Université de Lille
École Doctorale Sciences pour l'Ingénieur
Laboratoire de Génie Civil et géo-Environnement

THÈSE

Pour l'obtention du grade de

DOCTEUR DE L'UNIVERSITÉ DE LILLE
Discipline: Génie civil

Par
TO Thi Huong Quynh

SMART ASSET MANAGEMENT OF SOCIAL HOUSING

(Gestion intelligente du patrimoine de logement social)

Date de soutenance : 11 mars 2019
Président du jury : **M. Zoubeir LAFHAJ**

Membres du jury

M. Aziz SOULHI - Rapporteur
M. Yasin FAHJAN - Rapporteur
M. Isam SHAHROUR - Examinateur
M. Zoubeir LAFHAJ - Examinateur
Mme Alia HATEM-QUIRIN- Examinateur
M. François BUYLE-BODIN - Directeur de thèse

ABSTRACT

The thesis discusses how the Smart building asset management model could help to meet buildings challenges by supporting asset identification, tracking and update building asset database, sharing asset information, creating smart decision-making processes and measuring performances of assets throughout building assets lifecycle. The Smart building asset management model is illustrated through an application to French social housing sector.

The thesis is composed of three parts:

The first part includes a literature review concerning the state of building asset management, current management methods and related challenges. It includes also a description of systems used in building management during building life cycle.

The second part describes smart technology and its implementation to optimize asset management during building life cycle. The smart building management model improves the management performances for both individual building and management organization.

The third chapter presents an application of smart asset management model to the social housing sector. Based on analysis of the challenges of the French social housing sector, it proposes an adaptation of the model developed in Chapter 2 to social housing sector. The proposed model is applied to Lille Métropole Habitat organization.

Keywords: Buildings asset, Management, Smart technology, Social housing, performances, Life Cycle

RÉSUMÉ

Ce travail de thèse explique comment un modèle intelligent de gestion de patrimoine immobilier pourrait aider à relever les défis des bâtiments en facilitant l'identification des éléments de patrimoine, le suivi et la mise à jour de la base de données patrimoine, le partage d'informations, la création de processus de décision intelligents et la mesure des performances du patrimoine tout au long du cycle de vie. Le modèle intelligent de gestion du patrimoine est illustré par une application au secteur français du logement social.

La thèse est composée de trois parties :

La première partie présente une analyse de l'état de l'art concernant la gestion du patrimoine immobilier, les méthodes actuelles de gestion de patrimoine et les défis associés. Il comprend également une description des systèmes utilisés dans la gestion des bâtiments au cours de leur cycle de vie.

La deuxième partie décrit la technologie intelligente et son implémentation pour optimiser la gestion des actifs pendant le cycle de vie du bâtiment. Le modèle de gestion intelligente des bâtiments améliore les performances de gestion pour chaque bâtiment et chaque élément d'organisation de gestion.

Le troisième chapitre partie présente une application du modèle intelligent de gestion de patrimoine au secteur du logement social en France. Il propose une adaptation du modèle développé au chapitre 2 au secteur du logement social. Le modèle proposé est appliqué au bailleur Lille Métropole Habitat.

Mots clés: Patrimoine Immobilier, Gestion, Technologie intelligente, Logement social, performances, Cycle de vie

Table of contents

List of Tables

List of Figures

List of Abbreviations

AM	Asset Management
EAM	Physical or Engineering Asset Management
BAM	Building Asset Management
PAS	Publicly Available Specification
ISO	International Standards Organization
COBie	Construction Operations Building Information Exchange
IoT	Internet of Things
SAM	Smart asset management
FMS	Facility Management Systems
CMMS	Computerized Maintenance Management Systems
CAFM	Computer-Aided Facility Management
CMMIS	Computerized Maintenance Management Information System
BTMS	Building technical management systems
BAI Model	Building Asset Interdependency Model
BTMS	Building technical management systems
BMIoT	Building Management Internet of Things
Smart BAM	Smart building asset management
KPIs	Key Performance Indicators
O&M	Operation and Maintenance
HLM	Habitation à Loyer Modéré
LMH	Lille Métropole Habitat
OECD	Organization for Economic Co-operation and Development
PMS	Project Management System
MEP	Mechanical, electrical and plumbing
SH	Social housing/ Social building

General introduction

The social housing sector is submitted to increasing challenges, related to the aging of this sector, from poor quality, degraded life environment, high running expenses, tenants' low income; as well as reduction of the public funding for this sector and increasing sustainability requirement to reduce both consumption of building (energy, electricity or water) and greenhouse gas emission.

Researches concerning asset management showed lack of knowledge about asset state, management strategy and weak coordination of stakeholders, which result in deterioration in building asset and asset management performances. Consequently, this sector requires innovation in both management methods and operation procedures in order to optimize efficiency and performances. This strategy should could beneficiate from latest developments in the use of smart technology in building asset management. Today, this technology is recognized as an indispensable for improving asset management. Some building management organizations have been deploying and integrating smart technology systems into their assets management. However, the smart technology is not yet used to optimize the entire asset management cycle.

Researches on building management mainly concern property management, asset management and facility management. In which, managing asset and facility have deep correlation because of their causal relationship. Indeed, while asset management considers building assets to improve their performance and condition, the facilities performance upgrades also. This research will focus on building asset management and facility management.

Therefore, to propose a smart asset management model for existing buildings, in particular social housing buildings, this research will analyse features of building asset management, from individual asset, to the building and management organization. The proposed model will use advanced technology in managing building asset to track for all original and real-time information of assets to create building asset database. The second goal is to build a smart-knowledge strategy for whole life cycle of asset management to improve the efficiency and quality of social housings. A strategy will be proposed for each process of building asset management, including performances evaluation. The final target of the smart asset management is to track the optimal management of the social housing asset by building an ecosystem where stakeholders (such as owners, contractors and users) work together for the highest benefit for all parties.

To simulate the effectiveness of the smart asset management system, a case study will be presented to investigate the current adoption and practice in managing a French social building management organization.

The thesis is composed of three chapters.

The first chapter presents the state of the art in building asset management and related challenges. It includes invention of conventional methods used in building asset management. It describes also systems used in building management, their characteristics and what happened during building life cycle; the major challenges in building management, such as lack of information, interoperability, difficulty to manage the existing buildings with available valuable data and optimization of energy consumption also discussed.

The second chapter discusses smart technologies and their implementation for building asset management. It shows the advantages of the combination of intelligent tools into management processes as well as organizational activities. It details the adoption of advanced technologies to optimize asset management for the building life cycle. It presents how smart technologies could be combined together to make a smart asset management system. It presents the creation of the smart building management model with management strategy and methods for both individual building and management organization.

The third chapter presents an application of smart asset management model to the social housing sector. Based on analysis of the challenges of the French social housing sector, it proposes an adaptation of the model developed in Chapter 2 to social housing sector. The proposed model is applied to Lille Métropole Habitat organization.

CHAPTER I. LITERATURE REVIEW

1.1 Building asset management – what does that mean

1.1.1 The definitions

The study from recent researches shows that there is no clear definition of building asset management. According to (Amadi-Echendu *et al.*, 2010), "Building management" or "Building Asset Management" (BAM) is one part of Engineering Asset Management (EAM) in particularly or Asset Management (AM) in general, and takes care one specific kind of asset: building (Fig 1.1). Therefore, it takes all characters and natures from AM to EAM as well, and also under control of ISO 55000 (the International Organisation for Standardization) – the development from Publicly Available Specification 55 (PAS 55) as the based- document. Thus, to understand how to manage building asset, a competently study about AM and EAM from where they formed (ISO 55000, PAS 55) is an important requirement.

ISO 55000 and PAS 55 had been introduced by the collaboration between The Institute of Asset Management (IAM) and the British Standards Institution (BSI) with several other organizations. It is a specification standard for managing assets, which is known as a provider of an impression on "what needs to be done to manage physical assets for business objectives at any moments in its life cycle" (Alfatih, Leong and Hee, 2015). For these purposes, AM had defined in clause **3.2** of PAS 55 as:

"systematic and coordinated activities and practices through which ***an organization optimally*** *and sustainably manages its assets and asset systems, their associated* ***performance, risks and expenditures*** *over their* ***life cycles*** *for the purpose of achieving its organizational* ***strategic plan****"*

And, in clause **3.25** the definition of strategic plan of organization is:

"overall long-term plan for the organization that is derived from, and embodies, its vision, mission, values, business policies, stakeholder requirements, objectives and the management of its risks"

After PAS 55, in 2014, the ISO 55000 standard has developed a well-considered definition for asset management (clause 3.3.1) that much broader in scope: *"the coordinated* ***activity*** *of an organization to realize* ***value*** *from* ***assets****",* in which an asset (clause 3.2.1) is an *"item, thing or entity that has potential or actual value to an organization".* Besides this definition, there are some notes for it state that:

- “*realization of value will normally involve a balancing of costs, risks, opportunities and performance benefits*;

and the term

- *“activity” has a broad meaning and can include, for example, the approach, the planning, the plans and their implementation"*

In ISO 55000 (and PAS 55 before it), AM demands a disciplined approach to effectual implementation that is useful for managing building asset. This approach could allow a building management organization to maximize building assets’ value and achieve its strategic objectives by the effective asset management during whole life cycles of its assets. This comprises determinative of relevant assets to create or acquire in the beginning, the best procedure of operating and maintaining them, and the adoption of various options: optimal renovation, decommission and/or disposition (British Standards Institute, 2008).

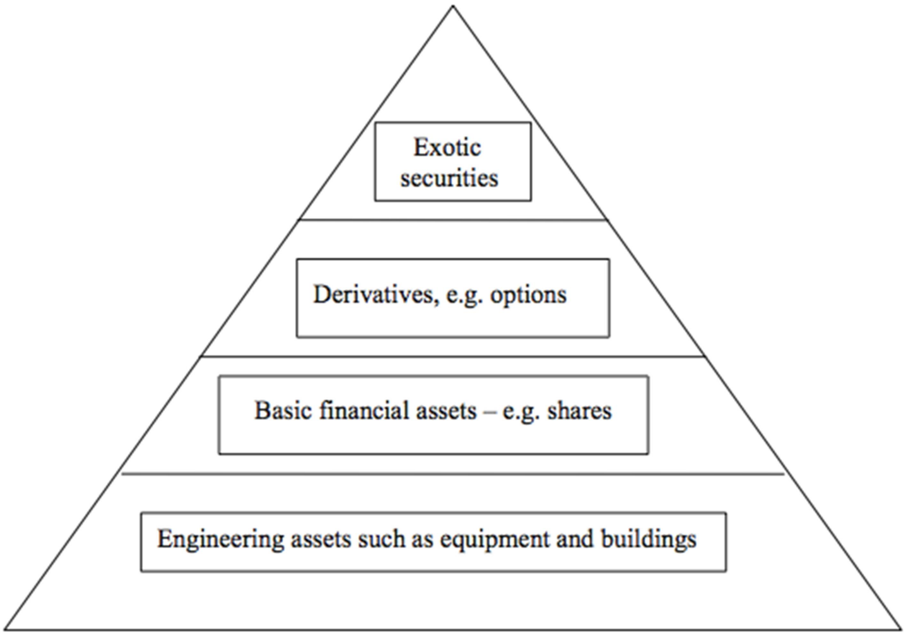


Figure 1.1. The fundamental nature of engineering assets (Amadi-Echendu et al., 2010)

Conclude from others researches, EAM, in general, mention to management activities of the engineering assets like: buildings, equipment (Fig 1.1). (Amadi-Echendu *et al.*, 2010) expressed that EAM requests a system of information to collect useful data supporting for making decisions. Therefore, it cannot be denied from all the aspects and state of building assets that BAM - as a part of EAM - is a multidisciplinary approach, including management, economics, and information technology. BAM's decisions spread over a wide range of areas from operational to strategically aspects. In order to achieve the business objectives for an organization that owns or manages building assets, the concerning of BAM is the building asset life cycle management.

In brief, applying all definitions of AM in general and EAM to a specific engineering asset type – buildings – BAM could be defined as ***a system*** enabling ***building's stakeholders*** to extract the most value from their ***building assets***. This system is broad in scope, covering a wide variety of areas, including ***all activities*** related to building assets from ***operation/maintenance to upgrade/ renewal*** for their ***whole lifecycle***. BAM system has diverse missions: ***performance management, risk, and cost*** for achieving its ***organizational strategic goals***, not only of ***building assets*** but also of ***this organization***.

This approach will take as its starting point the conceptualization of BAM system, including its objects, scope, and missions, to provide a basis for analysing BAM general problems and challenges, exploring possible solutions to upgrade its capability. In this research, the term "Building Asset Management" will be used to mean the integration of three disciplines: engineering, management, and finance, which are together applied to the stewardship of the building assets.

1.1.2 Related objects of building asset management: Stakeholders and building assets

1.1.2.1 Individual building Assets and building asset systems

Assets are the major buildings' components, for example, doors, floors, plumbing, stairs, corridors and so on. Building Asset Management (BAM) is a supported framework for management and decision processes, which covers the building assets' service for the whole life, "from cradle to grave" (CHOA's, 2013). It could manage both, tangible assets such as building components, elements, equipment and intangible assets such as designs, software, and financial assets. Because the scope of the study is limited, only tangible fixed assets of buildings are studied. Therefore, starting from here, the term "building assets" in the research refers only to the types of tangible fixed assets.

Agreeing with the point of view of CHOA's researches, building assets can be divided into seven fundamental physical systems: Structure, enclosure, electrical, mechanical, fire safety, interior finishes& amenities and site work (Fig 1.2).

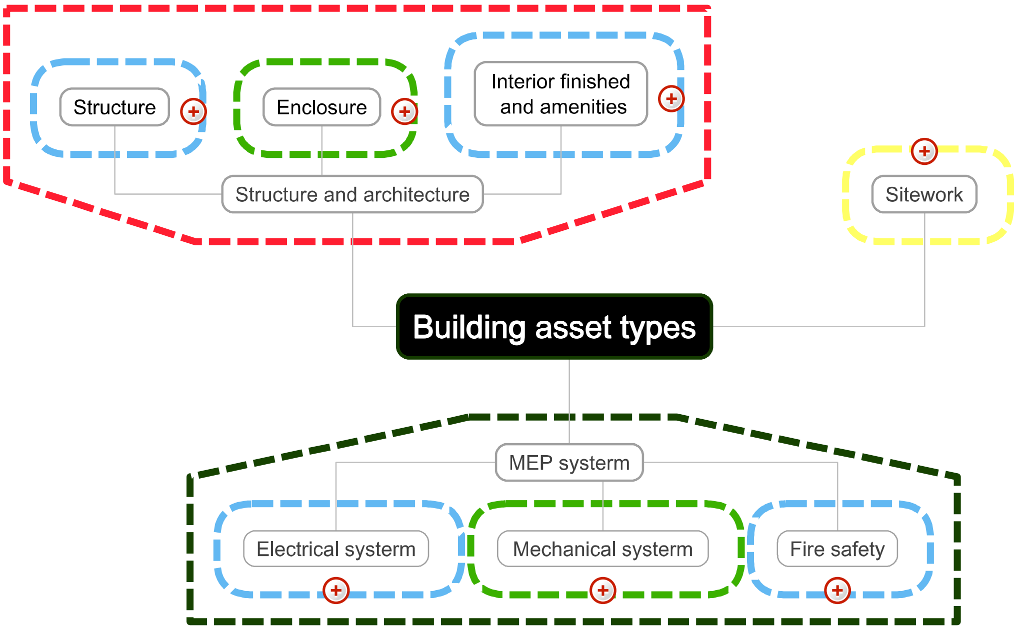


Figure 1.2. Building assets' types (CHOA's, 2013a)

However, things will be much more complicated while accessing into inventory field. Each asset has separately operation, maintenance and renewal planning, so from seven basic systems, managers have to separate out "many hundreds of different types: roofs, windows, doors, boilers, light fixtures, pumps, fans, floor finishes, fire extinguishers, emergency exit signs, elevators, smoker detectors… and the list goes on" (CHOA's, 2013a) (see figure 1.3, 1.4). In addition, almost every building is unique, so the list of assets aggregated from all the buildings concerned by an organization – building asset systems- can multiply over and over if calculate in total.

