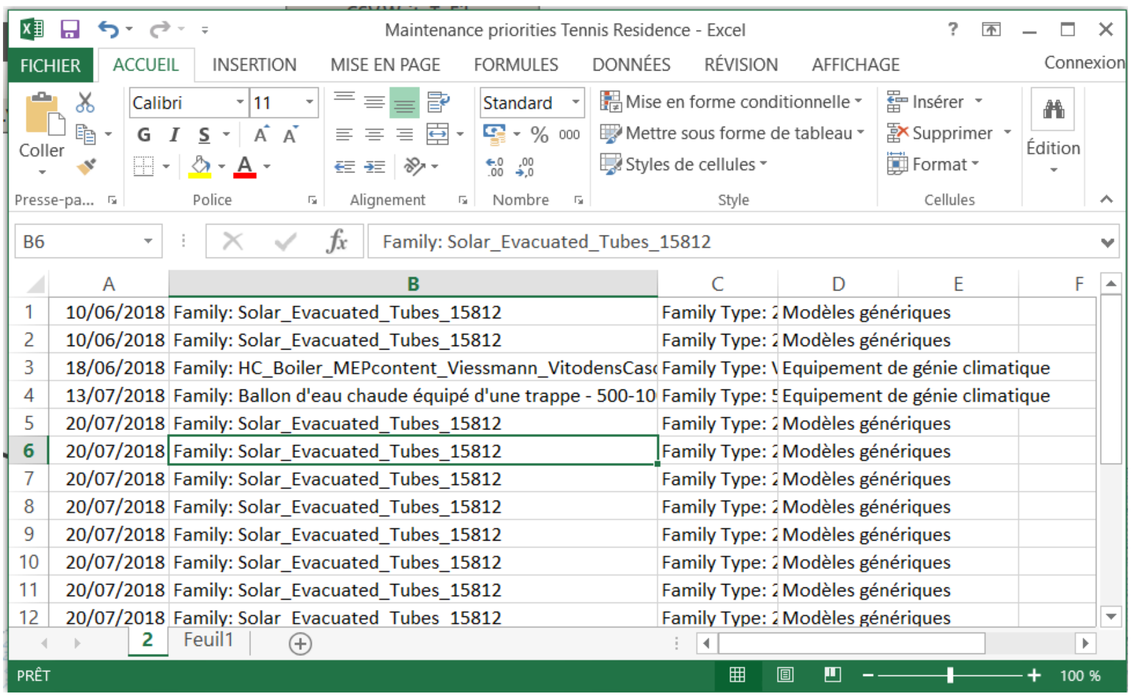


Figure 3.15. Maintenance priorities in excel

3.9 Advanced visualization

The BIM can be combined with advanced visualization and planning tools. It improves maintenance planning. Consequently, BIM enables a 4D sequencing process.

The advanced visualization can further enhance planning by using advanced design tools and game engines to produce process artwork. It can perform High Definition Rendering and Animations, Data Visualization and Virtual Environment.

The proposed method is based on linking the equipment maintenance schedules to 3D visualization. The objective is to simplify identification of maintenance priorities. It consists signaling the equipment in the 3D view or 2D plans of the project with colors corresponding to the maintenance status.

The script is developed on Dynamo and Python with the help of Revit's BIM database and maintenance schedules. Figure 3.16 shows the script principle; the details are given in Appendix B. The settings created for maintenance management are extracted with the scheduled preventive maintenance dates in dynamo. Data are processed in a python script to assign a color to each device according to the agenda. Three cases are considered:

- Imminent maintenance; equipment concerned marked in red.
- In one-month maintenance; equipment colored in orange.
- Accomplished maintenance; equipment colored in blue.

The visualization is conducted using Revit.

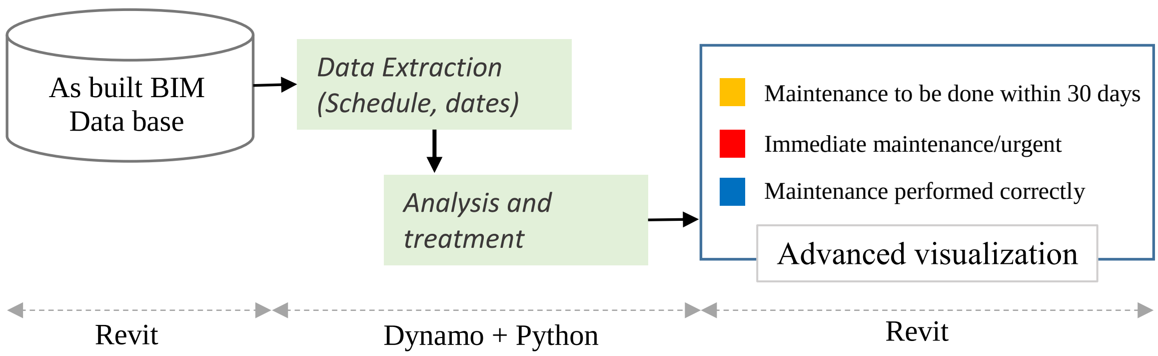


Figure 3.16. Process of advanced BIM based visualization of maintenance

Figure 3.17 and table 3.7 show the state of the maintenance of the boiling room and solar panels of the Tennis residence.

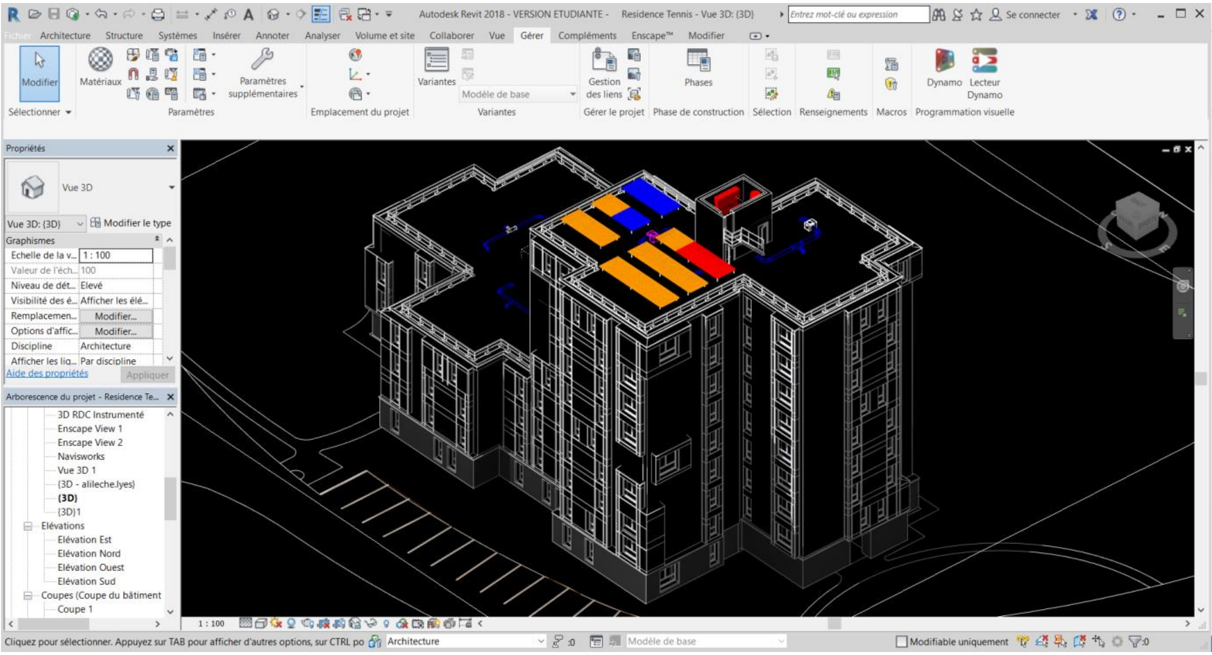
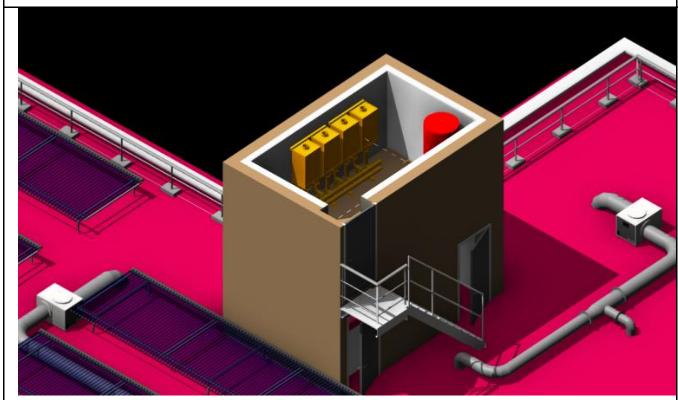
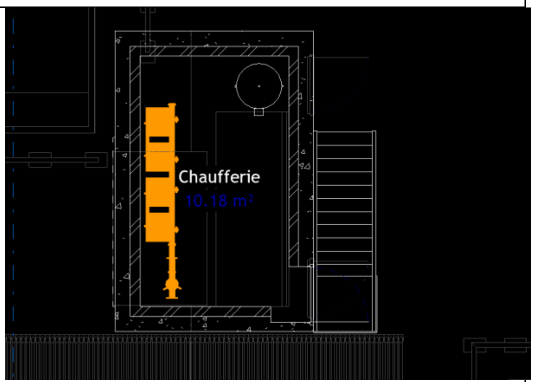
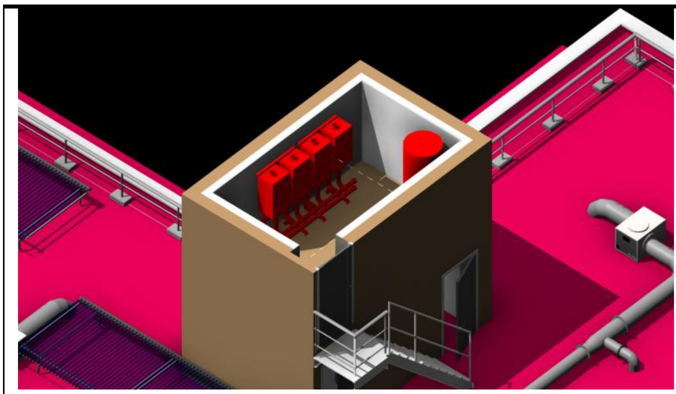


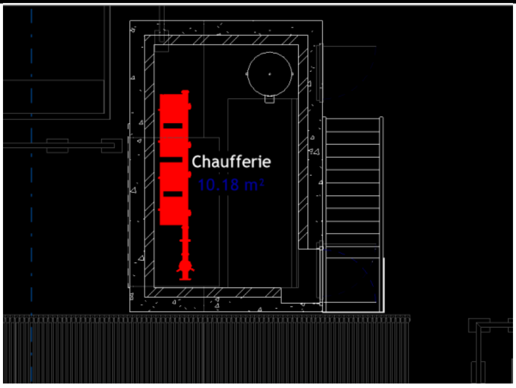
Figure 3.17 advances visualization of the building maintenance

The following table shows some results of advanced visualization in the case study.

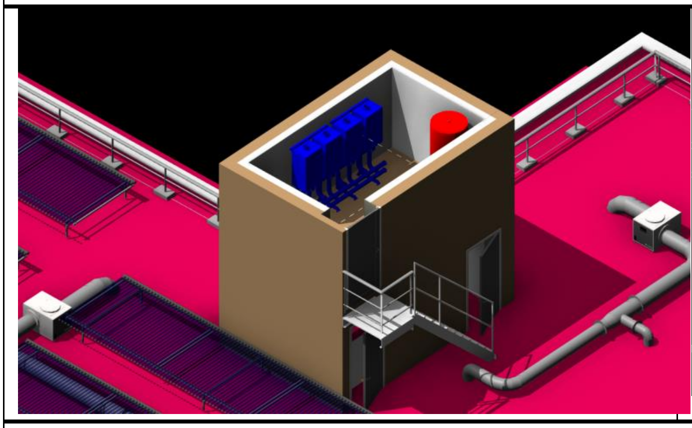
Table 3.7 Results of the advanced visualization, case of the boiling room, Tennis residence

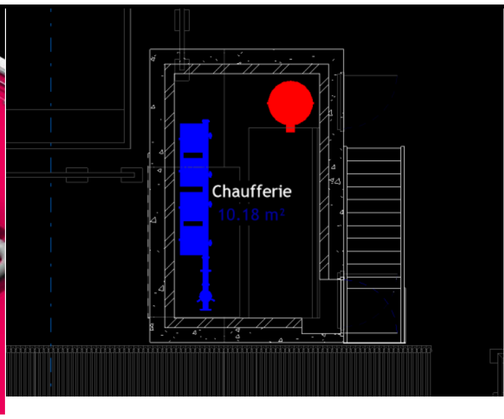
<table>
<tr><th>3 D view</th><th>2D technical plans</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">The maintenance date is scheduled for (18/06/2018), one month before (18/05/2018) the planned maintenance date. The BIM object of the boiler room is indicated in orange color to remind the manager that the maintenance must be carried out in the coming weeks.</td></tr>
</table>





When the date of maintenance in the agenda arrives, if not maintained, the equipment is indicated in red. The maintenance of the boiler must be carried out quickly to avoid any breakdown or degradation.