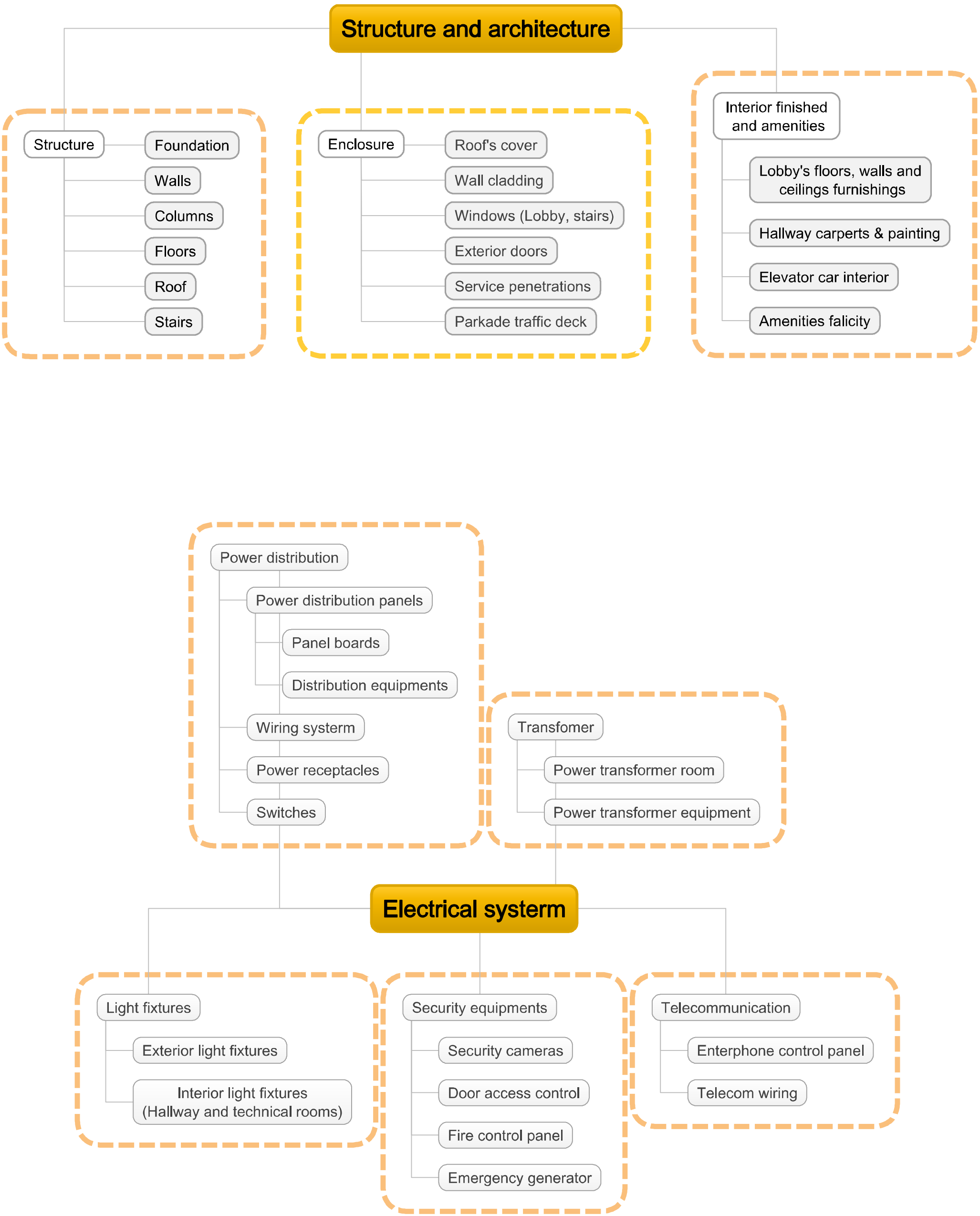


Figure 1.3. Details of Building assets' types –part 1 (CHOA's, 2013a)

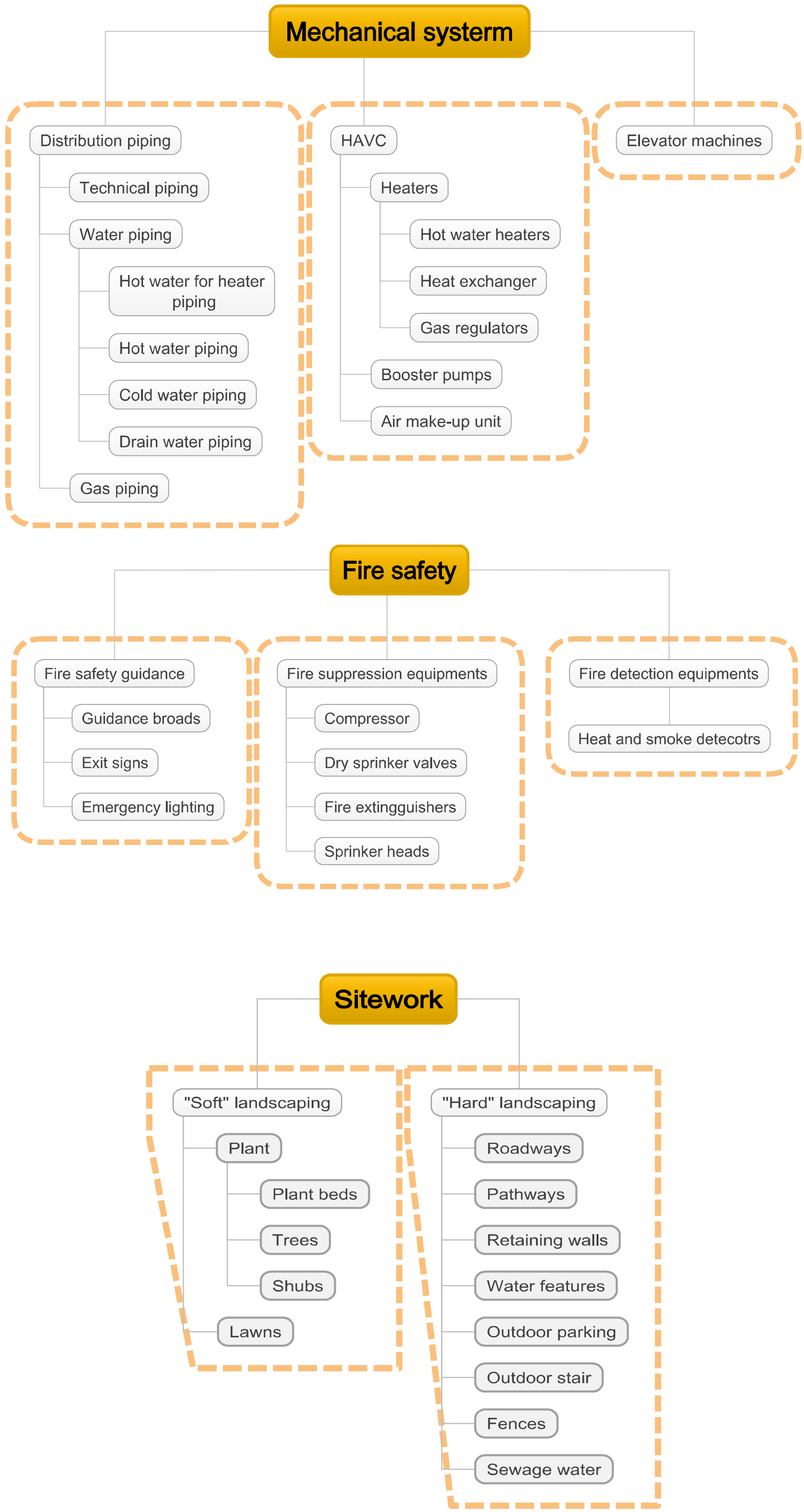


Figure 1.4. Details of Building assets' types – part 2 (CHOA's, 2013a)

1.1.2.2 Stakeholders of building assets

Building asset management is long-term and complicated. It requires effort contributions and consultants from involved parties from forming to using of property in order to succeed. Figure 1.5 points out all stakeholders in building sector. The first group-contractors- combines of the ones related to both construction and operation period. They are architectures or engineers of design consultant and building contractors corresponding to each asset types. They have responsibilities and duties, in order are author supervision and warranty in the using period. They also can be maintenance - renewal contractors or subcontractors, play an important role in managing building assets during operated period.

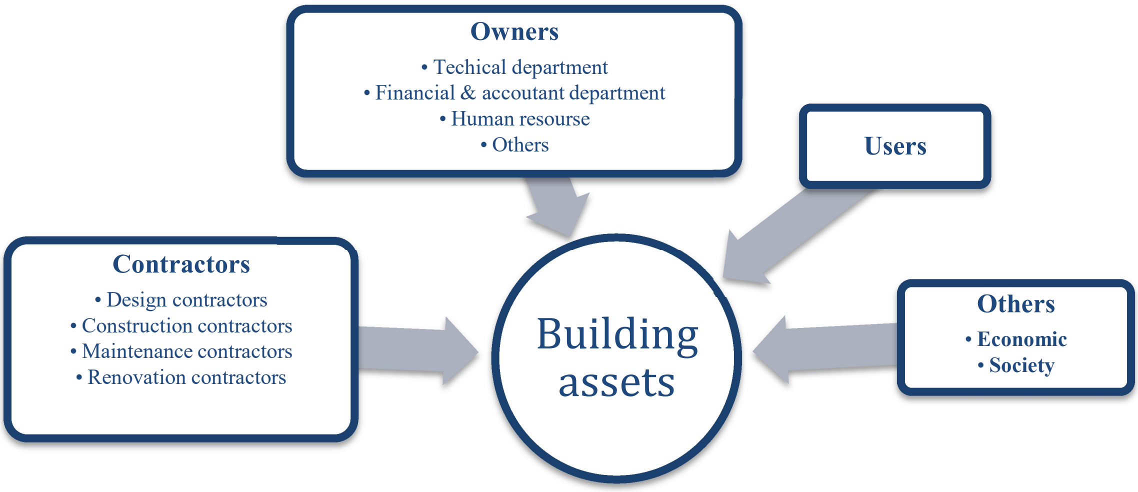


Figure 1.5. Stakeholders of building assets

The second is the group of owners/holders/shareholders. In general, they can be an organization or an individual. According to the aims of the research, only management organizations which hold a number of buildings are concerned. As identified previously, BAM system is the incorporation of overlapping interdisciplinary activities that controlled many building asset- related activities. It coordinates parties of an organization to undertake asset-related activities, for example:

- ➢ Establishing the requirements to enable investment, funding and budgeting, cost analysis and decision making demand the indispensable presence of procurement, finance, and accounting divisions.
- ➢ Establishing the required information flows to facilitate linkages and integrate across all asset-related activities and create a database is commands for the information technology department.

- Establishing the required development in assets or asset- related processes and the suitable technology or any new developments in technology for use in enhancing performance is the support and development mission of the technical division.
- Working for better performance, less risks, and safe environment is considered by human resources, inventory, quality and safety systems departments.
- Especially, sometimes there are also external suppliers or outsource for managing building asset's life cycle.

The third group - users- hold not less important position to BAM strategy. In fact, all their daily activities and requirement as one of the main goals of BAM have a direct effect on building assets and BAM strategy.

The last group – others- has benefits from BAM system, through performance, success of organizations (contractors/ owners) or impact of others stakeholders' activities.

Table 1.1. Stakeholders and their role during Building Asset Life Cycle

Building Asset Life Cycle Activities	**Supporting Activities of**									
	Contractors				**Owners**					**Users**
	Design contractors	Construction contractors	Maintenance contractors	Renovation contractors	Technical Support and Development	Procure-ment	Human Resources	Finances & Accounting control	IT/IS, Quality & Safety	
Research, Engineering & Design	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	NA
Acquisition, Development & Installation	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	NA
Operation (Utilization/Use)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Maintenance (Care/ Service)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Replacement, Retirement & Disposal	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Renovation/ Upgrade	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Yes: *Supporting for the activities –* ***No****: Not supporting for the activities –****NA****: Do not know yet*

1.1.3 The lifecycle of building assets and BAM lifecycle activities

Even though one building is unique and varies in the need for maintenance, repairs and asset renewals due to its factors, such as the quality of construction, design details, exposure conditions and the standards established by the owners and their BAM management team, stages and expenses of a building during its life cycle can display the same. As results of many researchers, we all accept that the life cycle of building generally can be divided into five stages base on the maturity and activities of building during its lifecycle (Figure 1.6). This stage dividing can apply for all building sectors: residential, institutional, commercial, industrial, and municipal (CHOA's, 2013a).

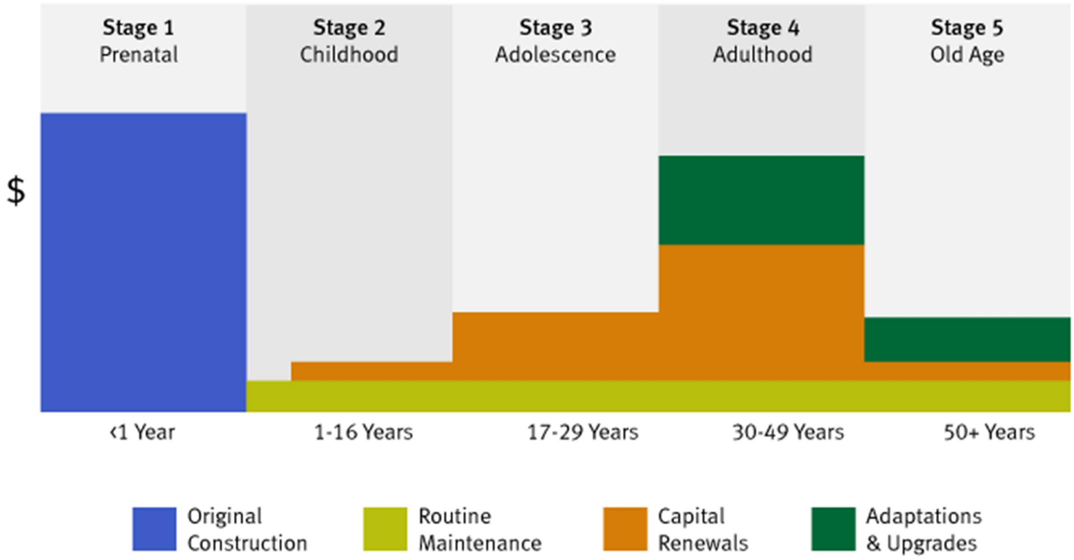


Figure 1.6. Stages and expenses in Building life cycle (CHOA's, 2013a)

a. "Pre-Natal" Stage (Under 1 year)

The building has the first life stage, which depended on the types of warranties on the project, occurred up to the end of the first (or second) year. In this stage, the building is handed over from the developer to the first owners. During this early stage in the life of the building, a variety of warranties still cover its new assets, so cleaning activities and periodic inspections are simple maintenance requirements must be focused on.

The first stage maintenance work is conducted base on the prescribing warranties, including inspections to identify any warranty defects. Repairs and Renewals rarely happen during this very young stage of the building's life. If there are any necessitated repairs or renewals occurred without un-careful cautions of owners or normal wear and tear or other such matters, the building provider would be one has to provide legitimate warranty services.

When the initial one-year, 15-month, and/or two-year warranties have expired, additional longer-term warranties, such as five- and ten-year warranties, are transit into the next stage - “childhood stage”. At the end of “pre-natal” stage, appropriate maintenance procedures for whole building lifecycle need to be established, including full information to demonstrate lately maintenance service contracts and maintenance log-books in the future.

b. “Childhood” Stage (2-16 years)

The second life stage of a building is 15 years, from about the 2nd anniversary to about the 16th year. During this period, full responsibility for all the maintenance, repairs and long-range renewal planning for the building, has been assumed by the owners.

Maintenance tasks are still focused on a combination of cleaning activities and inspection activities. For repairs/ renewals activities, at Stage-2, the owners will have to start with miscellaneous repair or replace projects for few required assets such as small motors (water heaters, pumps), or interior/ exterior painting, hallway carpeting, etc. Owners have to recognize that their short-life assets (those assets with useful service lives of 15, 10, 5 years or less) will require cyclical replacement in this period and during all the subsequent life cycle stages of the building. With management plans or strategies which consider the big-picture view over the life of building, owners could avoid nuisances for their objectives in present and future.

c. “Adolescence” Stage (17-29 years)

Moving to the third stage of buildings' life, though maintenance continues to be focused on all critical assets, owners have to face a dramatic shift in the number of presented challenges. Firstly, there is a significant increase in the amount of repaired or renewal projects due to the assets' age. Many assets are designed with a 20-25 year useful service life, so, closer to the end of this period, more and more assets are near the end of their design service lives.

Secondly, these big numbers of building assets that are deteriorating and reaching the end of their useful service lives require the much bigger maintenance budgets than the one established during the 2nd life stage to address the impending replacement. In case lack of budget, a few of the projects that would typically occur in life stage 3 may be postponed until the 4th life stage. To reduce this risk, owners must consider seriously their budgeting practices and make reasonable funding allocations.

The third challenge is the prone technological obsolescence of some assets, particularly electronic or MEP components may be no longer manufactured, it makes difficult to find replacement parts. This is one of the primary reasons why owners need to build long-term plans managing building asset (ie., like the 30-year plans or the window into the future). This enables the owners to anticipate and prepare proactively for the majority of the asset replacement projects during the building lifecycle.

*d. **"Adulthood" Stage (30-49 years)***

The fourth stage of a building begins at about 30th year. Owner faces similar kinds of challenges of the 3rd stage, but with the increase of capacity and intensity. Indeed, though essential maintenance has no dissimilarity with the earlier life stages, asset renewal projects occur during the 4th life stage are the largest and most expensive. It is due to some of the shorter life assets (that were replaced in earlier stages) will now require their next round of renewal. Besides, a facility containing a range of assets of different ages and deteriorating at different rates now challenges for owners and their property manager.

*e. **"Old Age" & Beyond (50+ years)***

At about 50th year, the 5th life stage of a building commences. There is no specific evidence about the direct correlation between the age and the condition of a building. The necessary and sufficient maintenance, repair, and renewal processes can keep older building in good shape; even return them to life Stage-2. Similarly, the failure or inadequate processes can lead to the poor condition of new buildings.

In reality, most buildings will continue to operate for many decades beyond their 50th anniversary. There is the fact that buildings tend to have renewal or upgrade instead of rebuild due to recent sustainable construction policies. After this juncture, all the major assets could have one renewal cycle; however, assets condition would be based on not only the efficiency of renewal or upgrade projects but also the previous management performance. Therefore the necessary and sufficient maintenance during all asset lifecycle stages, coupled with timely repair/ renewal of assets, will ensure that the owners receive many decades of good value from their real estate investment.

1.1.4 Building asset management benefits

Optimizing life cycle asset management could bring back numerous benefits to the organization. Among them, some namely principal improvements of a successful AM system include:

- Optimized cost and return on operation or investment. So, even within a constrained funding regime, the best value-for-money ability is still demonstrated.

- Improving asset or asset system performance (quality, health, safety) and environmental performance (energy, resources, waste, etc.). Thus, customer satisfaction is enhanced together with sustainable development is actively demonstrated.

- Having adequate evidence for demonstrating legal, regulatory and statutory compliance, reducing risk through long-term planning, confidence, and performance sustainability, controlled and systematic processes;

The benefits above are all that social housing owners anticipated solving their problems and meeting their challenges. Therefore, the following assignment is determining the essential elements to be implemented successfully the BAM system.

1.1.5 Building asset management system

(British Standards Institute, 2008) has given an entire and intelligible concept of AM system in PAS 55 (Fig 1.7). As one kind of assets, building asset also could be managed with similar model.

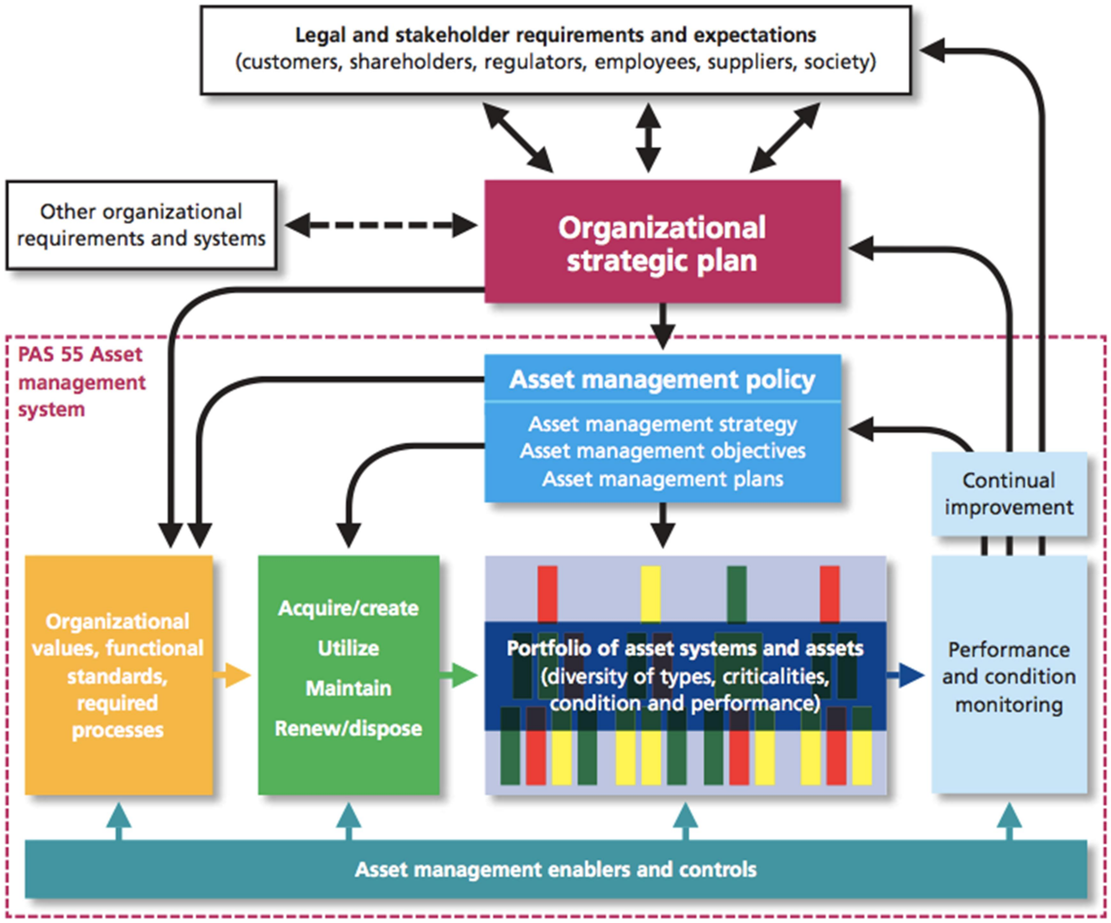


Figure 1.7. Structure of AM system in the relationship (British Standards Institute, 2008)

Figure 1.7 indicates that the core of BAM system is ***BAM policy, strategy, objectives, and plans***; with the development starting point is the organizational strategic plan. Then, in their turn, they direct the optimal combination of life cycle activities to be applied across the diverse portfolio of asset systems and assets (in accordance with their criticalities, condition, performance and chosen risk profile of the organization). In the BAM system, the importance of monitoring and continual improvements within its elements is highlighted (such as the asset management strategy will be optimized with the asset performance). It the importance of continual improvement has externally demonstrated through direct influence upon the organizational strategic plan and stakeholder expectations.

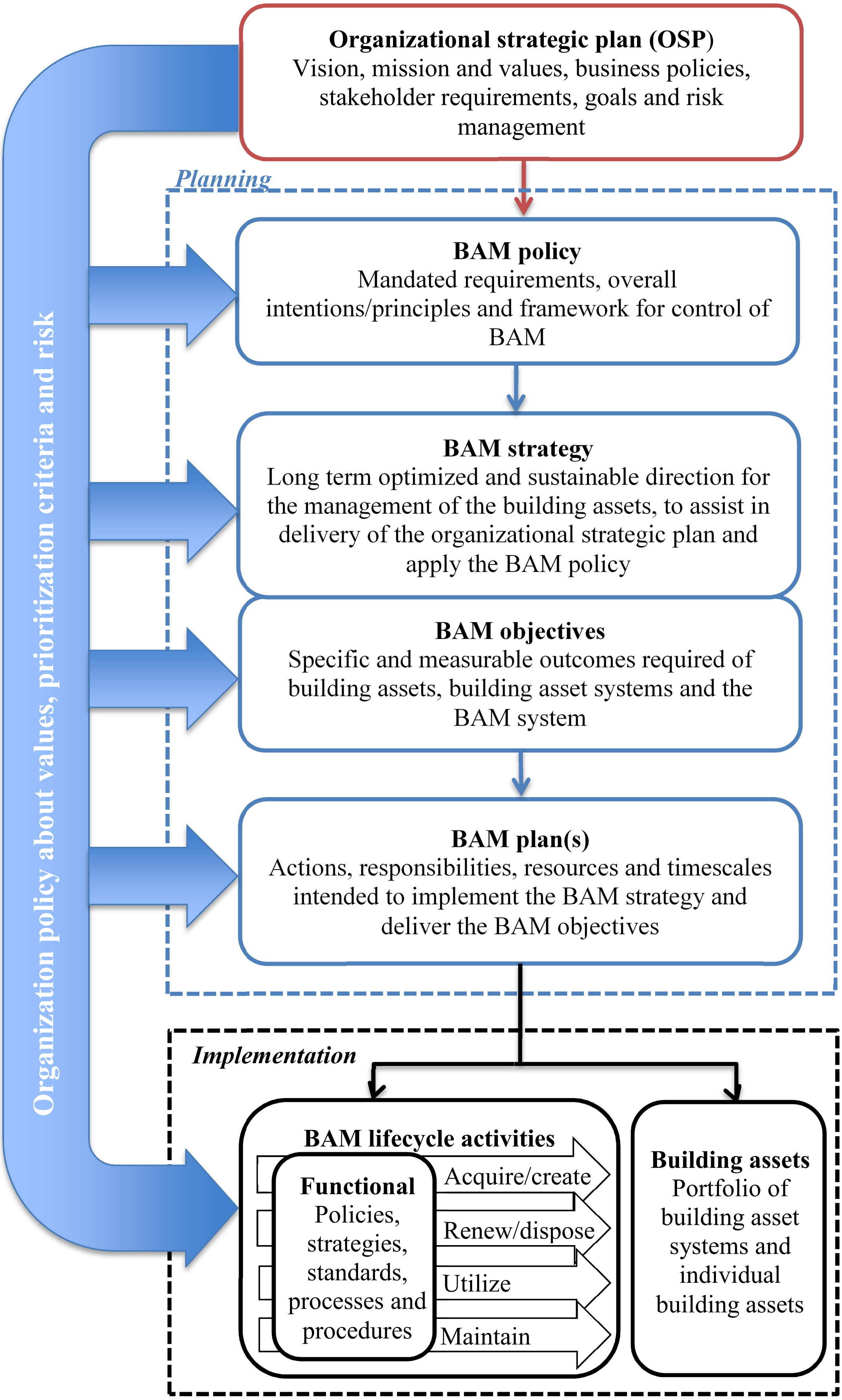


Figure 1.8. BAM system's elements: Planning and implementation – The adaptation of AM system (British Standards Institute, 2008)

(British Standards Institute, 2014) stated that the strategic asset management plan (AM strategy in PAS 55) is the combination of "documented information that specifies how organizational objectives are to be converted into asset management objectives, the approach for developing asset management plans, and the role of the asset management system in supporting achievement of the asset management objectives". It means the strategic asset management plan is the principal road leading an organization to its AM objectives and, furthermore, its objectives.

It also could be intelligible from what exhibited in Figure 1.7 and 1.8 that the ideal BAM plans will yield optimal asset management results. These ideal plans are the implementation and realization of one BAM strategy to deliver to the BAM objectives. Considering all BAM system's elements, it may notice that the acquired performance of BAM systems with accurate policies and objectives depend primarily on whether the BAM strategy is effective. Therefore, a continual improvement for BAM strategy will deliver the better building asset system performance, is the most effective way to face with the challenges of the building sector in general and social housing in particular.

1.1.6 Building asset management strategy (PAS 55) or strategic asset management plan (SAMP) (ISO 55000)

The studies above about BAM system and its elements manifest that for each organization, with diverse legal and stakeholder requirements and expectations (customers, shareholders, regulators, employees, suppliers, society), will have dissimilar organizational strategic plans and formulate its own. Then, from dissimilar organizational strategic plans (which various in vision, mission, values, business policies, stakeholder requirements, goals and risk management), divergent BAM policies will be constructed. Therefore, BAM strategy of an organization, which is the BAM policy's application of this organization and with the mission of assisting in the delivery of this organizational strategic plan, may be far different from the one of another organization.

As stated in PAS 55, an established BAM strategy must "identify the function(s), performance/condition of existing asset systems, especially critical assets", then considering about "the clear approach and principal methods by which assets and asset systems will be managed", finally "monitor and measure the performance of the asset management system and the performance and/or condition of assets and/or asset systems" for BAM system improvement. It means owners have to prepare the good material - information of building asset system, to apply the desired methods of optimization and decision-making suitable for all relevant stakeholders, and evaluate results obtained to make some changes if necessary. These three major factors that make the success of BAM strategy, or further, the BAM system, are going to study in the next section..

1.2 Conventional methods used in Building asset management

Similar to manage assets in general, planning a perfect BAM strategy is the key to achieve BAM objectives. To determine this strategy, the organization need to take into account creating the full - complete information database of its building asset system and the relevant methods and criteria are employed for decision making/prioritizing/ performance monitoring of the activities and resources, or in managing its building assets over their lifecycles.

1.2.1 Building asset management system information

ISO 55001 perceives that “Asset information systems can be extremely large and complex in some organizations, and there are many issues involved in collecting, verifying and consolidating asset data in order to transform it into asset information”. Asset information system is the combination of Asset information strategy, Asset information standards, Asset information systems and data & information management, which covers all information related to AM system activities in Fig 1.7 (IAM- The Institute of Asset Management, 2015). To build this information system, the organization will necessitate the collaboration and mutual support among many parts of them and other stakeholders related to asset activities. This coordination normally requires the sharing involved resources. In the complex sector like building, the asset information system is already huge since the beginning due to various building asset types and diverse stakeholders. Its amount could be much bigger in case the organization has several buildings in charge.