This image showing the boiler room in blue color is the result once the maintenance of the boiler room is carried out correctly and registered in the system.

3.10 Conclusion

This chapter included the development of a BIM based solution for the management of an existing social housing residence. This model incorporates the asset data as well as the maintenance data with advanced visualization capacities. It allows visualization of the status of equipment maintenance as well as priorities. Figure 3.18 summarizes some of possibilities offered by the BIM-Based management system and compares it to the conventional management method.

The capacity of this system was illustrated through its application to the maintenance of some equipment of the Tennis residence. This application confirmed the high capacity of this system as well as its user-friendly interface and environment.

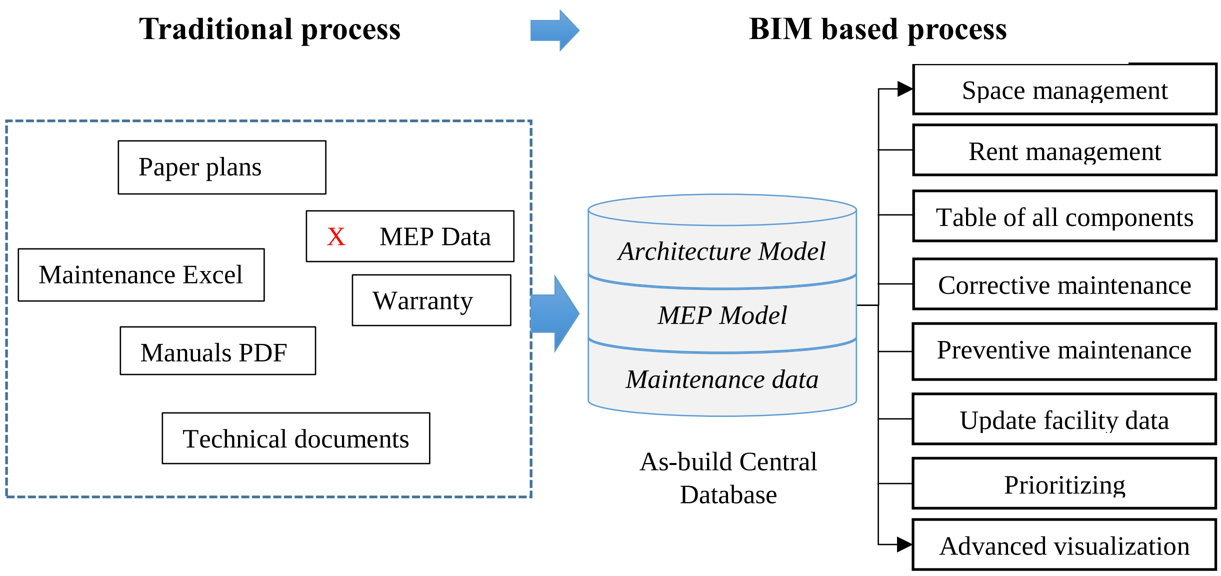


Figure 3.18. Comparison old process/BIM based process

Chapter 4: Dynamic BIM model for existing buildings

This chapter describes the development of a dynamic BIM model for existing buildings, using the as-built BIM. This development is applied on a research building in the campus of Lille University, as well as on a social housing residence. It allows to visualize data collected by sensors and to inform users and managers about energy consumption and abnormal events.

4.1 Introduction

Comfort conditions and energy consumption reduction constitute important issues for building's operators and social landlords. The BIM model presented in previous chapters contains information related to the building and its maintenance. However, these data are static and concern the physical state of the building and its components. In this chapter, we present a dynamic BIM model for both the Tennis residence social housing and the research building A4 of Lille University Campus.

The work included three steps. The first one concerned the monitoring of some spaces in the building A4 with sensors to track comfort parameters and energy consumption.

The second step included the development of a program to connect the BIM model to the SQL data base. The real time data can then be visualized in their precise location in the BIM model.

The last step concerned the construction of a platform that visualizes data in a user-friendly environment that helps both tenants and facility managers to make effective decisions quickly.

4.2 Monitoring system

The objective of the monitoring system is to measure in real-time the comfort parameters (temperature, humidity, and brightness), fluid consumptions (water and electricity) and the windows status (open/closed) for the reduction of energy consumption.

Wireless sensors send data to a central unit in the apartment, which transforms the raw data into operational data. Users can access data using a web friendly interface (Figure 4.1).

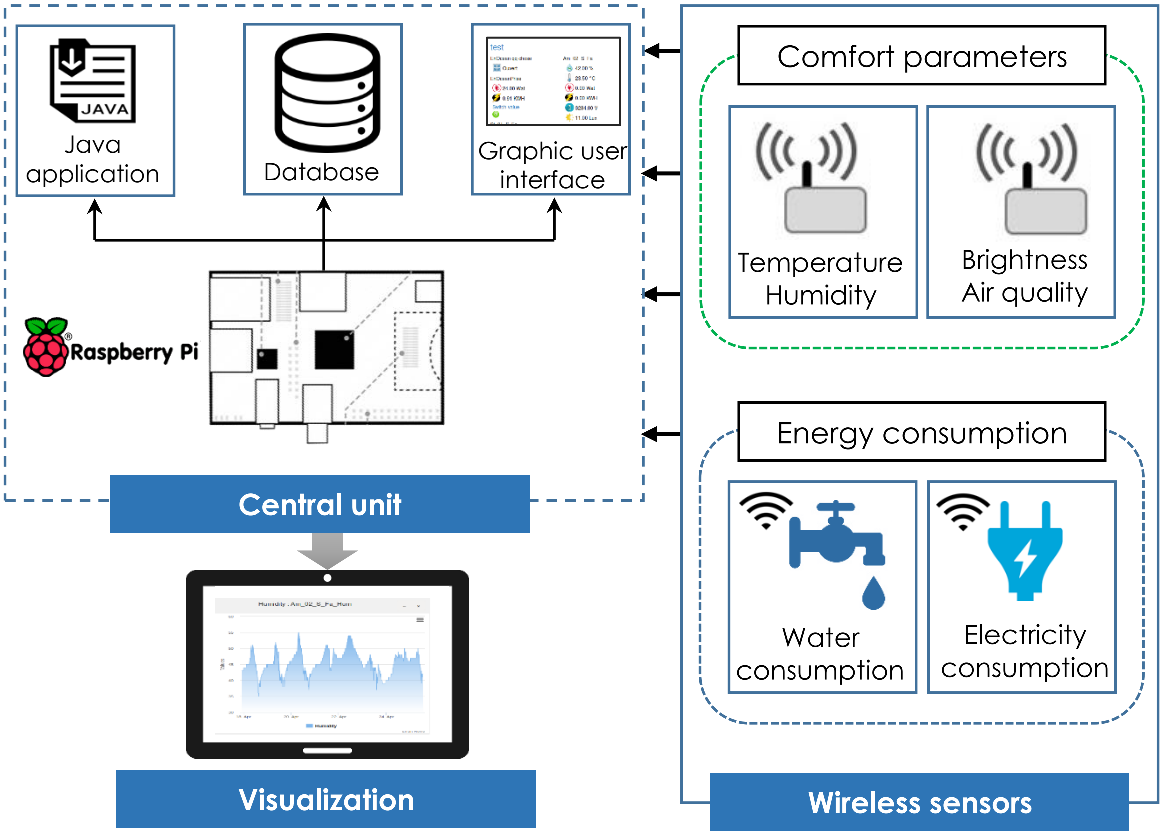


Figure 4.1 Architecture of the monitoring system

Radio-based wireless sensors are used. They are powered on battery. The frequency used for radio communication is 868 MHz, ISM frequency (industrial, scientific and medical). S17021 sensors are used for temperature and relative humidity. Temperature is measured in the interval -10 to 85°C with 0.4% precision, while the relative humidity is measured in the interval 0 to 80% with 3% precision. Luminosity is tracked using TSL2561 sensor, which works in the interval 0.1 to 40 000 lux.

Concerning water consumption, measurements are realized using Izar Pulse transmitter associated with an induction sensor. Current transformers are used to measure electricity consumption. Magnetic contact detectors are used for the determination of the doors and windows status (open/closed).

All these sensors are associated with a programmable electronic card including a microcontroller and an RF transmitter and specially designed for IoT applications with low energy consumption.

- Temperature, humidity and brightness are included on a single electronic board, also powered by AA battery. The advantage of including these sensors on the same card is to be able to send their measurements in a single communication, allowing a significant energy saving. The data sent by the sensors are received by a central unit which must be equipped with the receiver corresponding to the protocol of communication used.

This electronic card is called an adapter; each adapter includes three sensors.

A Raspberry Pi 2 is used as a central unit. It includes 4 USB ports, 1 Ethernet port, 1 HDMI port, and 40 GPIO, which are input / output ports. Data are stored on an SD card. The operating system uses free and open source Linux version. A Wi-Fi dongle allows the Raspberry to create a local Wi-Fi network.

A JAVA program decodes the raw data received by the receiver, verifies the "identity" of the sensor, decodes the raw data and then saves them in a database.

MySQL, free and open-source, is the relational database management system used. Data stored in MySQL are manipulated with the SQL (Structures Query Language) language.

A web interface allows the user to visualize real-time and historical data. This interface is coded in HTML, PHP, CSS and JavaScript. It receives data through the MQTT protocol. It allows data display using SQL queries.

Users follow the following steps to connect to the visualization interface:

- Connect to the central unit via the Wi-Fi network.
- Access to services on the home page (figure 4.2)

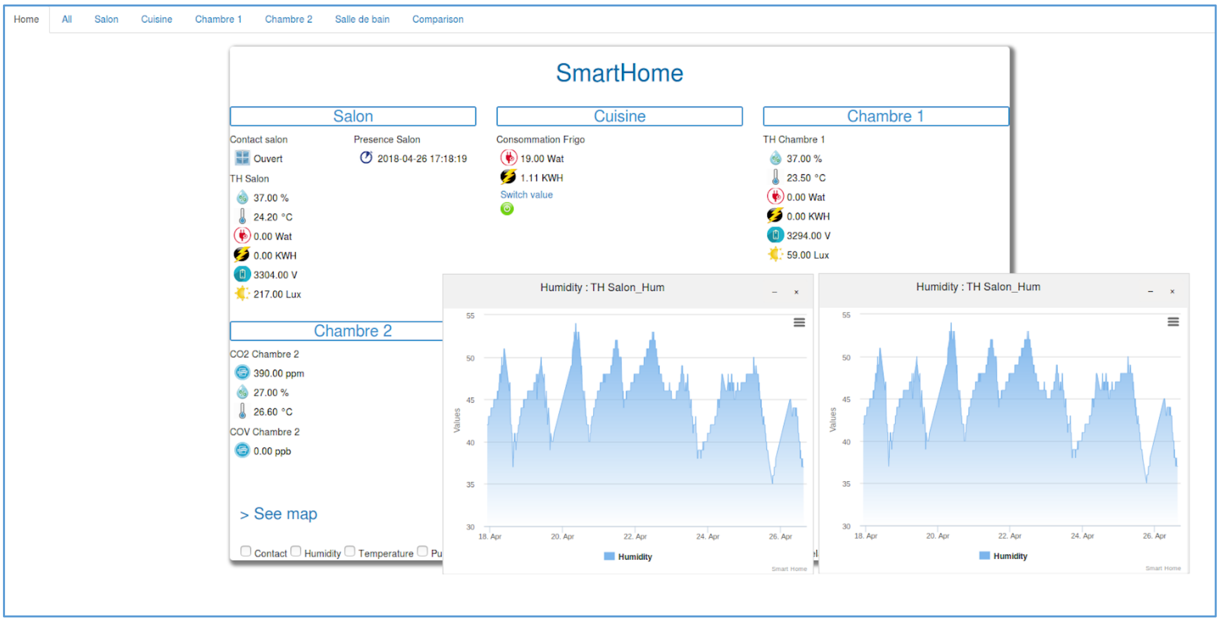


Figure 4.2 Web interface of the sensors system

4.2.1 Methodology for the development of a "dynamic BIM Model"

The use of models developed in existing BIM-based software rarely goes beyond the static information of the concerned building. During a facility's management, these models are treated as static information sources that contain the as-built data. This database can be enriched with real-time data and offers greater comfort and performance for the actors who operate the buildings.

Making BIM-based models dynamic to represent the real-time building information of energy consumption and indoor comfort parameters introduces various opportunities for facility managers to obtain accurate information about the state of various systems.

4.2.2 First solution

The first method used to display sensors data is based on the creation of links on the web interface. Tests showed the possibility of linking elements in the model. However, this method is not convenient to develop a decision support tool. A more developed method is therefore required (Figure 4.3).