Moreover, over time, the maintenance, repair, and renewal or upgrade regularly during building lifecycle make asset managers could not stop adding more and more information to this database. In addition, these kinds of information may not come from one source (Contractors/ Sub-contractors, organizational departments, legal, costumers…), in dissimilar formats (Drawing plans, Document reports, Calculated sheets…), and different forms (Printed documents, digital files…). With the manual method in used, there is no denial that building asset managers had to work diligently to process, update and store, provide asset information for the operation processes, decision-making and assessing BAM for the entire building life cycle.

1.2.2 Decision-making methods

(Grussing, 2014) presented the excellent review about "Life Cycle Asset Management Methodologies for Buildings". In which, Grussing acknowledged that methodologies and tools of BAM practices have exploited much more slowly to compare with what existed in the civil infrastructure domain for decades.

However, while building managers would like to apply these same techniques to buildings, they meet many challenges. The large part of these challenges is because of the complexity and diversity of building structures (such as the variety of construction disciplines, building use types, construction types). In addition, their stakeholders profile leading to various performance requirements that make the consistent management of building asset domain difficult. Therefore, in order to establish an effective asset management process for buildings, researches have shown that it needed to use various methods following each BAM strategy's step to achieve the desired perspective as analyzed in the section above.

Before, Lifecycle cost methodology is the most popular method to be used in managing building assets. With this method, decision-making processes use the total lifecycle cost calculates as the sum estimated lifecycle costs of all buildings belonging to the organization. The estimation is based on plans of maintenance in a short/ long term, and renewal/upgrade during the lifecycle of each building. One planned cost can be established by the concept or design of a building (material, characteristic and so on) from several plans or each for one type of asset. However, getting into reality, some risk can occur after that makes the owners must have to change their plans frequently.

Table 1.2. Comparison of cost-based and value-based asset management approaches (Srinivasan and Parlikad, 2017)

Approaches	**Cost-based (traditional)**	**Value-based (recommended)**
Core focus	Cost	Cost, risk and performance
Management philosophy	Minimize expenditure while maintaining satisfying performance requirements	Maximize performance while satisfying budgetary constraints
Stakeholder focus	Decision maker or asset owner	All stakeholders of the asset
Impact on service	Maintain minimum service levels	Explore innovative approaches to improving service levels
Difficulty	Well-established body of knowledge	Concepts not well understood
Decision focus	Generally focuses on asset-specific issues	Focuses on system-level dependencies and business value

Value-based asset management approach is much more complete than the cost-based one. Nevertheless, the value-based concept still not be studied deeply and not well knows understood. In addition, the difficulties in measuring values and risks are often the cause of uncertainty about expected benefits/losses, particularly in the case of managing such complexity and diversity assets as building assets. Thus, how then can an asset owner obtain the value-based methods within their BAM system?

In order to develop value-based asset management, it is essential to understand what constitutes the ‘value’ of building assets. This can be understood from the top-down and bottom-up perspectives. The top-down value is associated with organisation- level aspects such as business model, while the bottom-up value is attributed to the asset or the asset systems and its functionality, which allows value generation. The business model and objectives of organisations drive the different types of value required by various stakeholders. From the top-down perspective, the value generated by a building asset is attributed to the ability to deliver the intended functionality at the required level of performance while satisfying various stakeholders' objectives. It is important to note that the achievement of functionality needs to take place at the acceptable level of expenditure with clear understanding of the impending risks. Therefore, value-based asset management is about finding the optimal balance between cost, risks and the associated performance over the life cycle of the building (Srinivasan and Parlikad, 2017).

1.2.3 Performance measurement

William Edwards Deming was correctly quoted as saying, "You can't manage what you don't measure", when in fact he was adamant that the management of an organization couldn't be run on visible measures alone. His concerns were related to the long-term consequences that organizations confront but that cannot be measured in advance. It is with this awareness in mind that the theory of BAM is (IAM- The Institute of Asset Management, 2015) an integrated study. BAM can be described as a way to plan in advance by substantiating the validity of a decision with information and measurements. These decisions can then be used to justify future strategic processes and outcomes regarding building assets. Thus the statement can be made that these strategic processes are partly biased towards the interpretation of information collected from individual building assets and from an encompassing building asset network.

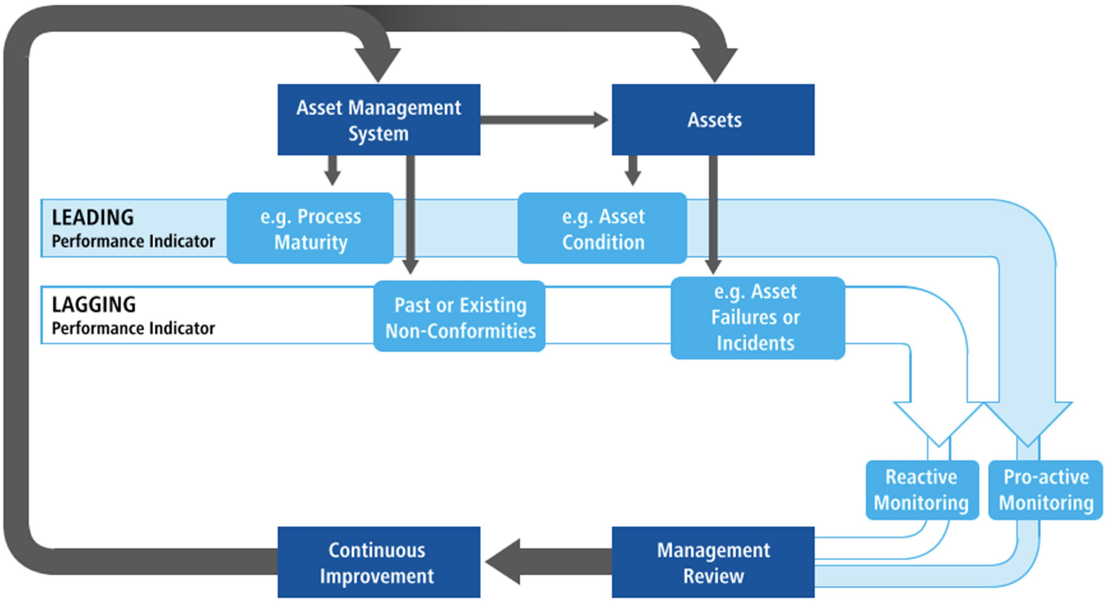


Figure 1.10. Performance measurement for assets and the Asset Management System (IAM- The Institute of Asset Management, 2015)

From PAS 55 to ISO 55000, performance measurement is much shorter in definition, but stable in content (Fig 1.10) (IAM- The Institute of Asset Management, 2015). Measure BAM system performance can use either quantitative or qualitative methods, as long as the results appropriate to the evaluation needs of the organization. The evaluated findings are in use to monitor the assurance of BAM operations as intended in their ability, such as the asset management system and assets and/or asset systems, activities, processes, products (including services), systems or organizations. With the large scope of BAM system, the organization must consider and nominate the parameters for measurement, the frequency of performance monitoring with the minimum of the costs of monitoring, the risks of failure or nonconformity. BAM system performance assessing requires leading performance indicators (Key performance indicator system -KPIs) to provide warning of potential non-compliance with the performance requirements, lagging performance indicators to enable detection of, and to provide data about, incidents and failures of the asset management system, and for incidents, failures or deficient performance of assets and/or asset systems.

However, organizations' managers are normally not very clear about how many indicators required establishing these KPIs. In addressing this issue, based on the research of (Parlikad et al., 2014) about "Measuring the performance of AM systems", the application of the performance measurement perspectives, which can be used for all building assets stakeholders (Table 1.3), can form the KPIs (like an example in Table 1.4) for measuring a BAM system's performance.

Table 1.3. Performance measurement perspectives (Parlikad et al., 2014)

Perspective	**Description**
Financial	This perspective is about developing performance measures for assessing capital cost-effectiveness of asset management system activities, typical performance metrics are return on investment, various cost, value produced and asset depreciation
Risk	Be measured from risk-based perspective, for example: safety, reliability, availability and sustainability
Performance	This perspective stands for thinking about performance measures for assessing the physical delivery of asset management activities, such as production efficiency, consumed time and manpower.

Table 1.4. KPIs for evaluating BAM system device to performance measurement perspectives and value-based method

(Example)

Indicators / Benefiters	Stakeholders					
	Contractors	Owners	Users	Others		
				Society	Environment	Economic
Financial						
Operating costs (per sqm) (S)	IB	DB	IB	IB	IB	DB
Building maintenance cost (per sqm) (S)	IB	DB	IB	IB	IB	DB
Life cycle cost (L)	IB	DB	IB	IB	IB	DB
Risk						
Indoor environmental quality (IEQ) (S)	DB	DB	DB	DB	DB	IB
Maintenance efficiency indicators (MEI) (S)	DB	DB	DB	IB	IB	IB
CO2 emission and Waste (S)	DB	DB	DB	IB	DB	DB
Performance						
Building performance index (BPI) (S)	DB	DB	DB	IB	IB	
Resource consumption – Electricity, Energy, Water, Materials, Labors (S)	DB	DB	DB	IB	DB	DB
Property and real estate (S)	DB	DB	DB	IB	DB	DB
User satisfaction with the quality of property (S)	DB	DB	DB	DB	IB	IB
User satisfaction with the services (S)	DB	DB	DB	DB	IB	IB

Note: **(S)/ (L)** Short-term /Long-term calculated indicators

DB/IB: *Have Direct/ Indirect benefits from good result of KPIs*

1.3 Requirement, challenges of buildings asset management and recommended solution

BAM system is complex, dynamic and interdependent on many factors (both inside and outside the organization; in technical, financial and social fields) that required monitoring, analyzing, and diagnosing frequently. The successful BAM system demands the building asset manager of today faces many challenges and requires, "not only engineering skills, but also those of strategic management, operational management, environmental management, economics, and a range of other professional disciplines".

Clearly, the one building asset manager/department could not ensure finishing himself the long list of missions such as planning, designing, developing, operating, maintaining, rehabilitating, retiring and disposing of building assets in a socially and environmentally responsible manner but still satisfies all stakeholders' objectives. Thus, the BAM system requires "an organizational structure that facilitates the implementation of these principles with clear direction and leadership; with staffs full of awareness, competency, commitment, and the ability of cross-functional coordination, and, the adequate information and knowledge of asset condition, performance, risks and costs, and the interrelationships between these" ((IAM- The Institute of Asset Management, 2015), (British Standards Institute, 2008)).

A robust BAM system could improve organizational efficiency and effectiveness, assurance of business growth and improvement, reduce risk. Additionally, it enhances stakeholder satisfaction through compliance and improved building asset system performance or sustainable development. The literature and characterization of traditional EAM system highlight a number of key requirements of the broader consensus interpretation nowadays that has recently begun to emerge (Amadi-Echendu et al., 2010). In the same context, BAM system would also inevitable meeting these requirements (Figure 1.11), has similar challenges due to the nearly same nature of the BAM system to EAM one.

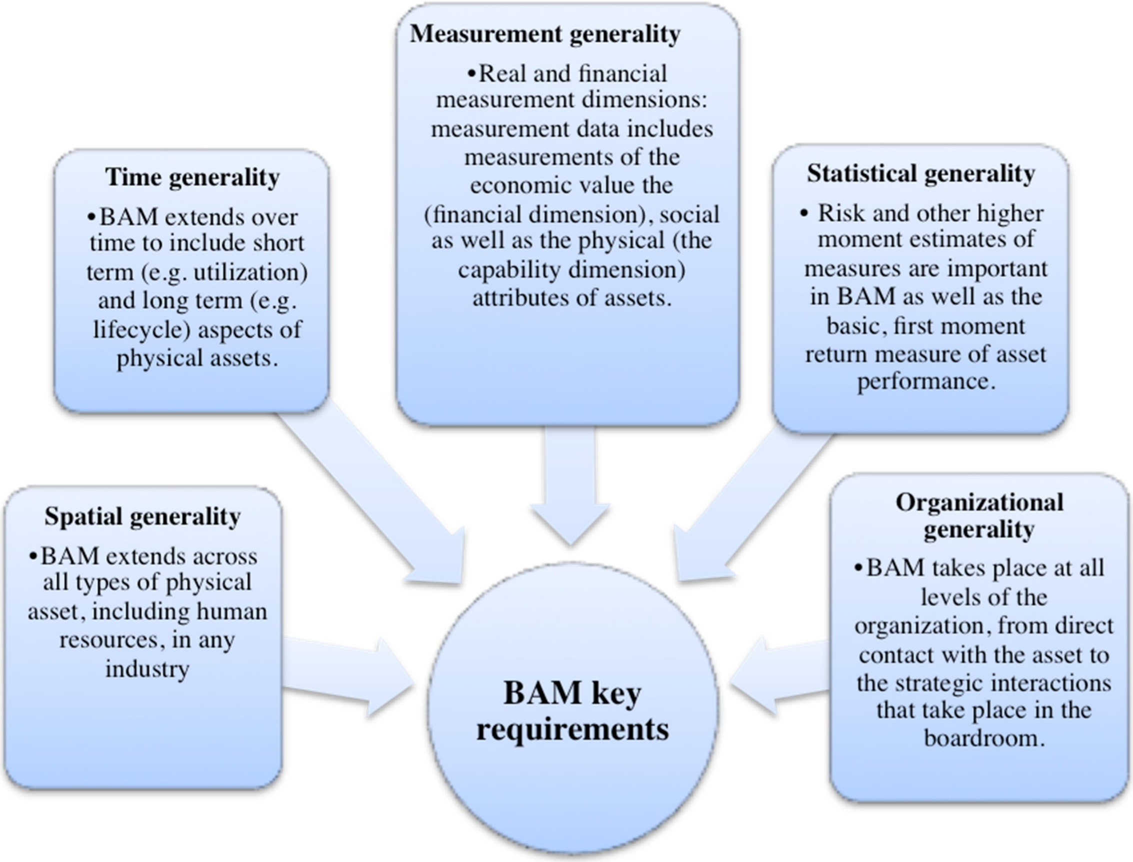


Figure 1.11. EAM key requirements (Amadi-Echendu et al., 2010)

Observation of Fig 1.11, it is easy to note that there are at least three challenges from these five generality requirements of BAM. The first challenge indicates that BAM is multi-disciplinary due to the input of skills from virtually any discipline source, such as traditional building areas; information technology, economics, and management are all required. The second one is the large extent of BAM decisions, which is from operational and tactical aspects of asset management to strategic aspects, such as life-cycle modeling. The last implication is the central value of BAM requires the consideration by using both qualitative analysis modes and the more classic quantitative ones.

Consequently, broadly based EAM requires a system of information capturing data to support making decisions across the areas proposed by the above implications or requirements in Fig 1.11. This ideal needed information system must be provided continuously the physical/ financial data and changes of a set of assets' condition. This information system needs to have the ability to provide data to each managed purpose of the asset set that is defined by reference to the function of departments in the organization (such as technical, human resource, accounting, financial...division). This may be the first key to maximize profits in a private company or providing satisfactory safety and environmental outcomes in a government agency, for example. However, from the opinion of many engineers in the vast majority of organizations, (Amadi-Echendu et al., 2010) had studied and concluded that "poor data quality is probably the most significant single factor impeding improvements of AM", is the first challenge for BAM.

It is noted that the data requirements for decision-making of comprehensive reach models as BAM, are significant great. However, the greatest difficulties for establishing BAM data system lie not only in developing the technical aspects (such as developing new sensors and diagnostic tests or better decision models) but also in changing the human behavior element (in collecting, entering, analyzing and managing data).

One of the other major challenges in (BAM) is the management requirement throughout building assets life cycle, at both strategic and operational level, to meet the satisfaction of a range of stakeholders'. Further challenges include the need to achieve the more traditional technical and economic goals as well as social and the recent environmental goals; the more attention request on risk management and its importance in making decisions; and last but not least, the need of applying the best-advanced technologies suitable with the asset management process.