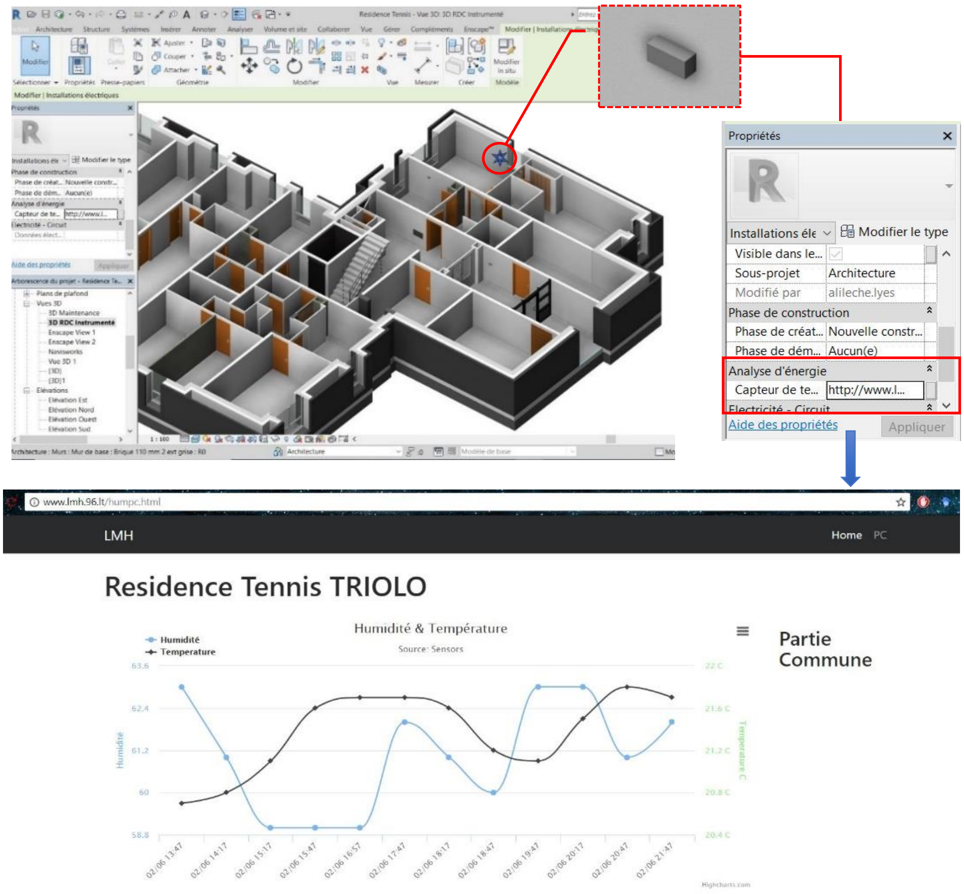


Figure 4.3 Access to sensors data through the BIM model

4.2.3 Dynamic BIM model

The Dynamic BIM model needs an architecture that involves the BIM created in Revit, building performance tools and sensors collecting data of comfort and consumption. The dynamic BIM environment represents the connection of all of the parameters as well as visualization and decision-making tools. Figure 4.4 shows the architecture of the proposed method.

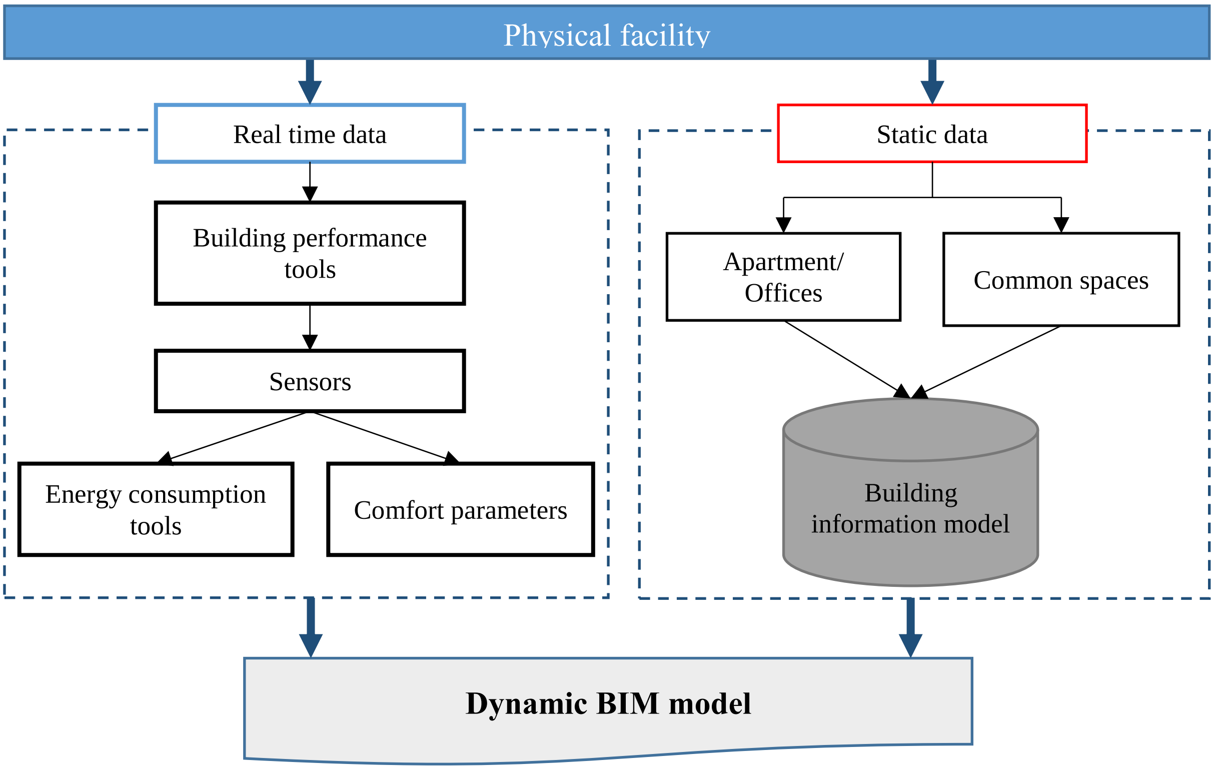


Figure 4.4 Architecture of the proposed Dynamic BIM model

4.3 Methodology

In this section we explore the use of BIM to support visualization and management of building performance via linking data collected by sensors in a Dynamic BIM model. To achieve this goal, a program was developed in Dynamo and python to link the SQL data base to Revit model. A color code is selected to visualize comfort parameters using colors.

The BIM implementation as a performance management tool is established using guidance for production and sourcing of data to support building performance management using BIM.

4.3.1 Spaces identification

Two tools are used to identify spaces (limits, perimeter and name): (i) "Coin" tool, which is dependent on the walls that form boundaries and perimeter and (ii) The "Surface" tool", which does not necessarily depend on the walls; it allows for example, to draw floor-by-floor surfaces or any areas such as parking. With the help of the tool "Surface separation", we can draw the contour. These tools offer the possibility of associating information of coloring and making nomenclatures of surfaces.

In this model, apartments are delimited with the tool "surface", while the distribution in each apartment is made with the tool "room". It is important to distinguish these two categories, because they will be among the main data of the script that we will develop, not only for the extraction of the geometry (room) and the attribution of colors to the volume according to the parameters of comfort, but also for the real-time data visualization on the surfaces of spaces or apartments.

4.3.2 Integration of shared parameters

In Revit model, each object is characterized by project parameters that contain related information. However, it does not contain information for building management and dynamic or real-time data.

Shared parameters concern parameters added to families or projects. They allow to add and extend information about any component in a project. This mode allows to enter different type of parameters for one or several categories (e.g text, number, URL) allowing to enrich the database that will facilitate information search. Shared parameters are explored by researchers to optimize the parametric definition of the models and also to facilitate the interoperability. Created attributes could be displayed in the properties of the family and organized according to the typological groups. For example, the identity data that can be created for a space, the dimensions, and the equipment such as plumbing. Information added with this type of parameter can be displayed in a tag and in the schedules. For all these reasons, they represent a prominent element for the management of facilities, allowing the creation of thematic views, lists of information-rich elements and significant selections of objects and the sorting of information and object. A shared parameter allows to display different categories of the family thanks to the attribution of the same parameter. Shared settings are stored in an independent way of any family file or Revit .txt file. It could be defined and reused for multiple families or projects. It allows to access the file from different families or projects. The shared parameter is a definition of a container for information that can be used in multiple families or projects.

The following shared parameters were created:

Identification data

- Type (Housing type/ space type)
- ID (Housing/space)

To visualize the real-time data collected by sensors, other parameters related to sensors were created for the surface entity of each apartment or space: Adapter_ID, to identify the adapter that contains multiple sensors as well as temperature, humidity, brightness, to display the latest digital value of the sensors.

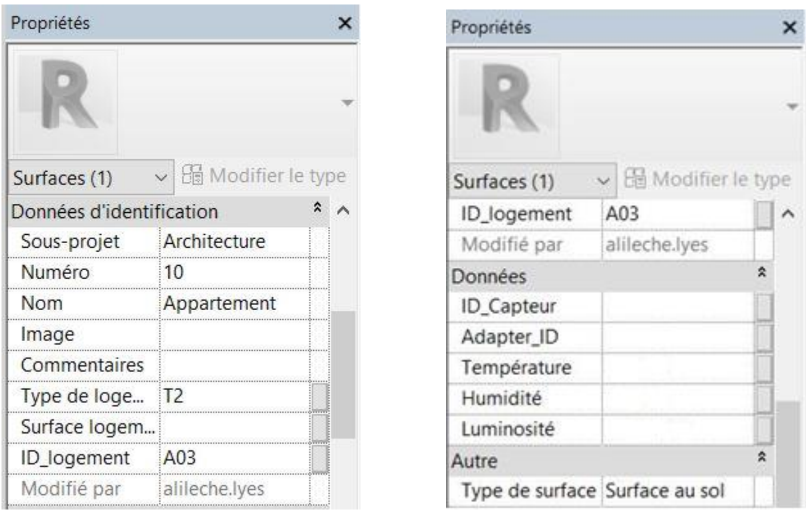


Figure 4.5 Created shared parameters in properties

4.3.3 Creation of customized tags

A tag is an annotation for identifying elements in a drawing. Properties associated with a tag can be displayed in schedules. A tag is an annotation for identifying elements such as the apartment's data in this case. When a tag is created, labels are added to display the value of desired element parameters.

We created a label for the apartments that contains the parameters created previously namely, the identification of the housing, as well as the temperature, humidity and brightness.

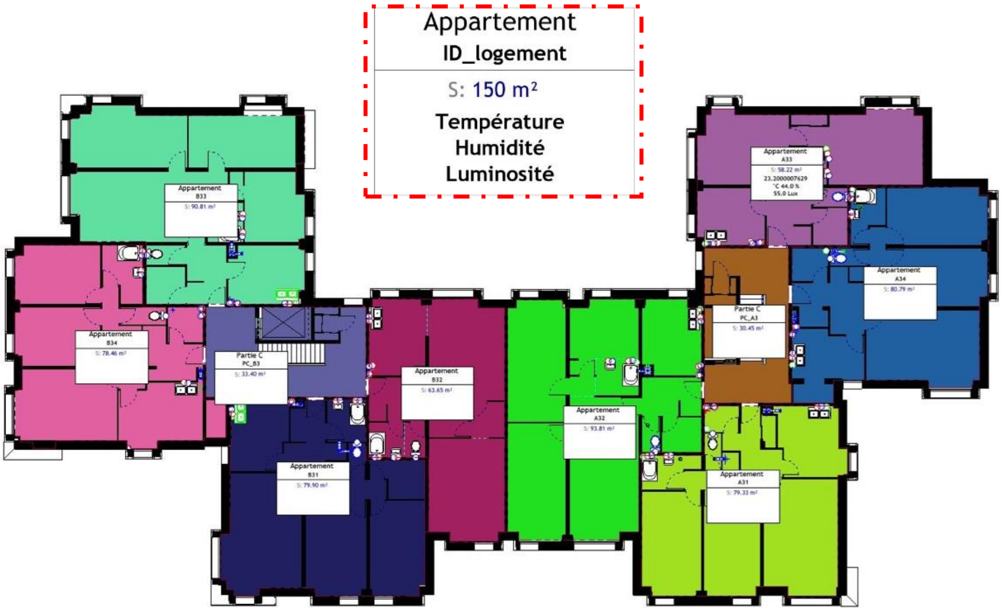


Figure 4.6 Integration of labels with the parameters created in the model

4.3.4 Integration of dynamic data

The tools used in the development of Dynamic BIM and performance monitoring link are described below.

A visual programming tool gives users the ability to visually script behavior, define custom pieces of logic, and script using various textual programming languages.