The research of (Parlikad and Jafari, 2016) had the same conclusions while mentioned some challenges remain to AM nowadays. They are: Capturing, managing and sharing Building asset database with the same data standards; Prediction and monitoring an acceptable performance of building assets which balanced between: risk-cost-value; Optimizing Investment/Expenditure by suitable decision-making methods; Changing Organizational working culture (processes, methods, techniques); Tracking sustainable development (Resources, waste, Co2 emission). To compare with (Amadi-Echendu et al., 2010), (Parlikad and Jafari, 2016) had the more comprehensive view to detect the difficulties of AM by paying the attention not only in the process of information gathering and decision making, but also directing a significant interest in monitoring and evaluating the results of those decisions to make appropriate improvements for BAM if needed.

In addition to identifying the key challenges, researches were asked to identify potential solutions that would begin to address the challenges. Almost studies on renovating AM in general and EAM in particular, have concentrated on two major aspects: “the technology and communication technology required in the management of data relating to assets and the decision-making techniques in the management of the building assets” (Amadi-Echendu et al., 2010). In BAM case, improving the implement performance of these two tasks can supply for all activities in the BAM system a value supporting which lead to the productive use of the BAM system to forward to a better performance of asset systems or organizations. Therefore, it is thus essential to the next step of study is determined the advanced technologies/methods that make all BAM aspects are carried through as effectively as possible. These integrated solutions should be scrutinized all classified aspects: models and tools; guidance and methodologies application, to provide an outline of one recommended model for BAM, is going to be explained and clarified in the next chapter.

1.4 Conclusion

BAM has become a vital part of business management for many organizations, especially building management ones when the capital investment cost in constructing or repurchasing buildings is far less than the total of expenditures for maintenance/ renewals count in long term. That drives the productivity and sustainability of building assets becoming the principal business competitive capability of BAM organizations. Indeed, BAM objectives concern directly to the objectives of organization particularly, and all stakeholder generally. As we could not living, working, studying without buildings, "Productive use of building assets that provide the value supporting all assets in the economy", thus, it is essential to all that is BAM carried through as effectively as possible.

This chapter has emphasized broad-based characterizations of BAM that been consent in the literature. These characteristics have been examined through consideration of the key basic concepts that BAM systems must encompass such as objects, stakeholders, concept, objectives, relationships, etc. This analysis also suggests the important thing to note is that BAM system has to meet its major challenges to be successes. Developments in technology and methodology factors can contribute to improvements in BAM.

However the biggest challenges for asset managers, due to the need to change traditional conceptions of BAM, are most likely the various aspects of its human dimension as manifest on organizational settings and associated cognitive dispensations. Thus, how to develop a consistent knowledge base towards effective human resource development, coupled with organizational refocus on both value and risk, plus a commitment to sustainable development are probably the add mission for BAM researchers in the short to medium term.

CHAPTER II. SMART TECHNOLOGIES AND SMART BUILDING ASSET MANAGEMENT

2.1 Introduction

As the conclusion from the state of Building Asset Management (BAM) in chapter 1, managing building assets have significantly altered because of changing building components' - equipment's designs, information and communication technologies between building stakeholders, pressures of budget and users, risk and failures tolerance ability. Moreover, recently, management-working environments are more and more complex and require simultaneously multiple reactions. This integrated high-level management implicating various sub-systems requests the collaboration of many stakeholders involve numerous systems and divisions. Their work together improves coordination and information sharing during the whole building asset life cycle process.

Aim to have an effective program; BAM also requires O&M staffs an enthusiastic commitment. A part of the process includes utilizing technology to determine the state of assets. There is no silver bullet but there are several dissimilar technologies that could deliver the best investment return for different asset configurations (Willson, 2013).

Indeed, the available technologies and their capabilities in supporting management are increasing yearly. Smart technologies are rapidly developing viewed as business enablers, and they have the effect, use and penetration of the marketplace to provide asset management activities. The first reason is smart technologies can support collaborative information sharing and delivers numerous benefits to an organization such as collaborative or separate working. In addition, depending on the complexion of building's structure, the costs to determine the building assets' condition for maintenance's purposes during whole their life can be very high with the traditional way. With the application of appropriate smart technologies, all real information can collect easily and fast. Therefore, this critical help is the second reason of using smart technology in BAM.

However, most of recent research or projects had only focused on applying individually technologies, without combination of various technologies into one smart system for managing building assets. Even though there are also some on-going projects focused on smart asset management, but their objects are general engineering assets or infrastructure assets. Those assets are quite different from building ones, which are already much more separate because of building types. So the first step of this research is selecting the right technology to build the Smart Building Asset Management (Smart BAM) system. Once this is known, the next process of forming a Smart BAM's strategy can begin. This framework is concerned with adopting and implementing smart technologies that meet all maintenance collaboration requirements or organizations can expand the existing technology to facing with all the requirements and challenges of BAM which analysed in chapter 1.

2.2 Smart technologies

2.2.1 What is Smart technologies

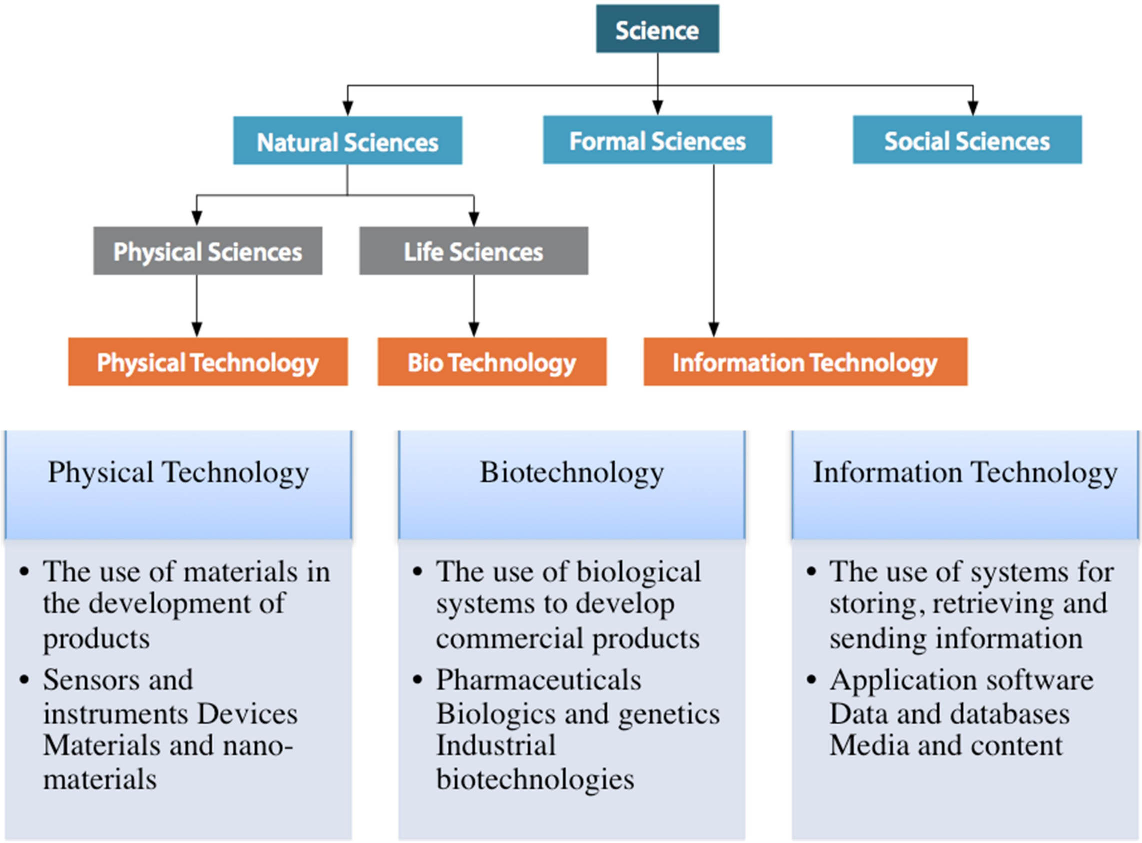
In (Neuhofer, Buhalis and Ladkin, 2015)'s reviews, Smart technology, "implying the word intelligent, commonly describes a new product, referring to the environment, condition or motion of technology that adapts to certain functions or is tailored to specific circumstances. Intelligent systems have been defined as systems with the two-fold ability to sense the environment and learn actions to achieve particular goals. Besides several attempts, the concept of smart technology remains scarcely conceptualized beyond technological fields and definitions remain largely ambiguously defined".

"Smart technologies are the technologies (includes physical and logical applications in all formats) those are capable to adapt automatically and modify behaviour to fit environment, senses things with technology sensors, this providing data to analyse and infer from, and drawing conclusions from rules. It also is capable of learning that is using experience to improve performance, anticipating, thinking and reasoning about what to do next, with the ability to self-generate and self-sustain. Technologies that allow sensors, databases, and wireless access to collaboratively sense, adapt, and provide for users within the environment. Such smart technologies are currently found in housing designs similar to sensors and information feeds" *(Dictionary Search - Embedding Ubiquitous Technologies).*

2.2.2 Smart Technologies application

(Plant and Veletanlic, 2017) has accepted that the breadth and depth of technology applications that could potentially gain an advantage from its concept, whether in medicine, engineering or physics, is vast. Though each application has several of its own exclusive design criteria - specified by its function intended, all smart technologies creation requires a necessitate solution for the same dilemma: "how to integrate the fundamental abilities of awareness and reaction into a coherent system with the minimum of complexity and cost". To answer it requires not only an inherently interdisciplinary design philosophy but also a good knowledge of numerous various enabling technologies.

From research of (Plant and Veletanlic, 2017) about classifying the world of science is to break it down into three areas; natural sciences and engineering (the study of natural phenomena), formal sciences (mathematics and logic) and social and human sciences (human behaviour and societies). The natural sciences in turn are broken down into branches that include; physical sciences (study of non-living systems) and life sciences (study of living organisms). Science becomes technology when it is applied to problems, and developed solutions are accepted in the marketplace. The formal sciences (logic, mathematics, etc.) primarily turn into information technologies in the market. Discoveries in the life sciences are the basis for biotechnologies, and the physical sciences are converted into physical technologies (a term that is not often used). These three main fields of technology include the following applications:



Physical Technology	Biotechnology	Information Technology
• The use of materials in the development of products • Sensors and instruments Devices Materials and nano-materials	• The use of biological systems to develop commercial products • Pharmaceuticals Biologics and genetics Industrial biotechnologies	• The use of systems for storing, retrieving and sending information • Application software Data and databases Media and content

Figure 2.1. Three main fields of technology's applications (Plant and Veletanlic, 2017)

With (Plant and Veletanlic, 2017) the classified in (Fig 2.1) above, it is not difficult to realize that information and physical technology adoption is the most important application for engineering sector. The increasing pervasiveness of technology throughout industries, the application of smart technologies has become a main focus of asset management attention. Mainly because of the convergence of the offline and online world, smart technologies have created new tools for asset management in numerous sectors. In these contexts, smart technologies have been represented as instrumental tools with specific functionalities that enhance value for asset management in a number of ways. For example, the implementation of QR codes can help owners in setting identify assets (Lin, Cheung and Siao, 2014), whilst combining of sensors, tags, RFID, semantics and cloud computing is applied in the establishment of civil infrastructures (Law, Smarsly and Wang, 2014) or electronic assets (Wang *et al.*, 2014). For complex assets like ones in construction sector, smart technologies play even more important roles in asset management. (Guillen *et al.*, 2016), (Re Cecconi *et al.*, 2016), (Arayici and Aouad, 2011) give examples of using BIM for engineering asset management. Base on the significant requirements for asset management of stakeholders (Owners, users and legality) in maintenance, renewal and upgrade through assets' life, increasing the use of new technologies to deliver enhanced assets' performance. The smart technologies' concept has received a significant growing attention in management as a dynamic domain characterized by constant need for renovation.

2.2.3 Smart technology for building asset management

Nowadays, BAM operations count on obtain to information and group expertise from scattering sites. Since the last 30 years, doing BAM practice has significantly changed by reasons analysed above such as asset itself, economic state and targets of stakeholders or management departments, current working circumstances etc. (Fig 2.3). Consequently, integrated high-level management system implicating various sub-systems with the collaboration of various building stakeholders (like several management systems and owner or users divisions involved) is required to face it challenges (Fig 2.3). This system aims to upgrade coordination relation in sharing information, management practices and optimize resources by using smart technologies (Fig 2.2). The new collaboration can generate a strategy to enhance operational effectiveness, even to adding income, reduce waste, pollution and cost. The emerging trend of smart technologies is speedily developing like business enablers, and has the potential to support BAM practice.