Once we've installed the application, Dynamo will enable us to work within a Visual Programming process wherein we connect elements together to define the relationships and the sequences of actions that compose custom algorithms. We can use our algorithms for a wide array of applications.

4.3.4.1 Script creation

The script allows to change the color of an apartment according to comfort parameters. The creation of the Dynamic BIM model includes:

- Retrieving the sensor IDs associated with their latest value received in the Smart Monitoring System database as well as adapters and type.

- Retrieving the parameters of the model, in this case the "surfaces" of the apartments that contain identification parameters including "sensor IDs", this parameter will be used to create the link in the Revit model and the SQL database.
- Data processing, data processing is done with Python, to connect the different variables in order to have all the information to display the color of the apartments according to its comfort parameters.
- Update the T (Temperature), H (Humidity), L (Luminosity) parameters of the surface according to the values retrieved in the smart system, to display these values in the 2D model label.

The visualization and decision support tool concern extraction of the geometry of rooms of the apartments in 3D, then the attribution of a representative color of the comfort. Figure 4.7 summarizes the organization of the script.

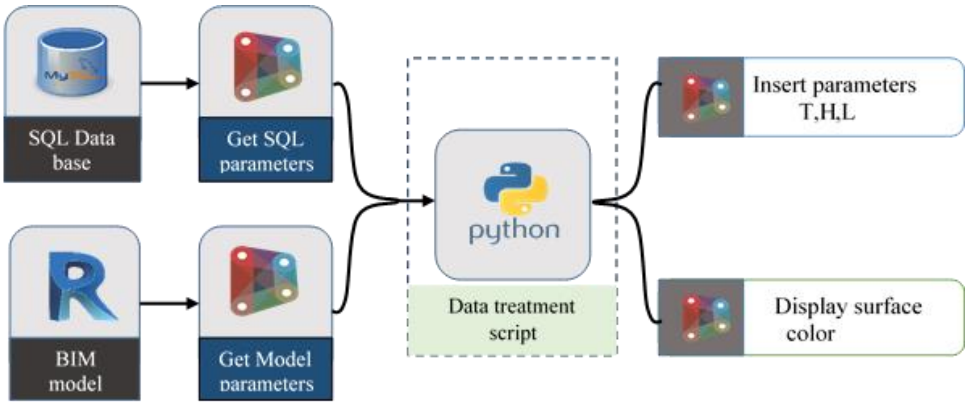


Figure 4.7 Process of creating the Dynamic model

4.3.4.2 Structure of Dynamo script

The connection to the SQL server containing real-time data is done using the node Slingshot for Dynamo Revit, which allows connection to the relational Database Management Systems (RDBMS). MySQL uses the RDBMS. The communication with RDBMS is done with the language Structured Query Language (SQL).

The node Query. MySQL of Slingshot allows to select information in the database using two SELECT queries. The first one returns the association of a unique identifier of the sensor, type of measurement and unique identifier of its adapter. The second request retrieves the unique identifier pair of the sensor with the last value received. The node requires two input parameters:

- Connection parameters to the database: IP address of the Raspberry Pi, port corresponding to the MySQL application, user, password and maximum time of command and connection
- SQL query to perform in the database.

A SQL.SelectFrom node is used for each SELECT query. This node uses two input parameters: the parameters or fields to be recovered and the table including data.

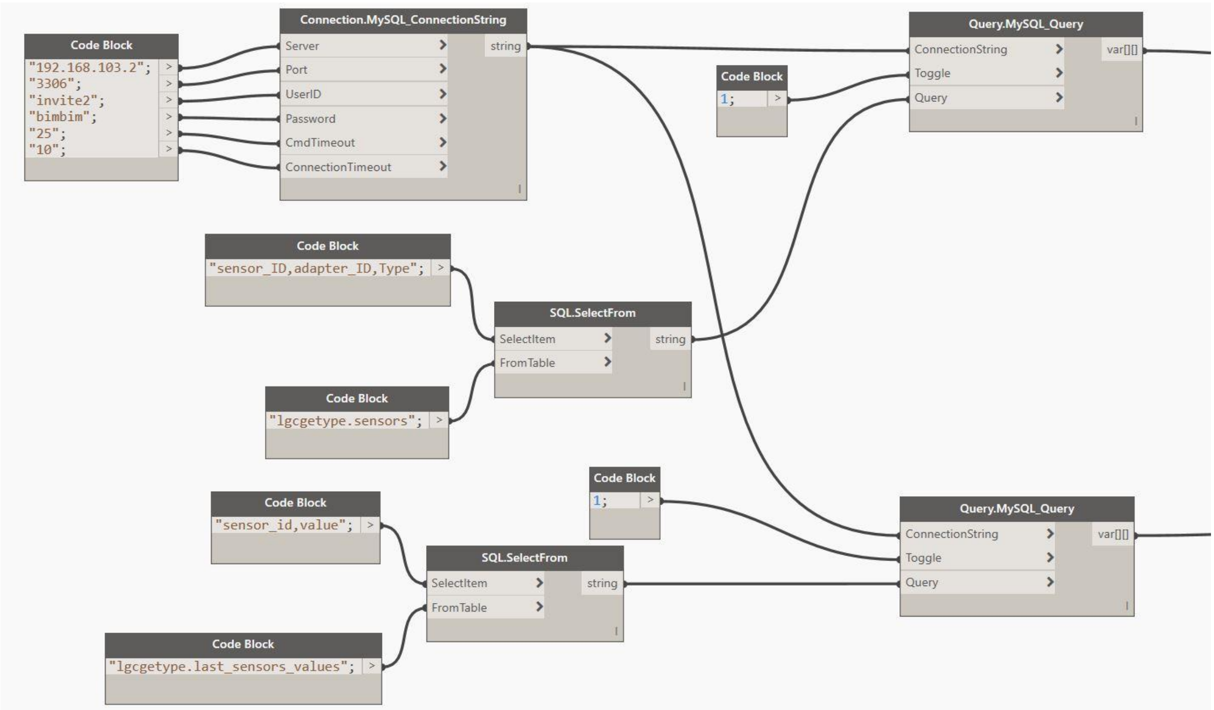


Figure 4.8 SQL request script

The output of this functional block includes two-dimensional lists with a main list, corresponding to the sensor, and containing in each index an internal list with the parameters of this sensor (figure 4.9).

The Watch node allows to observe the variables at the output of a node. It can be observed that the parameter 0 of each list corresponds to the ID of the sensor and therefore that the same sensor with the same index in the main list: 0 corresponds to the sensor of ID 9 in the two lists above; 1 corresponds to the index of the ID sensor 10.

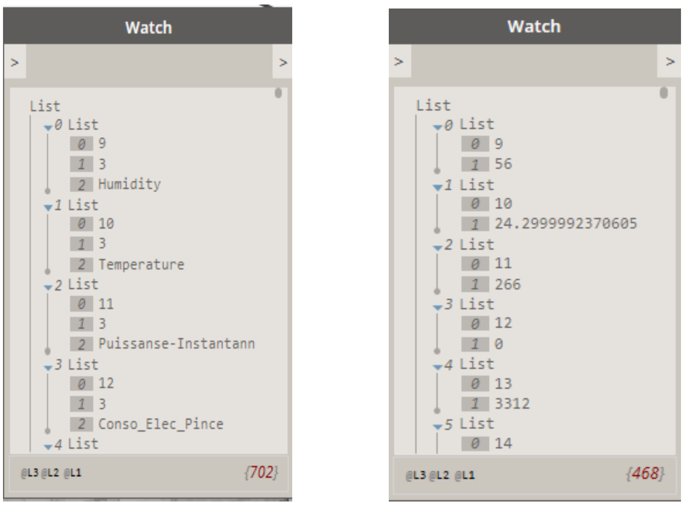


Figure 4.9 Watch of the variables at the output of nodes

To associate the measurements of sensors to their locations, we must recover the couple "ID_bureau" (office) and "ID_adapter" for each apartment included in the entity surface. As mentioned before, in a Revit project, a space can be categorized with the entities "surface" and "room". The 3D geometry is generated with rooms, and the "surface" entity is used to display the real time data throughout a customized tag. For this purpose, we must recover the parameters of comfort to determine the color in each apartment.

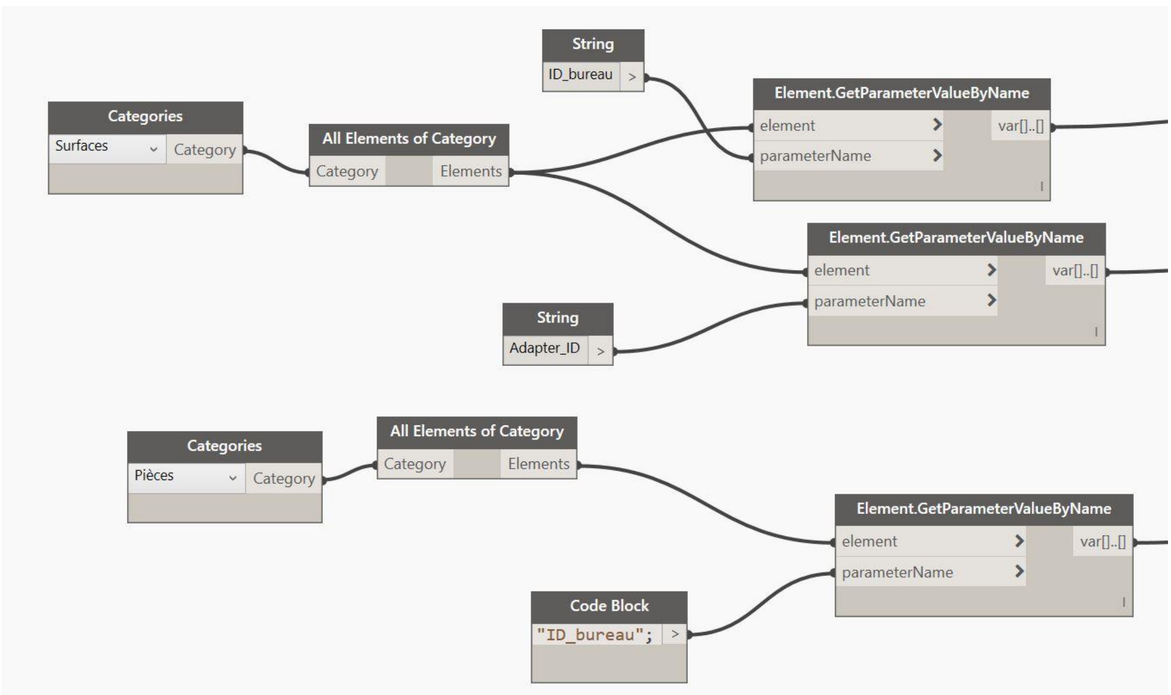


Figure 4.10 Script of obtaining parameters from the BIM model

4.3.4.3 Data treatment

The output of the script includes temperature_values, humidity_values, luminosity_values, as well as comfort indicators for each apartment:

- 0 for comfort condition
- 1 for uncomforted condition.

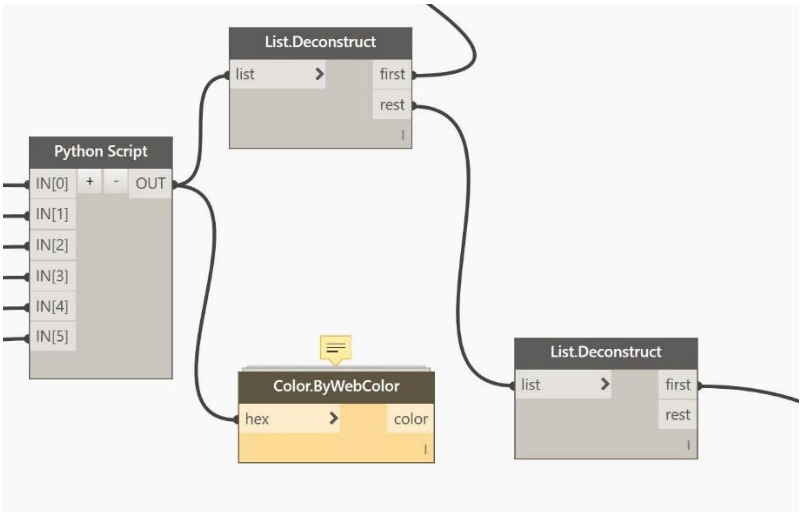


Figure 4.11 Data treatment nodes including Python script

4.3.4.4 Updating comfort parameters

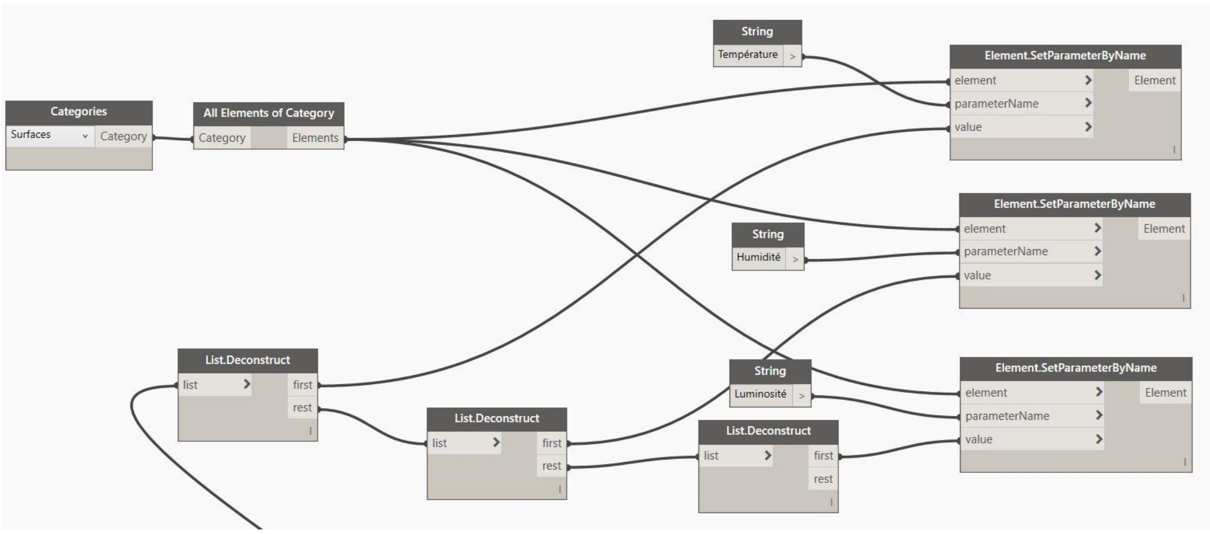


Figure 4.12 Updating sensors data parameter script

We use the **List.Deconstruct** node to separate the output list of python script into 3 distorted lists, which will be used to modify the temperature, humidity and brightness parameters in the "surfaces" of the BIM model. This is done using the **Element.SetParameterByName** node with the input parameters: name and the list of values.

The concept of comfort is based on technical parameters as well as feeling of the occupants. This notion of feeling is traditionally determined from several parameters such as ambient air temperature, wall temperature, metabolism and clothing. Table 4.1 summarizes the comfort conditions.

Table 4.1 Comfort conditions

	Parameter	**Unit of measure**	**Comfort zone**
Energy consumption	Electricity	Kwh	
	Water	M3	
Comfort parameter	Temperature	°C	18-25
	Relative humidity	%	35-70

Figure 4.3 shows colors associated to thermal values and colors associated to humidity values. The third line shows colors used for comfort conditions considering both temperature and humidity.

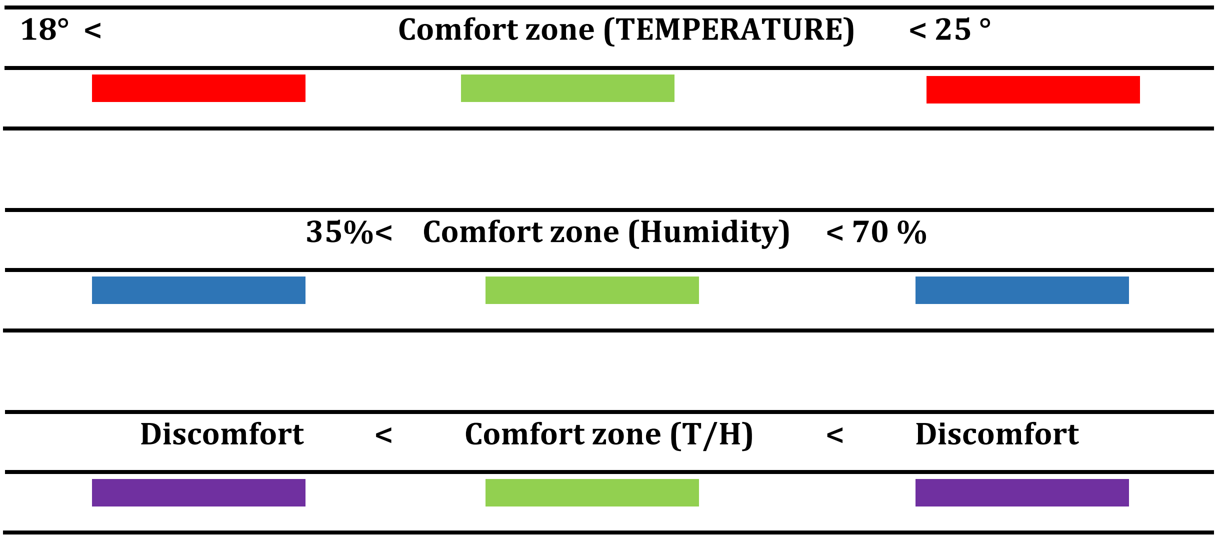


Figure 4.13 Colors associated to comfort conditions

The creation of the BIM dynamic model aims to help the managers and users to make effective decisions regarding comfort and energy consumption. The principle is explained in Figure 4.14. Visualization allows to see the state of comfort and energy consumption. If conditions are not good or a sudden overconsumption is pointed out, actions must be taken to verify some equipment. Therefore users can use this simplified visualization to take quick actions to improve comfort conditions.

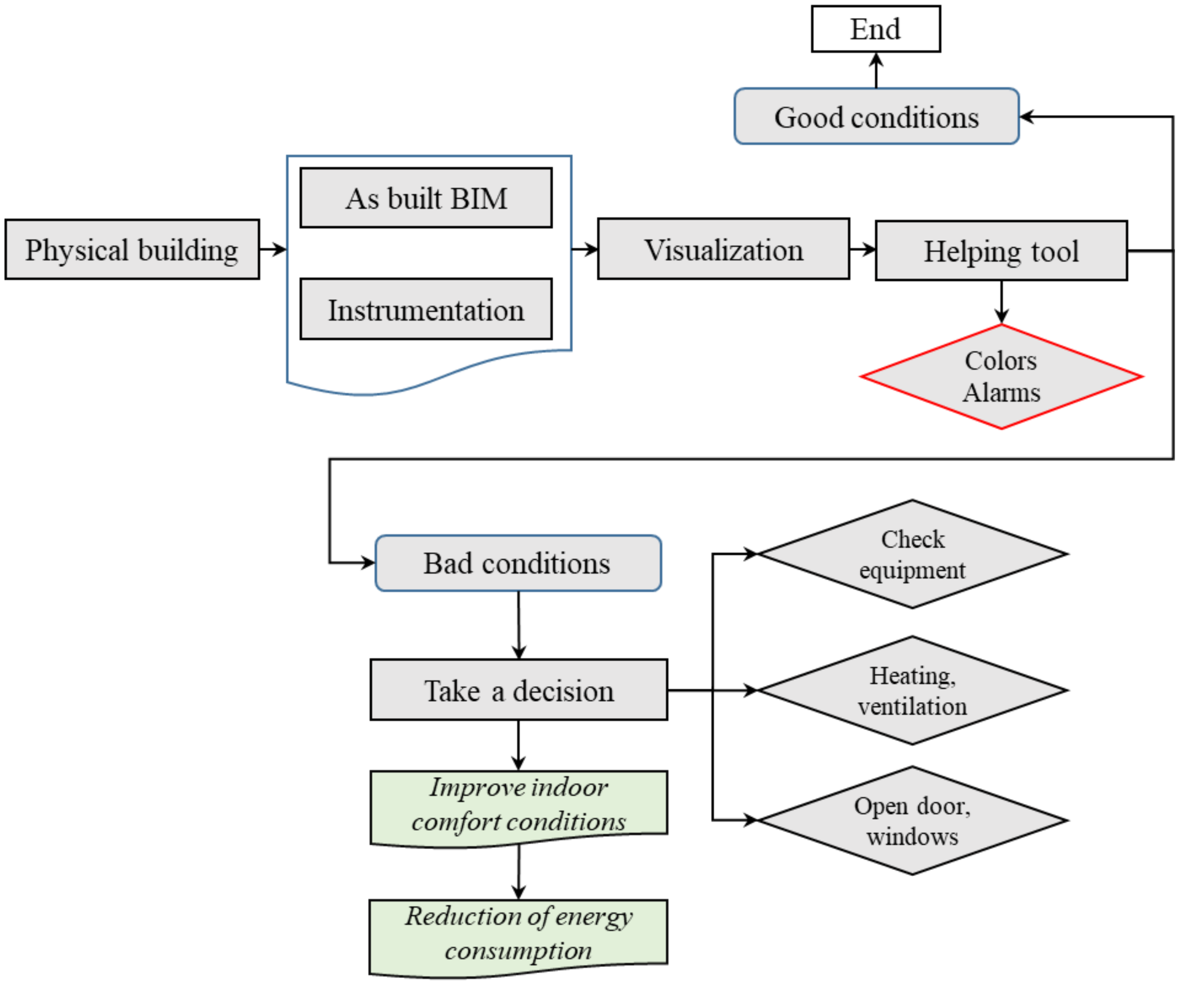


Figure 4.14 Decision-making process with the proposed method

4.4 Application to a research building

This section presents an application of the dynamic BIM model on a research building at the Scientific Campus in Villeneuve d'Ascq (Building A4). The building is composed of 1000 m^2 of ground floor. It includes 25 closed offices, two meeting rooms, technical rooms and a large open space.

4.4.1 Creation of the BIM model

A semi-automatic method was used to create the BIM model from existing dwg plans. A script to automatically create walls with the corresponding attributes has been developed with Dynamo. The code uses dwg plans as a reference, then uses the geometry of each line type to assign a wall type to it. The script is composed of 7 nodes. Heights are chosen according to the levels created in Revit beforehand. The type of wall is attributed by a node which gives access to the categories of walls.

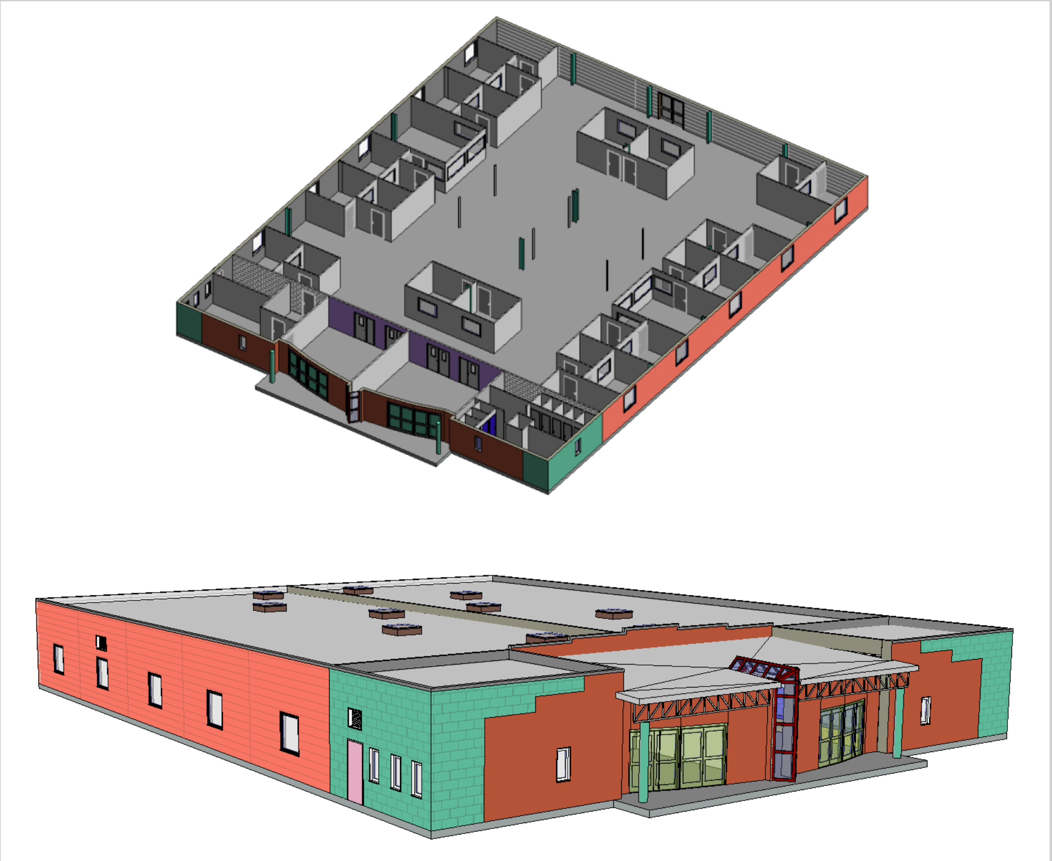


Figure 4.15 3D views of the A4 building

4.4.2 Adaptation of the script for the building

The dynamic BIM model requires organization of data to access to necessary parameters concerning spaces and sensors identification. The identification of monitored spaces was added to this model (Table 4.2). The building was divided into four types of spaces:

• Open space zones, offices, meeting rooms, and the hall

The shared parameters created for this model are:

• Temperature, humidity, brightness data

• Adapter_ID

• ID_capteur

Table 4.2 Identification parameters in the model

Apartment/ space	**Identification (ID)**
Open space zone 1	Z1
Open space zone 2	Z2
Open space zone 3	Z3
Open space zone 4	Z4
Offices	1,2,3…
Meeting rooms	SR1, SR2
Hall	HA

- **Building Monitoring**

The building is monitored using 72 monitoring units. Each unit contains temperature, humidity and brightness sensors. Table 4.3 and figure 4.16 shows the building monitoring. The open space is divided into four areas; it is monitored using 26 monitoring units. Offices (6, 7, 8, 9, 12, 14, and 25) are monitored with one to seven units and the trainee's office is equipped by four units. The hall entrance is monitored by 2 units. The outer facades are equipped with 4 units.