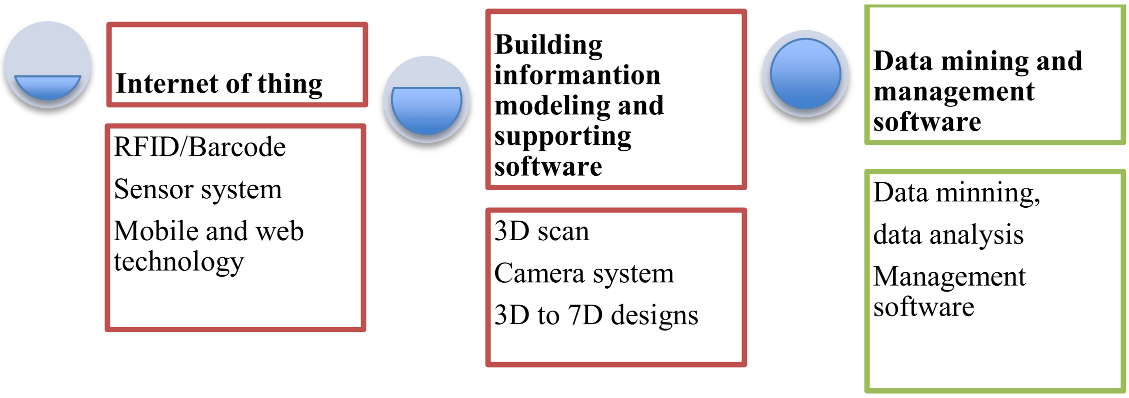


Figure 2.2. Smart technologies for BAM by application levels

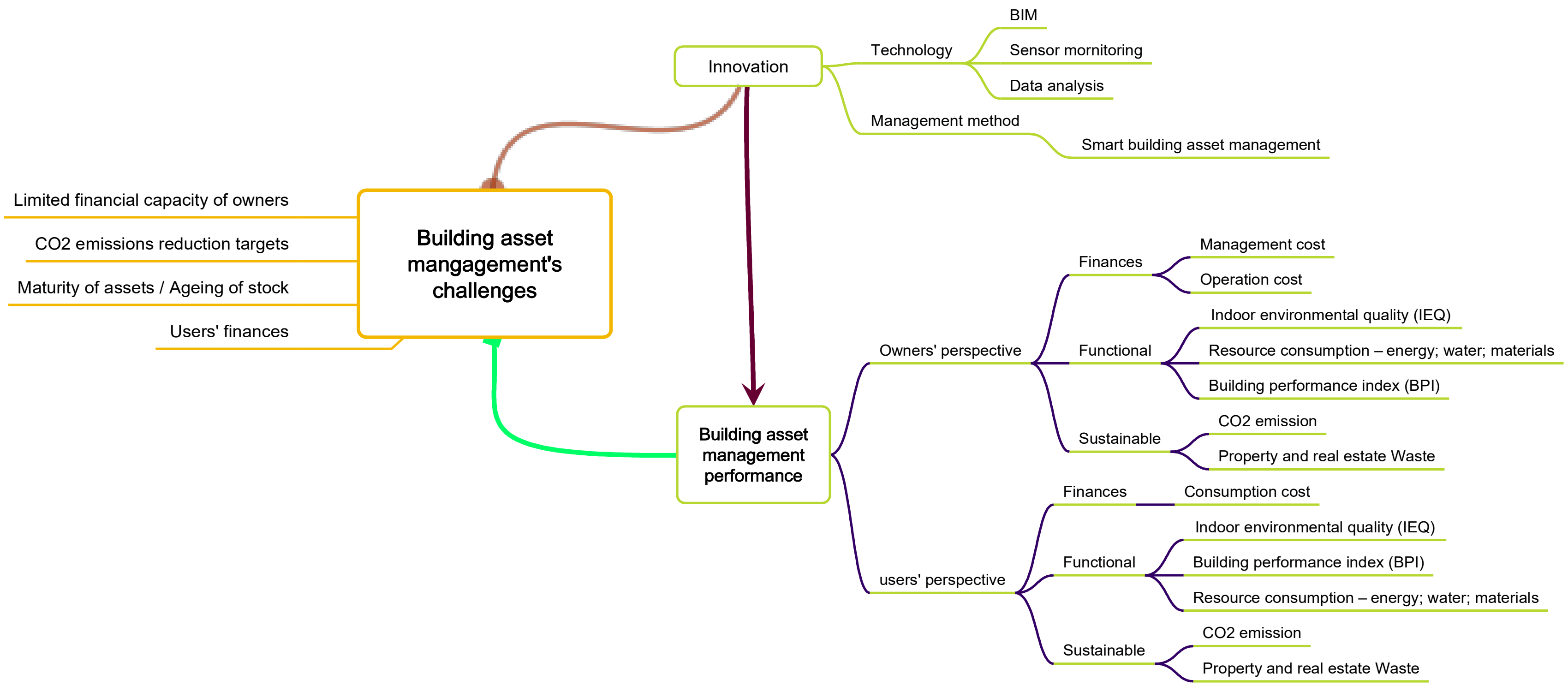


Figure 2.3. Smart technologies facing BAM's challenges

2.3 Applying smart technologies into building asset management

2.3.1 Technologies required for managing building assets

(Parlikad *et al.*, 2017) presented their report about state of art of using intelligent technologies into infrastructure assets management, in spite of the dissimilation between an infrastructure asset system and a building asset one which has been study in section 1.2.2 of chapter 1; there are a lot of common aims to BAM. From this research and others related to smart technologies needed, it is not difficult to find the fittest smart asset management system for building assets. Indeed, a Smart BAM system also needs to be smart into seven steps (Fig 2.4).

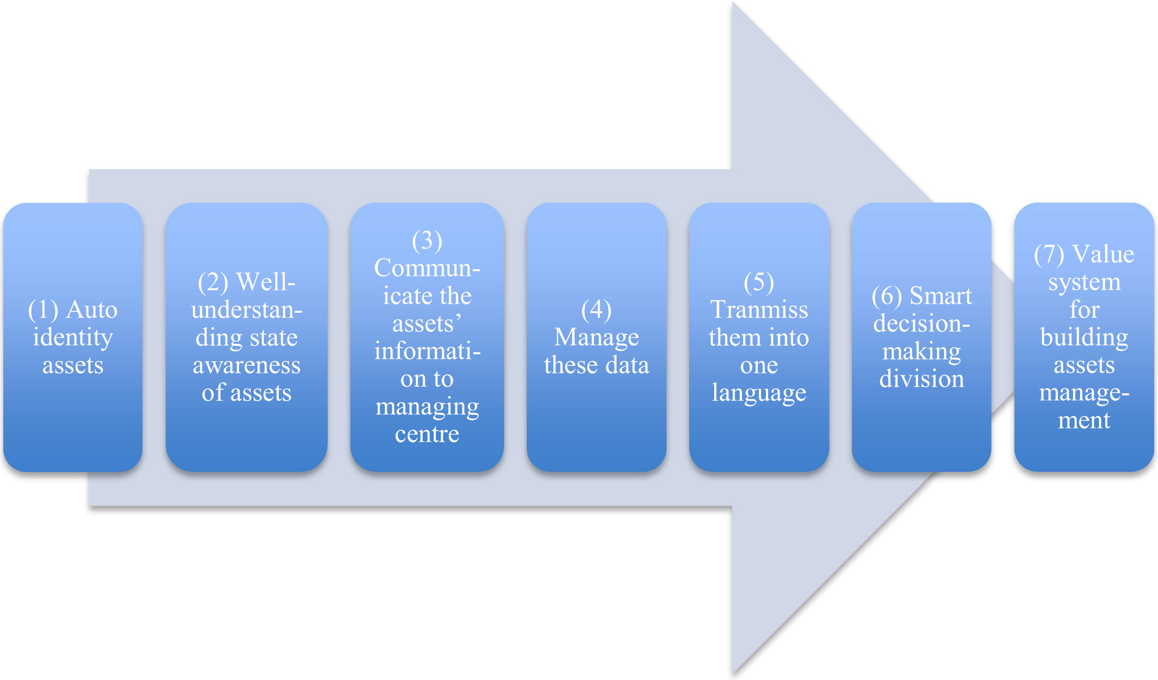


Figure 2.4. Smart asset management system (Parlikad *et al.*, 2017)

Parlikad et al. mentioned that there is a wide variety of product and asset identification technologies is now available on the market, offering different capabilities in terms of storage capacity, line-of-sight requirements and longevity. Simple barcodes and numeric tags have been in use for asset identification for forty years. Two-dimensional barcodes are increasingly popular due to the increased amounts of data that can be held in a small space. Radio Frequency Identification (RFID) tags has also been in use in recent years due to their advantages in non-line-of-sight accessibility, which is invaluable for infrastructure asset identification. In most deployments, the ID technology simply provides a unique identifier for each asset, which can then be used to retrieve linked information from networked asset management systems (1).

For state awareness aim of assets (2), a variety of sensing technologies have been developed to help understand the state or condition of assets. These sensors monitor the critical parameter that can provide an indication of the rate of progression or the likelihood of development of different failure modes of an element, an asset or the system. The Cambridge Centre for Smart Infrastructure and Construction (CSIC) has been instrumental in developing new types of sensing technologies as well as improving the effectiveness of the deployment of such sensors. Distributed fibre optic (FO) sensors, available for some time for the monitoring of civil structures an infrastructure, are also gaining popularity.

Then, for communication database purpose (3), the data captured by the sensors needed to be communicated to data management and analysis systems for making critical decisions. This can be performed either by connecting the sensors physically using wires for data transmission, or (increasingly) through wireless sensor networks. Such networks enable communication between the assets and data management systems, as well as between the assets themselves.

For managing data (4), identifying the right data to be collected for effective whole life management of single or multiple assets is a big challenge. Standards such as the PAS-1192 series and the development of BIM compliant solutions offer industry the capability to manage asset data efficiently. The intention of the intelligent asset model is that a mechanism be available to enable all asset data to be accessed via a single query, without requiring searches across multiple databases and storage locations in different organisations. Developing this capability will draw on the developments in the field of the Internet of Things (IoT) where, for instance, the EU-funded Internet-of-Things Architecture (IoT-A) project has created an architectural reference model for managing data in smart, connected assets.

Nevertheless, how to transmit asset information (5) in a standardised format is a challenge in a world where different organisations (and in fact different departments within the same organisation) use different types of information systems and databases. One of the major developments towards this in the infrastructure sector (in particular) and in engineering sector (in general) is the move towards standard formats for exchanging asset data such as the Construction Operations Building Information Exchange (COBie). COBie is a formal schema that helps organise formation about new and existing assets. It helps "capture and record important data at the point of origin, including equipment lists, asset data sheets, warranties, spare parts lists and maintenance schedules". Similarly, Hypercat is a format designed for exposing information about smart assets over the web in a standard manner. It is built on the same web standards that are now common for client-server interfaces.

After having the "right" asset databases, how the making decision support (6) from this information is the main question for asset managers. Because new sensors often produce new engineering datasets (that were not previously available), it is required novel techniques for the interpretation of this new engineering data. For example, some fibre optic technologies provide a continuous set of strain data long the fibre optic cable embedded in or attached to the structures. In addition, advances in the area of predictive, analytics help us not only to understand the state of our assets, but also to predict impending failure and create the opportunity to tale optimised preventative action. Developments in the area of software agents enable the concept of smart asset management to become a reality; for example, where every asset is represented by a software program that continuously seeks data from various sources (including sensors), analyses it and takes decisions without the need for human intervention.

As the ISO 55000 family of standards (and PAS -55 before it) has helped shift the emphasis of asset management from minimising cost to realising value. The value of an asset essentially (7) will depend on three factors:

i. The benefits arising from the asset to the stakeholders through effective performance of the system;
ii. The risks posed by the asset (its operation and its condition) to the system and its stakeholders; and
iii. The expenditures incurred on the asset. Value-driven Asset management is, therefore, the aggregate of activities carried out to realise benefits (and opportunities for further benefits) while minimising both the costs and risks over the lifecycle of the asset. CSIC has developed a structured methodology to determine how an asset contributes to the system's value, how its condition can affect that value, and how value can be managed by making the right decisions. A key element in future smart asset management system is the use of sensory data (condition, environmental, and operational) in combination with other relevant data sources to develop a better understanding of value, including improving the predictability of the effect of asset condition on value. This will enable the right

asset management decision to e made with better confidence to maximise asset value.

2.3.2 Using smart technology for managing building assets

2.3.2.1 Advanced technologies for identity, real-time tracking status of building assets and communicating their stakeholders

2.3.2.1.1 Automatic identification (auto ID) technologies: RFID tag and Barcode

Automatic identification (auto ID) technologies are leading to allow managers to use machines or computers to identify items by capturing data automatically. Radio Frequency Identification (RFID) is one type of auto-ID technology that "uses radio waves to identify, monitor, and manage individual objects as they move between physical locations" (Caglar and Yavuz, 2016). RFID is revolutionizing the way organizations around the world in tracking the location and movement of vital organizational assets. RFID technology utilizes wireless RFID chips (sometimes referred to as tags) that report their location to scanners nearby. Objects with RFID tags can be traced throughout building locations.

Although RFID methods could use for identifying assets is variety, storing a serial number that is able to identify an asset and its related information is the most common method. RFID devices and software requires supporting of an advanced software architecture that enables the collection and distribution of location-based information in real-time.

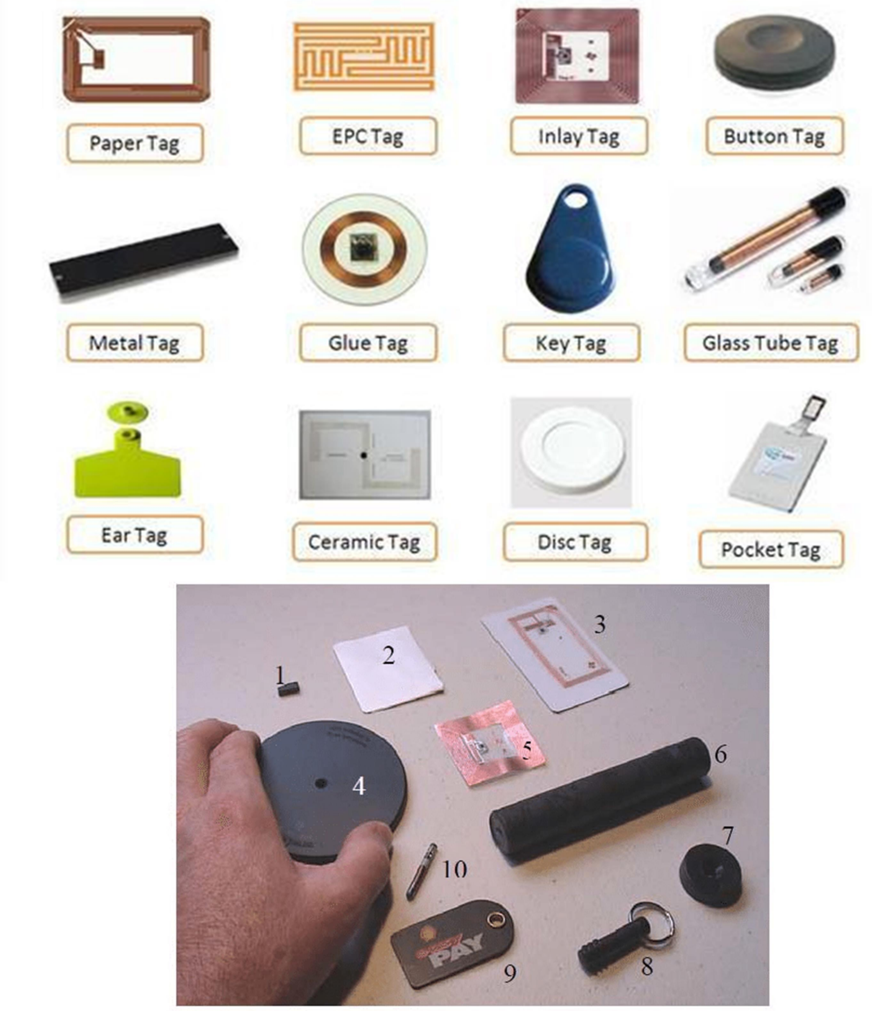
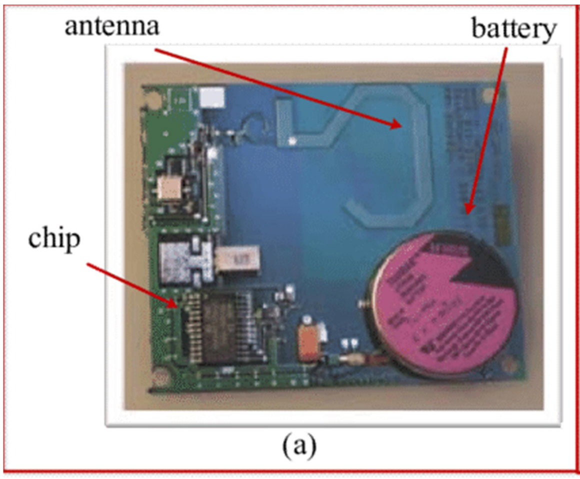
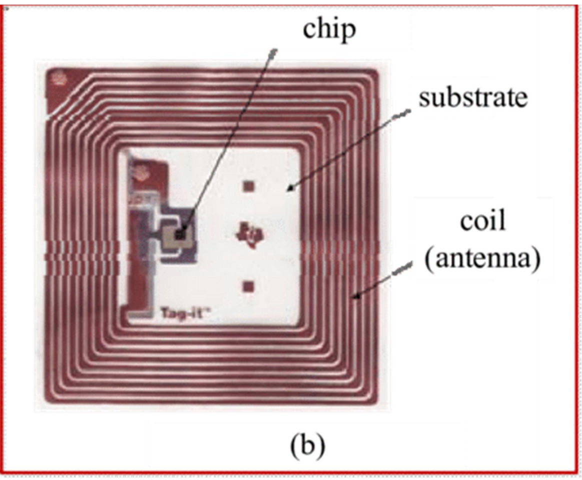


Figure 2.5. *RFID tags' types and their size* (Caglar and Yavuz, 2016)