Table 4.3 List and location of the sensors in A4 building

	Nam	Hex	Dec		**Nom**	**Hex**	**Dec**
Office of intern	St_01_S_Fa	14	20	**Open Space zone 1**	O1_01_S_Mu_Nh	42	66
	St_02_E_Mu	23	35		O1_02_S_Mu_Nm	4C	76
	St_03_M_Ai	1D	29		O1_03_E_Ai_Lu	2B	43
	St_04_O_Mu	44	68		O1_04_M_Ai_Ve	59	89
Office 9	Am_01_S_Fe	6A	106		O1_05_E_Ai_Nh_Ve[4][4]	43	67
	Am_02_S_Fa	36	54		O1_06_E_Ai_Nm_Ve[4][4]	1B	27
	Am_03_E_Mu	37	55		O1_07_N_Mu	60	96
	Am_04_M_Ai	45	69		O1_08_O_Po	1A	26

	Am_05_O_Mu	32	50		O1_09_E_Mu	38	56
	Am_06_N_Mu	1F	31		O1_10_N_Ai	65	101
	Am_07_N_Vi	2F	47		O1_11_M_Ve[4][3]	33	51
Office 8	Ch_01_S_Mu	2E	46		O1_12_S_Ve[5][3]	35	53
	Ch_02_S_Vi	15	21		O1_13_E_Ve[5][4]	4B	75
	Ch_03_E_Mu	22	34	Open Space zone 2	O2_01_E_Fa	54	84
	Ch_04_M_Ai	6B	107		O2_02_E_Fa	55	85
	Ch_05_O_Mu	0B	11		O2_03_N_Ve[1][3]	5D	93
	Ch_06_N_Mu	2A	42		O2_04_E_Ve[1][4]	48	72
Office 6	Is_01_S_Fa	0E	14		O2_05_M_Ve[2][3]	4A	74
	Is_02_S_Fe	1E	30		O2_06_E_Ve[2][4]	12	18
	Is_03_E_Mu	0F	15	Open Space Zone 3	O3_01_N_Ve[1][1]	46	70
	Is_04_M_Ai	28	40		O3_02_O_Ve[2][1]	49	73
	Is_05_O_Mu	5B	91		O3_03_M_Ve[2][2]	58	88
	Is_06_N_Vi	56	86	Open Space Zone 4	O4_01_O_Ve[4][1]	64	100
	Is_07_N_Mu	66	102		O4_02_M_Ve[4][2]	5C	92
Office 7	Ma_01_S_Vi	69	105		O4_03_O_Ve[5][1]	52	82
	Ma_02_S_Mu	41	65		O4_04_S_Ve[5][2]	68	104
	Ma_03_E_Mu	40	64	Entrance	En_01_M_Ai	62	98
	Ma_04_M_Ai	31	49		En_02_M_Ve[3][0]	3B	59
	Ma_05_O_Mu	67	103	Office 25	Di_01_S_Mu	4D	77
	Ma_06_N_Mu	16	22		Di_02_E_Mu	2C	44
Meeting room 1	Re_01_S_Fa	30	48		Di_03_M_Ai	2D	45
	Re_02_E_Mu	47	71		Di_04_O_Vi	3A	58
	Re_03_O_Mu	57	87		Di_05_O_Mu	51	81
	Re_04_N_Mu	5A	90		Di_06_N_Mu	26	38
	Re_05_N_Vi	3F	63	Br 14	Sa_01_N_Fa	29	41

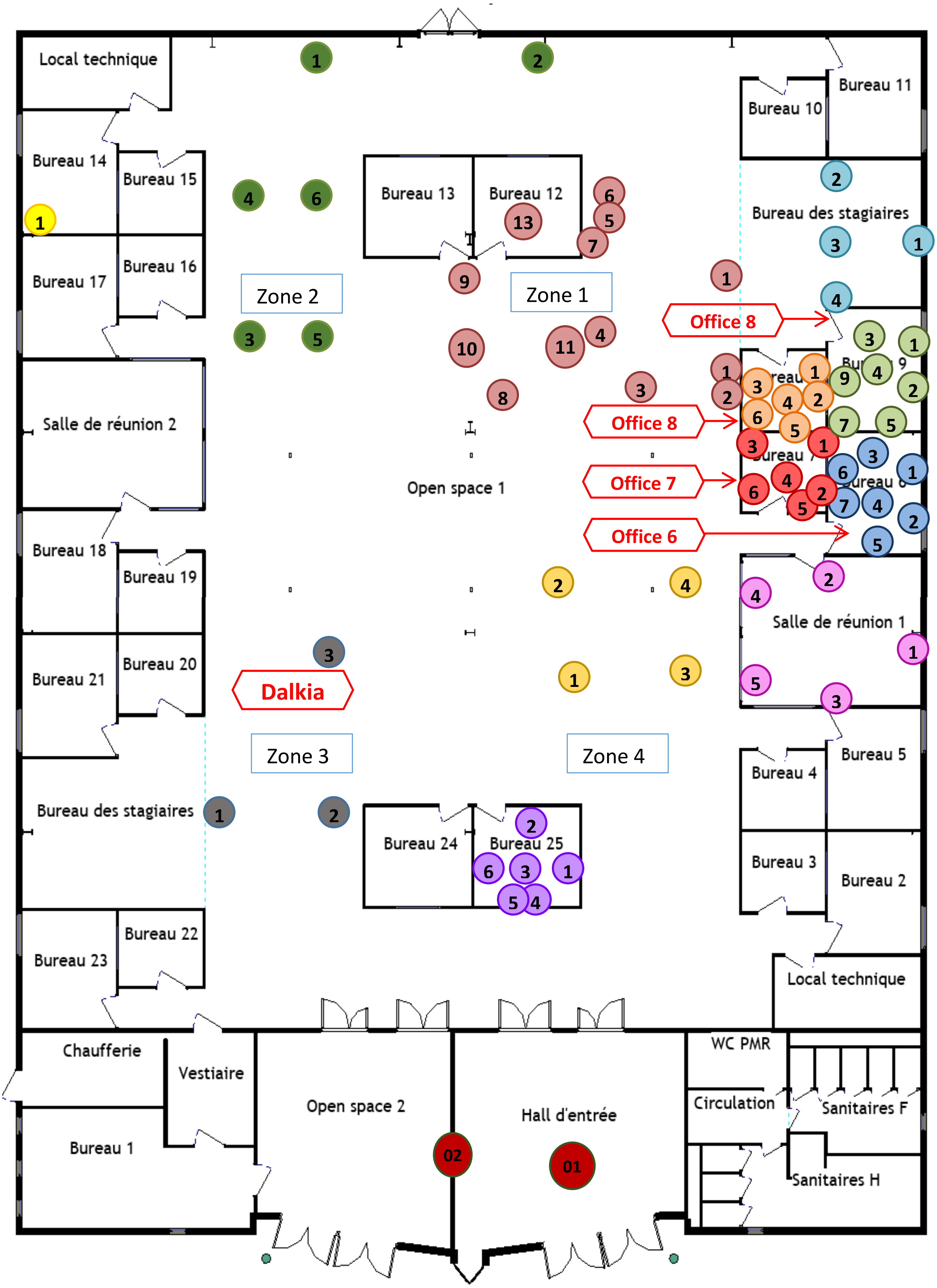


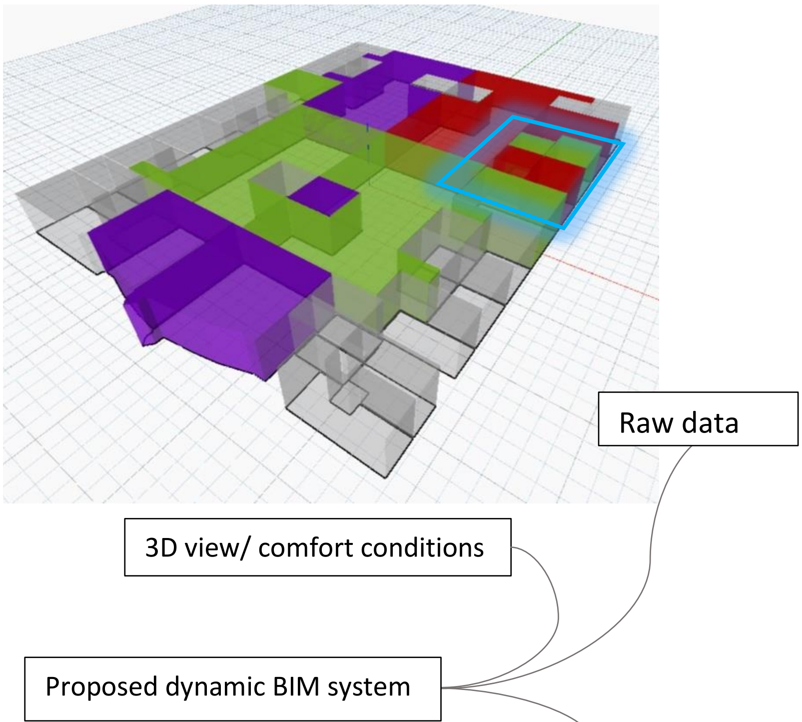
Figure 4.16 Plan view of A4 building including installed sensors

4.4.3 Visualization

Data can be visualized in different ways as shown below. The system shows the state of comfort in each room. The static BIM model is upgraded to a dynamic level, where the building visualization is continually updated according to data collected from the physical building and users. Preliminary results show that the open space is regularly in the discomfort zone, due to the ventilation system.

Figure 4.17 shows the indoor condition recorder on June 13, 2018: zones 3 and 4 are green with a temperature of 24 °C and humidity around 40%, while zone 1 and the office of internship students as well as the offices 6 and 7 have temperatures higher than 25°C, while the humidity is correct.

Rooms name	C	T	H
Open space Z1		25,9°	50%
Open space Z2		26,1°	33%
Open space Z3		23,5°	59%
Open space Z4		23,5°	59%
Meeting room1		24,4°	42%
Meeting room 2		24,4°	53%
O of internship s		25,4°	52%
Office 6		25,9°	47%
Office 7		25,4°	52%
Office 8		24,3°	52%
Office 9		24,1°	53%
Office 25		25,8°	35%
Hall		26,5°	78%



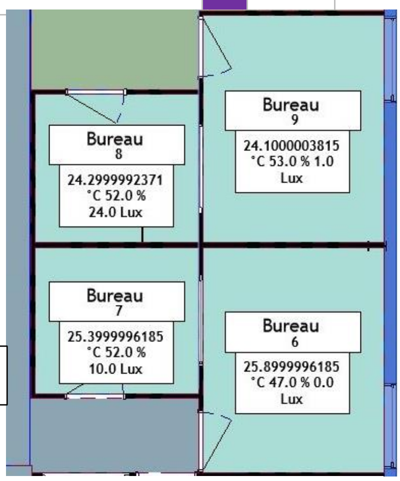


Figure 4.17 Visualization principle in the proposed system

This second example is taken during another period. All building spaces are reported as are in the discomfort zone for both temperature and humidity. Verification of the equipment showed that the abnormal situation is due to the failure of the ventilation system.

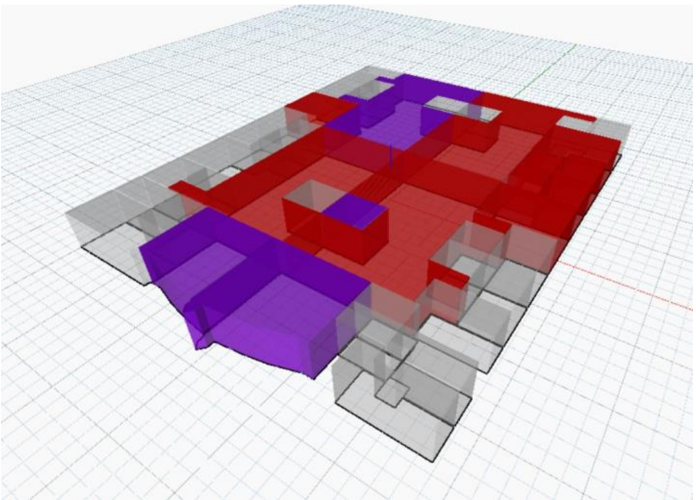


Figure 4.18 3D view of the comfort stat

The windows and doors of several offices have been opened for 30 minutes. The BIM showed that almost all spaces became green (Figure 4.19).