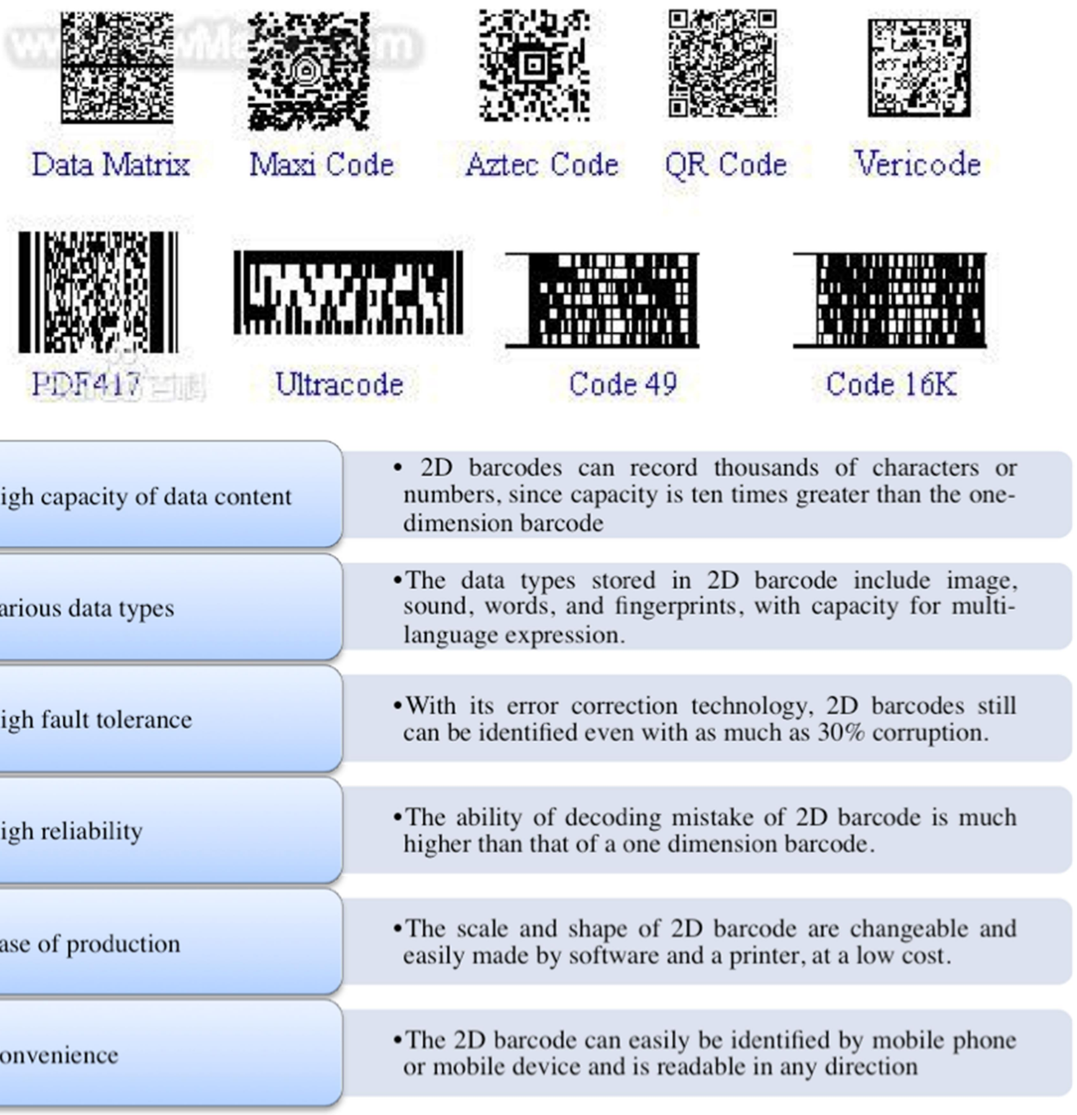
Readers and tags are the main elements of a RFID system. There are numerous kinds and sizes of RFID tags (Fig 2.5), nevertheless, they are all small devices consisting a chip and an antenna stores the information of object identification. Tags can be used for equipment, component, or individual items. RIFD tags do not require line-of-sight, so, information is transmitted to the reader, and then the reader turns the incoming radio waves into a kind that a computer system can be read. There are two types of RFID tags: active (with a battery) or passive (powered by the signal strength emitted by the reader) (Table 2.1).

Table 2.1. Two types of RFID tags (Caglar and Yavuz, 2016)

Active Tags	**Passive Tags**
Can be read since more than 100 feet long-range distance	Can only be read from a short-range distance of approximately 5–10 feet.
Ideal for tracking high-value items over long ranges, such as tracking shipping containers in transit.	Can be applied in high quantities to individual items and reused.
Have high power and battery requirements, so they are heavier and can be costly.	Are smaller, lighter, and less expensive (and therefore more prevalent) than active tags.
 (a)	 (b)

The barcode system is another auto-ID technology explored for inspecting real-time information accurately and reliably. The barcode system also has the ability to store and deliver any kind of information, which may include text, audio, and video on location.

Since being invented in 1950, during subsequent years, Barcode technology has a rapid development and wide applications in many fields of life. Typical sectors include sales management, logistics management, auto motives, advertising, websites, etc. The first generation of Barcode is the one (1D) barcode with maximum capacity is only 28- bit. However, the next version - the 2-dimensional (2D) barcode with a lot of advantages has been in use widely since 1990. The 2D barcode with higher capacity and lower cost still has the abilities to increase security, traceability, anti-corruptibility, and mistake-correcting functionality (Fig 2.6) (Lin, Cheung and Siao, 2014).



(1) High capacity of data content	• 2D barcodes can record thousands of characters or numbers, since capacity is ten times greater than the one-dimension barcode
(2) Various data types	• The data types stored in 2D barcode include image, sound, words, and fingerprints, with capacity for multi-language expression.
(3) High fault tolerance	• With its error correction technology, 2D barcodes still can be identified even with as much as 30% corruption.
(4) High reliability	• The ability of decoding mistake of 2D barcode is much higher than that of a one dimension barcode.
(5) Ease of production	• The scale and shape of 2D barcode are changeable and easily made by software and a printer, at a low cost.
(6) Convenience	• The 2D barcode can easily be identified by mobile phone or mobile device and is readable in any direction

Figure 2.6. Some 2D barcode examples (http://www.qrcode.com/en/about/) *and its advantages* (Lin, Cheung and Siao, 2014)

The 2D barcode main characteristic is its capacity to represent the content significant quantities of data recorded, and the arrangement of a specific geometric diagram in a relatively small matrix area. Two typical types of 2D Barcode classified by their design principle are the 2D Stacked Code and 2D Matrix Code. The 2D Stacked Code was upgraded from the basis of the 1D barcode by thinning it down and stacking it in layers to create multi-raw symbols. Code 16K, Code 49 and Code PDF417 are some representative types of Stacked Code, while Code One, Maxi Code, QR Code, and Data Matrix are of the 2D Matrix Code (Fig 2.6). Dissimilar with Stacked Codes, Matrix ones are the combinations of black-white picture elements (square, dot or another type) distributed in a square area in a relative matrix position. Using the 2D barcode is very convenient and at a low cost, because 2D barcode technology was developed rapidly, there are many web-based platforms supporting the generation of 2D barcode (such as the Kaywa company (http://qrcode.kaywa.com/)). Quick Mark and QR Code generation functionality is provided by these platforms from Internet. Thus, to create a 2D barcode, users can find and download easily the software to install on a PC (Lin, Cheung and Siao, 2014).

RFID and Barcodes have their own advantages and inconveniences. Although it is often thought that RFID and barcodes are competitive technologies, they are in fact complementary.

Table 2.2. Comparing RFID tags and 2D Barcode

Abilities	RFID tags	2D Barcodes
Reading capability	Rapidly in bulk to provide a nearly simultaneous reading of contents	Require line-of-sight technology
Reading method	Need only be within range of a reader to be read or "scanned"	Must be scanned at specific orientations to establish line-of-sight
Durability	More durable withstand chemical and heat environments	Easy to be destroy by environment, not work if the label is damaged
Re-writing or Re-use capability	Read and write capabilities, can be updated	Cannot be updated unless reprinted
Capacity	A greater amount of data compared to barcodes	Only static information such as the manufacturer and product identification
Data transmission	Do not require any human intervention	Require human intervention
Cost	More expensive	Easy to create, cheap

It is not difficult to see from the comparison result in Table 2.2, how RFID has become indispensable for a wide range of automated data collection and identification applications. With the distinct advantages of RFID technology comparing with 2D barcode, however, comes an inevitably higher cost. RFID and barcode technologies will continue to coexist in response to diverse market needs. However, in areas for which barcode or similar optical technologies are not as efficient RFID will continue to expand.

Both a 2D barcode and RFID tag have been shown to be effective as automatic identification technology tools that automatically access relevant information of asset components/ elements in buildings. 2D barcode and RFID technologies are not far in conceptual of identifying asset due to both are intended to provide asset information rapidly and reliably. Nevertheless, as there are important differences between these two technologies in Table 2.2, the asset managers should be careful while select and use of either or both of the systems depend on the character, placement and information requirement of the equipment/ elements. RFID tags are more durable and easier to read compared to 2D barcode reading. Thus, when ease of use and big store capacity are the major issues, like using for engineering equipment, an RFID system may be preferable. However, this advantage is no longer valid if there are large number of assets need to identify, but with not so much database required (such as windows, doors) that make the major issue turn to cost, 2D barcode system should be chose. Therefore, in the BAM system, the use of both the 2D barcode and RFID system is preferable and inevitable.

(Lin, Cheung and Siao, 2014)'s research has shown that both 2D barcode and RFID systems "can be used as the key to open remote database of information" with the usage flowchart like in Figure 2.7. Despite some difficulties indicated, the system proposed has shown a great possibility of desired results in managing equipment and instruments. By integrating Auto-ID technologies into BAM systems, the effectiveness of asset information systems is improved and enhanced the completeness, accuracy, and ability to update information entire the building's life.

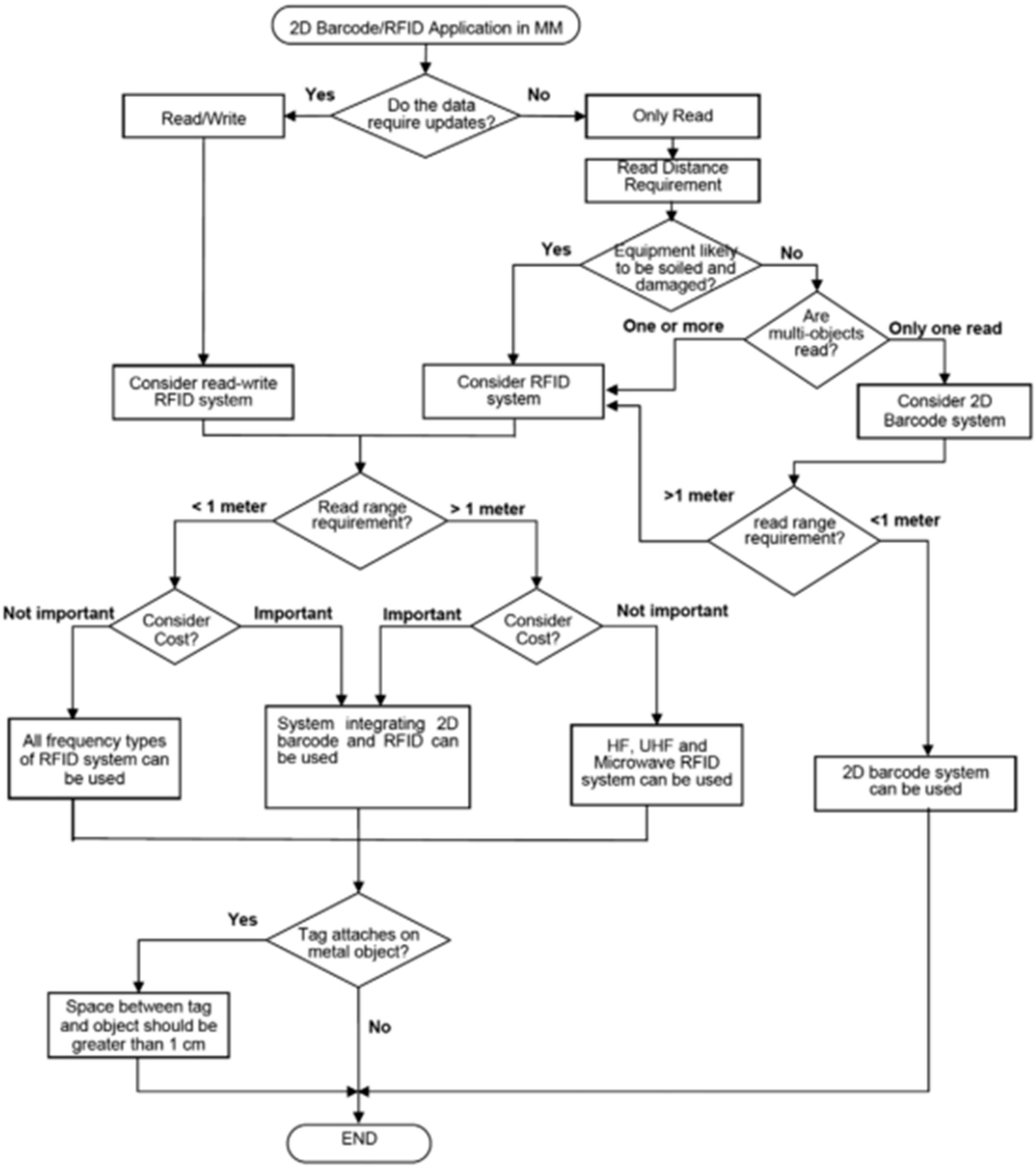


Figure 2.7. The usage flowchart of the integration of RFID and 2D barcode
(Lin, Cheung and Siao, 2014)

Besides, smartphones have become very popular all over the world recently. With mobile technology advancement, almost mobile phones are equipped with cameras so it is easy to enable the 2D barcode/RFID scanning function (Fig 2.8). When a 2D barcode/RFID reader program is installed, not only the owners but also the users of building assets can quickly access product descriptions, link and share information by scanning the barcode. By these activities, the users could join in to BAM system as an updater and provider real-time asset data for building asset information system. For example, the users can use their smartphones, which equipped with a camera and enable the application of 2D barcode/RFID scanning, to report the problem happened. Thus, maintenance manager can use this first information in detecting, predicting and preparing to recover the damaged asset.

Figure 2.8. Asset identification with both RFID and Barcode and Asset tracking workflow (https://nationalofficesystems.wordpress.com/rfid-blog/)

Furthermore, an Internet of Things (IoT) technology can improve the collaboration between the stakeholders to meet the requirements of building assets' information exchange in BAM process. Therefore, the following part of this chapter is going to study how integrates 2D barcode/RFID and IoT technology to enhance maintenance work and provide detailed information communication.

2.3.2.1.2 Auto tracking real-time asset information: Wireless Sensor technology

Along with the progress and outstanding growth of communication and sensor technology, wireless sensors technology and its communicate ability have developed tremendously in the past couple of decades. With embedded microcontrollers, wireless sensors and wireless sensor networks have opened many new and exciting opportunities for their deployment in BAM systems. Indeed, identical to intelligent building assets use sensors as the most basic and primitive entities in an asset structure and its vicinity to auto-control (on/off function), measure response data (e.g. tension, speed, and distance) as well as environmental data, such as light intensity, temperature, humidity (Fig 2.9). BAM system can even use wireless technology to support a wider range of its activities such as gathering and transmission of building asset information to the BAM database or stakeholder.