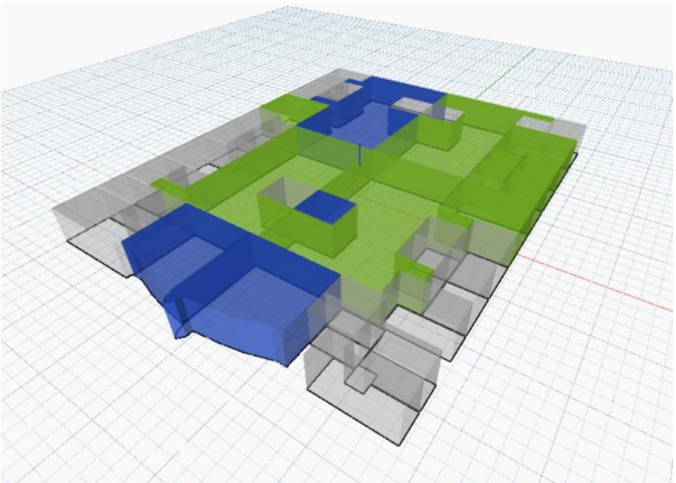


Figure 4.19 3D view of the comfort stat

4.5 Application to Tennis residence

4.5.1 Description

The monitoring system was implemented into three apartments (A, B and C) as well as in the common spaces of the residence.

Apartment A was instrumented with two multi sensors module for temperature, humidity, brightness and two contact sensors (Figure 4.20).

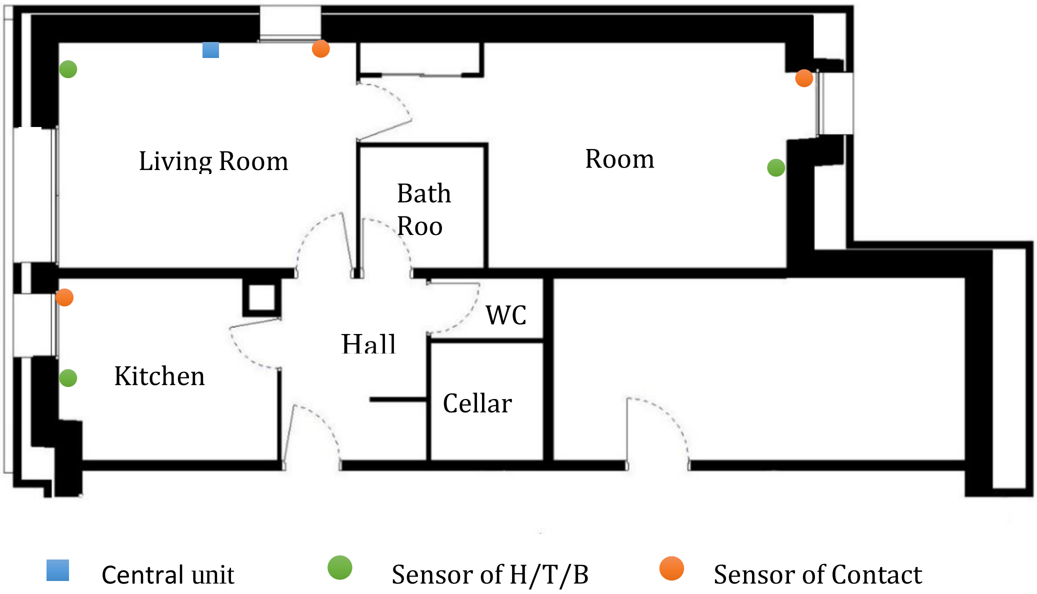


Figure 4.20 Instrumentation of apartment A

Apartment B was monitored with a multi-sensor module in the bedroom, living room and kitchen. One contact sensor was installed in the living room.

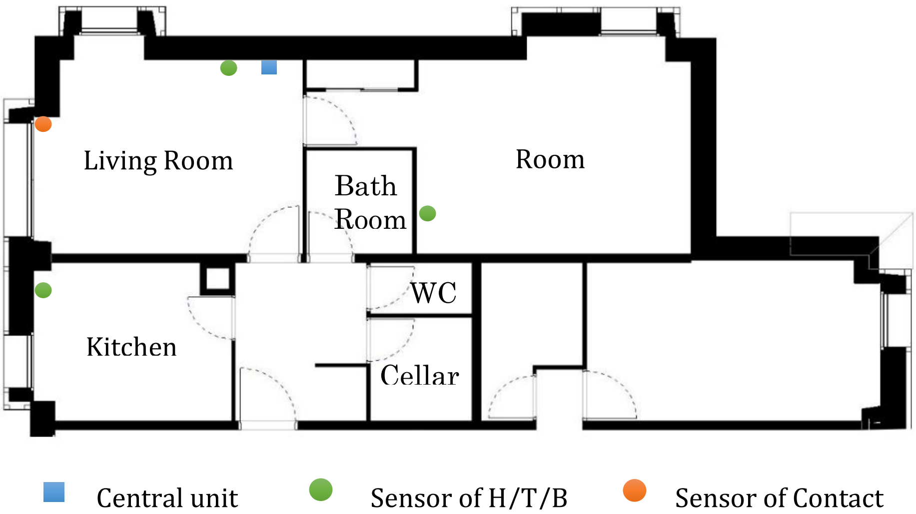


Figure 4.21 Instrumentation of apartment B

Apartment C was monitored with the multi-sensors unit in bedrooms, living room and kitchen. A contact sensor was installed in the big window of the living room while the central unit is installed in the kitchen.

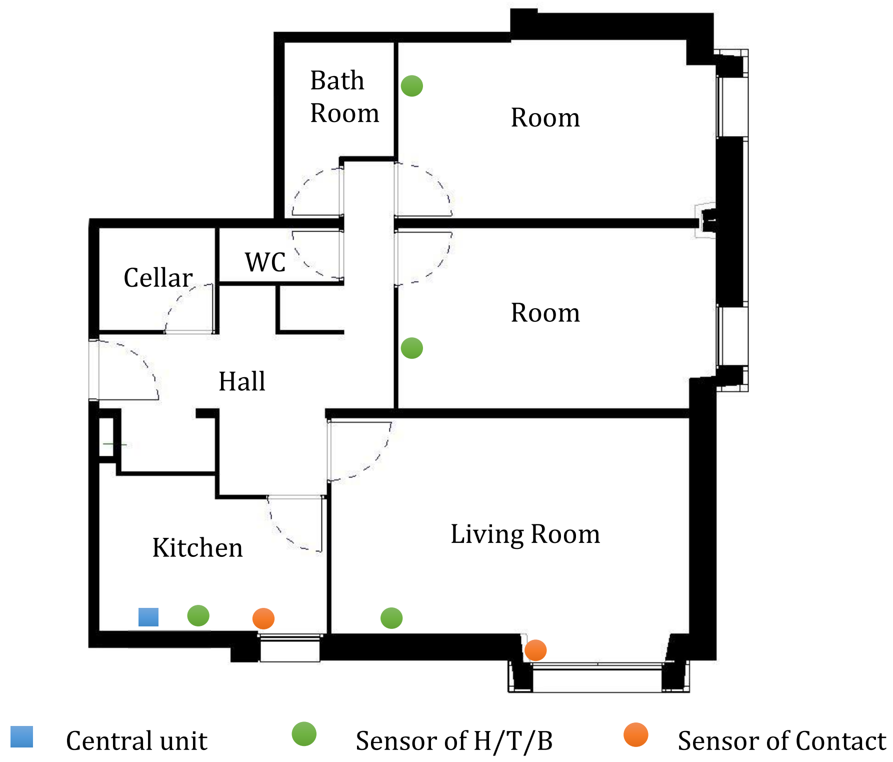


Figure 4.22 Instrumentation of apartment C

4.5.2 Visualization

The model allows a global 3D view of the building, and to point out alerts concerning abnormal events, tenants can access and visualize recorded data via web interface. Different visualization configurations can be figured out by attributing specific attributes to objects. In this way, only the outfitting corresponding to a specific layout can be displayed. In the Tennis residence, data is visible only by concerned tenants and information can be adapted according to personal needs. Figure 4.23 shows the principle of information visualization.

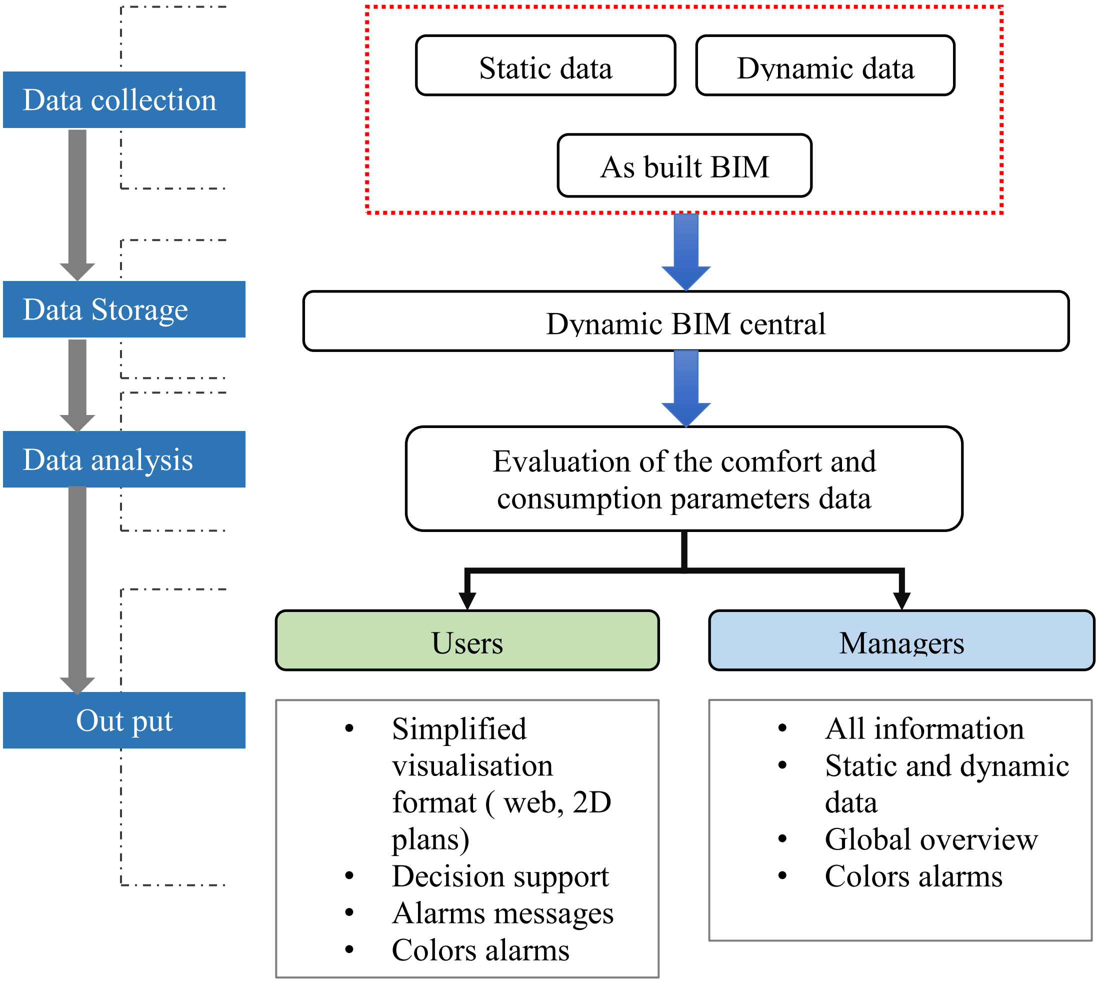


Figure 4.23 Principle of proposed system output

Figure 4.24 shows comfort parameters in the common space.

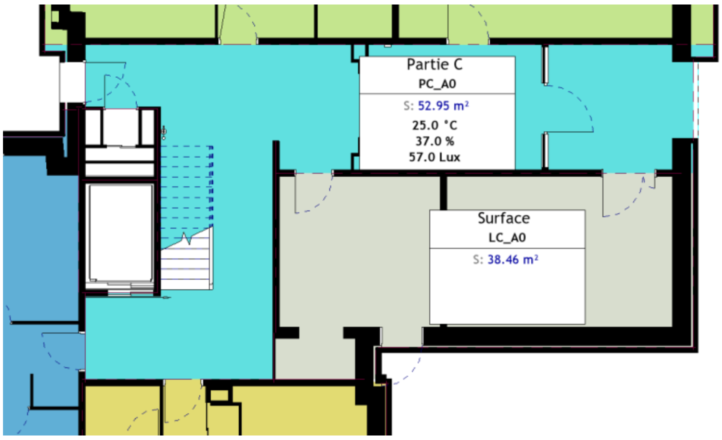


Figure 4.24 Result of visualization of real time data

The following example shows the situation on February 8, 2018 at 21:37. The recorded temperature is equal to 29.3°C and exceeds the temperature threshold; the humidity is equal to 33%. According to the recorded temperature and humidity, the apartment is in the discomfort area. The system attributes purple color.

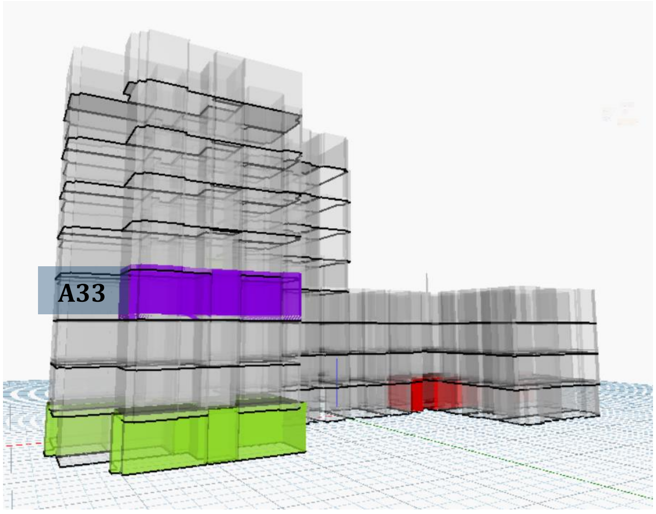


Figure 4.25 3D view of the alert system

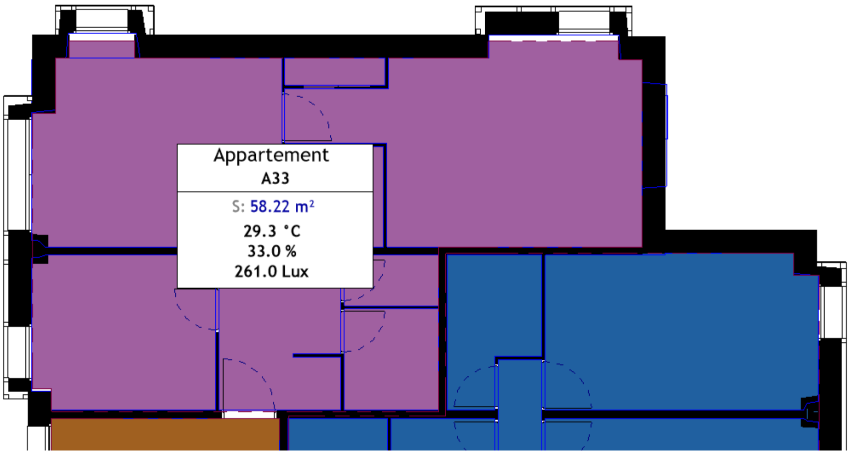


Figure 4.26 Real time data in an apartment

4.6 Conclusion

This chapter showed the development and use of a dynamic BIM for the real-time visualization of building operating conditions. Based on this capacity, the model could help in buildings management by the identification of abnormal events as well as their distribution. It could also help to evaluate the impact actions on building performances.

The dynamic BIM model could be easily adapted to meet specific requirements of buildings managers as well as users. It requires discussion with the buildings stakeholders in order to understand their needs and the way to use data visualization for building management. After this phase, the dynamic BIM model could be easily developed to consider privacy.

General conclusion

This work concerned the application of BIM for the management of existing buildings in order to improve their management.

The literature review showed the necessity to develop new methods for buildings management to reduce operating expenses, improve the security of both buildings and users and to ensure a high quality of life for users. It showed also the high capability of BIM to be used as innovative solutions for the optimal buildings management.

In order to explore and develop the use of BIM for the management of existing buildings, a BIM model was established for an existing social housing residence. The construction of this model was laborious, because of the absence or lack of data concerning the residence architecture, equipment and maintenance. However, this work resulted in the construction of a powerful BIM-based tool for the management of the social housing residence including the residence architecture as well as the plumbing, HAVC and fire protection systems. Furthermore, it integrates existing systems such as BMS and CAFM.

The use of the BIM model for the maintenance of some equipment of the residence showed the high advantage of this model in developing an effective maintenance of social housing buildings. The system uses dynamic visualization to provide actual state of the equipment as well as the equipment maintenance history and reports.

In addition the BIM model was connected to sensors used in buildings to track comfort conditions (temperature, humidity, etc.) as well as energy and water consumption. Thanks to the real-time data, historical data and some rules, the BIM model provides pertinent information and alerts both the residence manager and users.

A BIM model was also established for a research building in the Scientific Campus of Lille University. This one floor building was monitored by a large number of thermal and humidity sensors. Analysis of comfort conditions in this building using the BIM model showed some uncomfortable conditions related to the high temperature and humidity in some areas of the building. The system allows the technical staff to detect rapidly uncomfortable areas in order to take appropriate measurements.

The construction of BIM model for existing buildings is still laborious. However, according to our experience, this construction is worthy, because it highly improves buildings management and security.

This system could be extended to include predictive maintenance as well as some tools to reinforce user's involvement in the sustainable management of their buildings.

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Appendix A

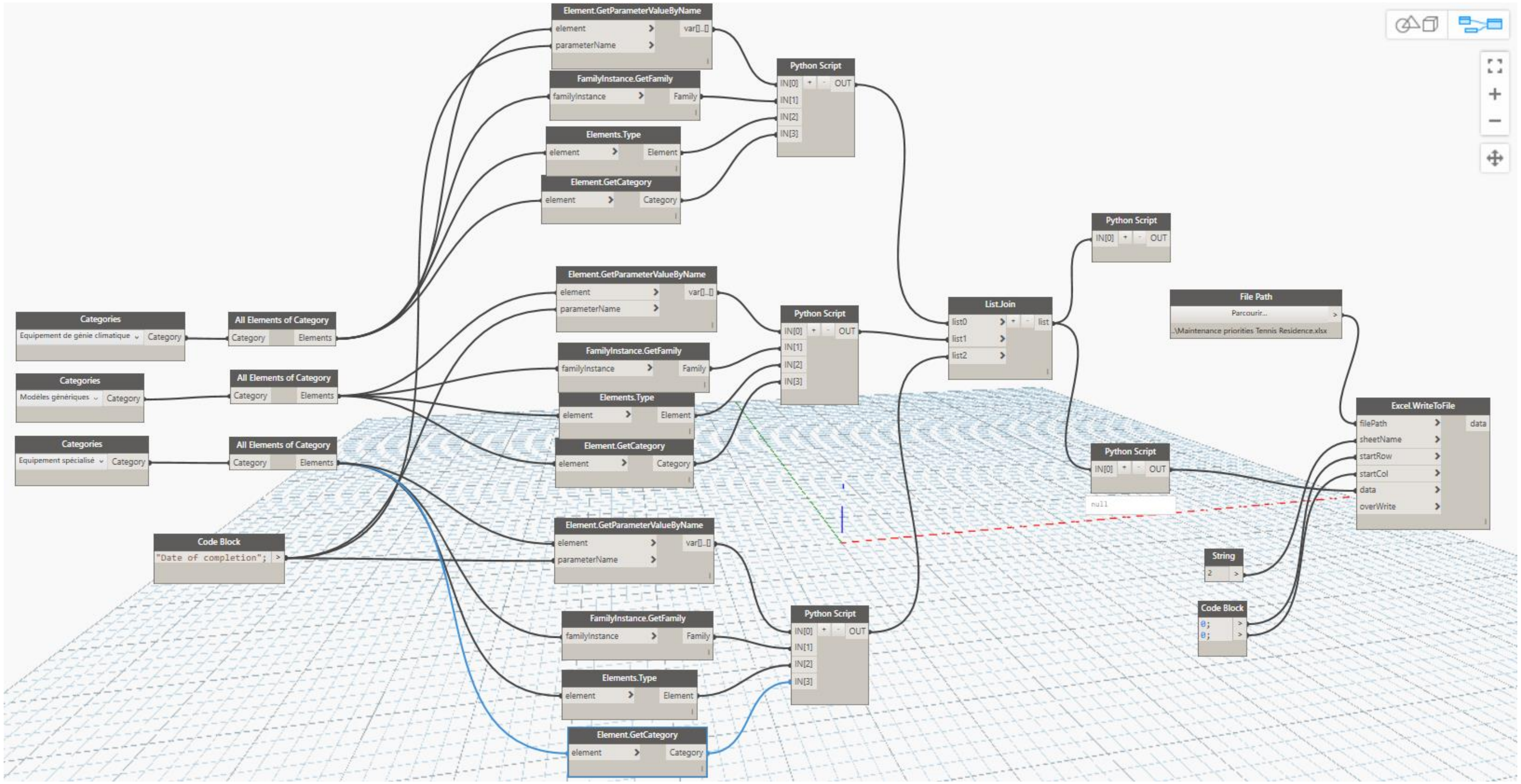

Figure A1 Script of prioritizing maintenance

Appendix B

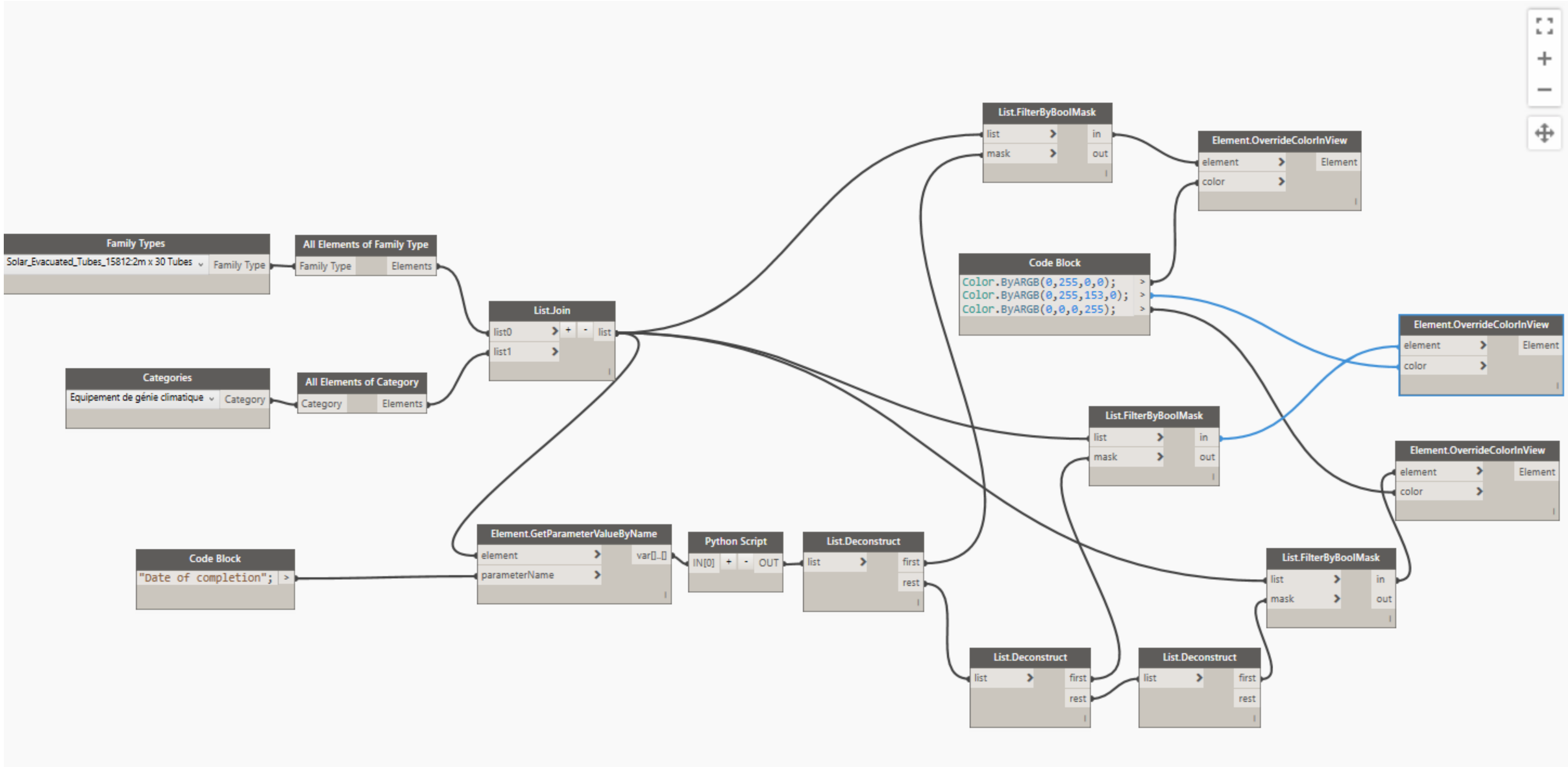

Figure B1 Script of dynamic visualization of maintenance