Figure 2.9. The suite of ambient sensors enables to detect a wide range of events without the need for complex installation. (https://urbanise.com/platform/iot-sensors/)

The cost of measuring equipment statement or other performance indicators is decreased significantly by using models that relate to outputs desired of virtual sensors (e.g., regression equations) which for to low-cost measurements function. Steady-state virtual sensors have been developed a big number of different applications for buildings lately years (Fig 2.10). (Frei et al., 2017) has given an easily deployable wireless sensor network for building energy performance assessment. (Sun, Zhang and Wang, 2017) used sensor devices to propose to control electrical wiring and equipment for the energy-saving buildings. By combining with the characteristics of the building with the actual demands of users and the indoor dynamic environment parameter, the proposed model can control indoor electrical elements to comprehensively energy-saving but still provide a good indoor environment condition for users.

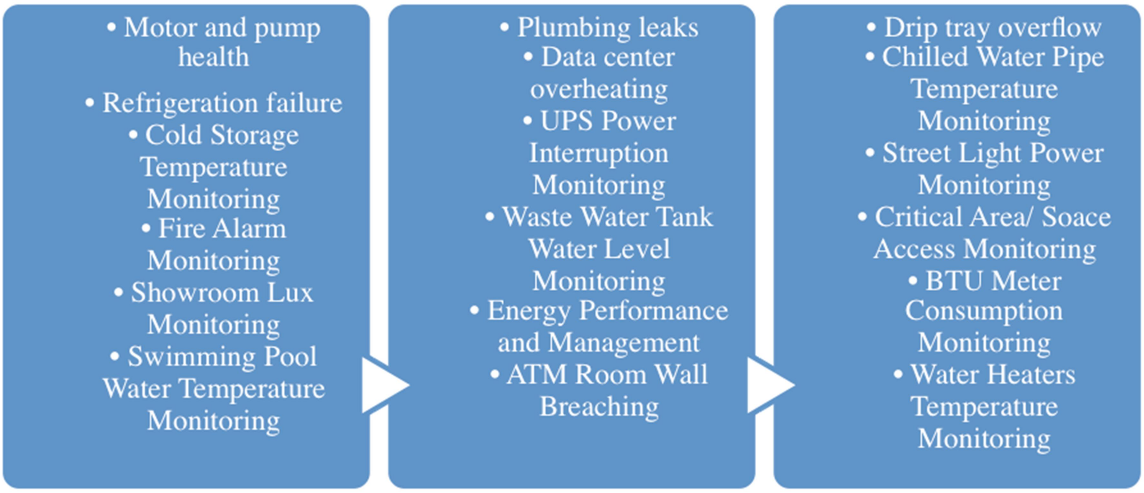


Figure 2.10. Sensor technology's applications in reality (https://urbanise.com/platform/iot-sensors/)

Sensor technology with flexible system configurations has allowed eradicating cables and the associated material and reducing labour cost. Nevertheless, along with a number of advantages, some limitation still remains inside the wireless sensor system such as energy usages, communication range to send data, and data loss possibility. As power supplies of many wireless sensors are by batteries, it needs to minimize as much as possible their use of energy. Moreover, among the environment with many other common sensors, protocols of communication must be designed to assure that data is being transmitted and received properly in the monitoring environment.

The database for measurement is a special kind of asset has many values for assessment performance of assets, for monitoring management of the building assets' system as a whole life cycle. Therefore, to effectively support data access, during designing the overall data management system, be able to constant data storage is the most important consideration. However, the cost of maintaining data systems with constantly increasing sizes is also another big challenge for designers. There are also some researches further for enhancing the efficiency of a sensor system such as: The algorithm of (Cheung and Braun, 2016) aims to minimize the amount of data collection needed for calibration of steady-state of HVAC equipment from which be obtained by virtual sensors during normal operations. (Pietrabissa *et al.*, 2013) provided an optimization framework that determined the optimal placements of the sensors, can be proposed to plan a sensor network in building aimed at tracking equipment assets or environments.

With the proliferation of the Internet and ubiquitous computing, advanced software technologies have been deployed to facilitate for analysis, processing, storage and distribution building asset data system from asset information which been detected, collected and accessed by sensor and wireless sensor system. It is much more convenient than before in supporting the maintenance and operation of the monitored structure, and to self-monitor in the BAM system itself. Data management integrates with system monitoring is an intriguing subject that is worth for considering as a solution for monitoring BAM systems.

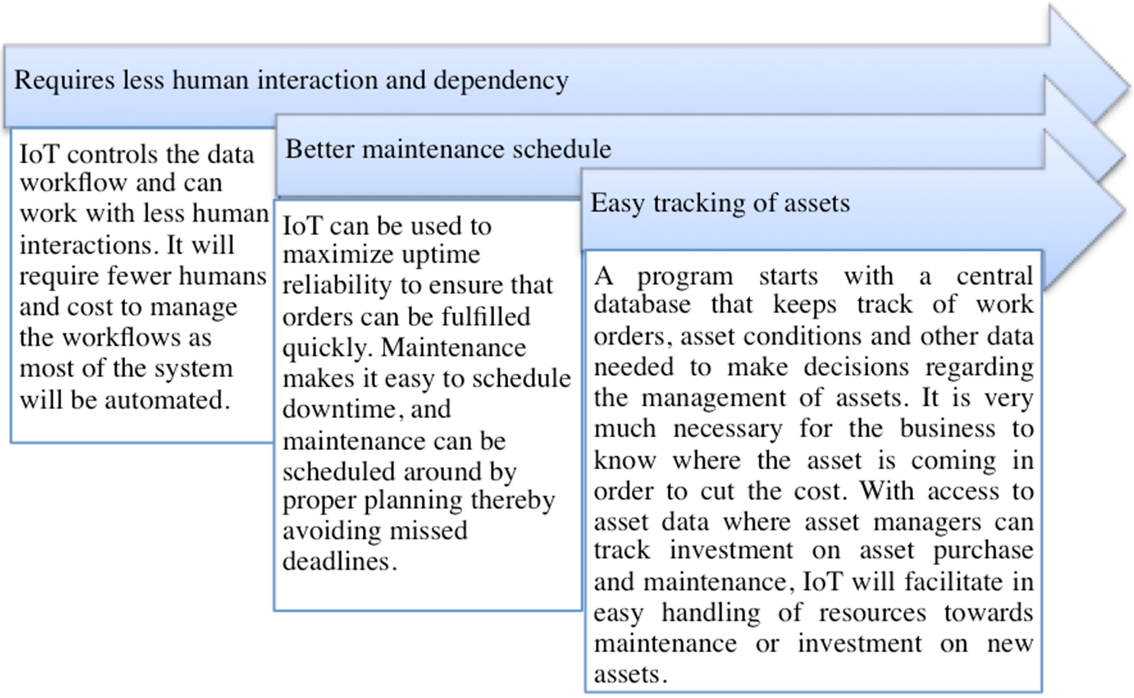
2.3.2.1.3 Mobile technology and Internet of Things supporting collaboration and information sharing

Mobile technology is in the emerging trend that developed rapidly. Be viewed as business enablers, it have the potential to support asset maintenance practice. Indeed, the mobile system is providing various benefits to the organization such as the ability to facilitate working collaboratively or separately; or maintain collaborative of sharing information between stakeholders. For example, users can report damages of assets for maintenance personnel from home with 2D barcode/ RIFD tag reader software on their mobile devices (Which mentioned in analysis of 2D barcode and RIFD tag above).

The other example is the maintenance of the organization. In the context of organizations site, they can ensure that their maintenance personnel are always reachable 24/7. It means they are more available for planned and/or unplanned maintenance and provide information as quickly as possible by implementing mobile collaboration technology. Additionally, mobile/wearable computers can combine with wireless technology to develop greater effectiveness and accuracy applications in maintenance which allow maintenance personnel to communicate with a remote expertise centre from a specified location through digital data, audio, and images. Therefore, even a non-expert maintenance crew (or even users) with these capabilities, could carry out simple repair duties with the remote expert's desk assistance.

It is clear that mobile technology also plays an important role in managing asset smarter. It enables to ease works or cost of maintenance process in an organization at strategic, tactical and operational levels, along with Internet Technology, it will be one of a basic supporting structure needs to be built (Syafar and Gao, 2013).

The Internet of things, or IoT, is “a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction”. In the simplest terms, the IoT is a network of sensors, meters, appliances and other devices that are capable of sending and receiving data. It is not a single technology and rather a concept in which most new things are connected and enabled. It will pave way for big data analysis and performing operations for smart building asset management that were impossible to do without IoT.



Requires less human interaction and dependency

IoT controls the data workflow and can work with less human interactions. It will require fewer humans and cost to manage the workflows as most of the system will be automated.

Better maintenance schedule

IoT can be used to maximize uptime reliability to ensure that orders can be fulfilled quickly. Maintenance makes it easy to schedule downtime, and maintenance can be scheduled around by proper planning thereby avoiding missed deadlines.

Easy tracking of assets

A program starts with a central database that keeps track of work orders, asset conditions and other data needed to make decisions regarding the management of assets. It is very much necessary for the business to know where the asset is coming in order to cut the cost. With access to asset data where asset managers can track investment on asset purchase and maintenance, IoT will facilitate in easy handling of resources towards maintenance or investment on new assets.

Figure 2.11. The advantages of IoT for BAM (Mathew *et al.*, 2018)

From the research above, it cannot be denied that IoT and supporting technologies is forming a very first step to create the smart building asset management system. Indeed, with IoT benefits (Fig 2.11), building asset managers could be able to apply IoT easily into the 'old' building asset management system while waiting for building the new one. Because there are many building owners cannot afford (they do not have the resources and capacity) to refurbish/reinvest the whole building management network at the same time. In these cases, IoT shows them the methods that will allow them to assess and monitor the condition of the assets automatically for whole the rest life of their assets. IoT paves way for such a transition.

2.3.2.2 Building information modelling (BIM) as BAM's tool for life cycle information management and supporting for decision making processes

2.3.2.2.1 **Building Information Modelling (BIM) – The definitions**

Professor Chuck Eastman is the first proposer of Building Information Modelling (BIM) concept at the Georgia Institute of Technology in the 1970s. Since then, BIM started to be adopted in pilot projects to support designers' activities, that made 3D modelling has been slowly developing an integrated analysis and object-oriented tools. BIM models include "geometric and non-geometric data, characterizing, among others: the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, project schedule and operation, and maintenance" (López *et al.*, 2017).

Nowadays the term BIM can be used to indicate a process, a discipline or a technology. This model is much more than a 3D representation of the building. The knowledge database of BIM is its real strength and power. Conjunction other software with this database information could deliver quicker and more reliable in areas of sustainability, estimating, structural analysis, demolition and reconstruction (Guillen et al., 2016). That creates several definitions of BIM along with its development and aims, since this first model was born.

(Volk, Stengel and Schultmann, 2014) has defined BIM by international standards as "shared digital representation ***of physical and functional characteristics*** of any built object which forms ***a reliable basis for decisions***". In other research, (Farghaly *et al.*, 2018) defined BIM as "a shared digital representation ***founded on open standards*** for interoperability. BIM can enable ***information from all project phases*** to be stored ***in a single digital model***. A BIM model/database can be the ultimate platform ***for collecting, capturing, and visualizing information using different technologies***, such as standardized barcodes (As 2D barcode) and radio frequency identification device (RFID) labels ***during the planning, design, construction, and O&M phases*** of a facility". For this study, BIM will be used as the major model and tool to assist BAM system to manage building assets effectively throughout their lifecycle. So, the definition of (Farghaly *et al.*, 2018) which closed to aim of BIM for BAM system will be chose.

2.3.2.2.2 **The concept of BIM models**

In the past decades, due to many benefits and resource savings during design, planning, and construction of new buildings, the interest in the use of BIM had been growing in the construction sector. Until the early 2000s, BIM started to be applied widely for supporting architects and engineers in designing building (Volk, Stengel and Schultmann, 2014). The research of (Guillen et al., 2016) showed the way buildings are conceived, designed, constructed and managed is changing by using BIM models. However, the current use of BIM model like 3D, 4D, 5D focus more on pre-planning, design, construction phases and project delivery than maintenance and operation management processes. However, in recent years, the more complex BIM models such as BIM 6D, 7D has been more and more considered and studied for managing buildings till the end of their lifecycle despite the fact that BIM could provide an advanced approach to get more efficiency and efficacy in the lifecycle management of building and facilities (Fig 2.12).

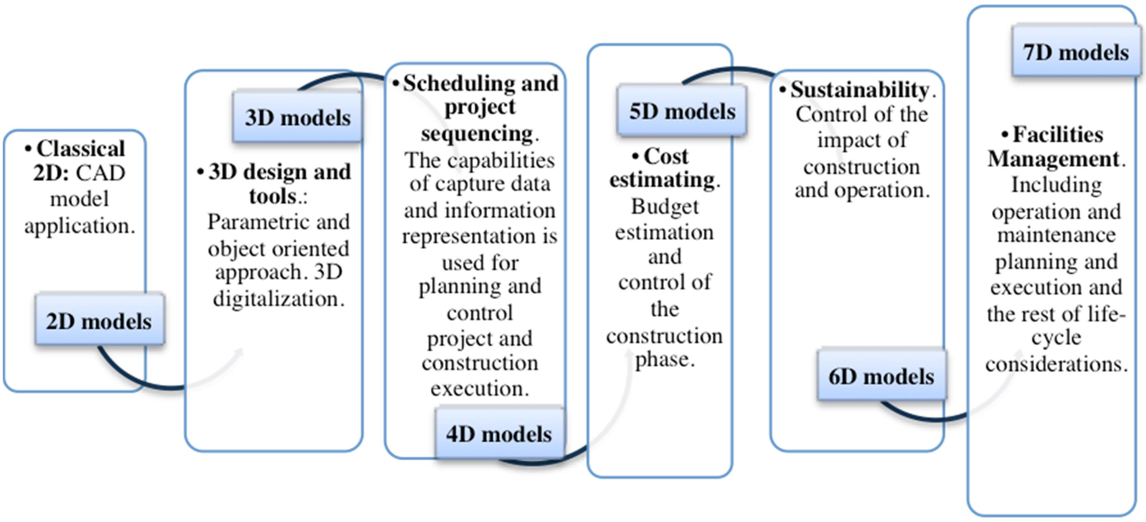


Figure 2.12. BIM models' concepts (Guillen et al., 2016)

Indeed, (Guillen et al., 2016) has proved that complied with guidance of PAS 1192-2 and PAS 1192-3 standards to have a common language for building information, BIM has a lot of potential as listed below to support the asset management process:

a. A digital representation of physical and functional characteristics of a facility/ asset. Not only graphical information of the building elements but also the rest of information types that can be used to ***manage all the lifecycle phases***:

manufacture and vendor data, service and use requirements, operation and maintenance data, performance parameters, energy consumption, etc.

b. A shared knowledge resource for information about a facility, forming a reliable base for ***decision during its lifecycle***.

c. A platform for ***collaboration by different stakeholders at different phases*** of the facility lifecycle in order to insert, extract, update or modify information in the BIM support reflecting different roles according to each stakeholder's interest.

d. The BIM is shared digital representation founded on open standards for interoperability. In addition to the standardization needs, this point highlights the open character of BIM conception, in order to allow ***the combined use of different software and application*** (3D design, ***AM/FM software and others***) and to support the successive software updates.

2.3.2.2.3 BIM data standards and combined software or applications available for BIM

The key point of BIM application for BAM is the information and data management which is one of the key elements in BAM Fig 2.13 (Guillen et al., 2016). BIM development would provide the opportunity to collect and manage a bigger amount of information with greater quality, incrementing its use and applicability. However, at the same time, it is a great challenge to obtain such a powerful information system, including the integration of other software and technologies that can be information sources. One of the keystones of BIM models and its uses is the interoperability and connectivity between different that take part along the building lifecycle. These organizations and roles may use dissimilar software or may require or supply different types of data.

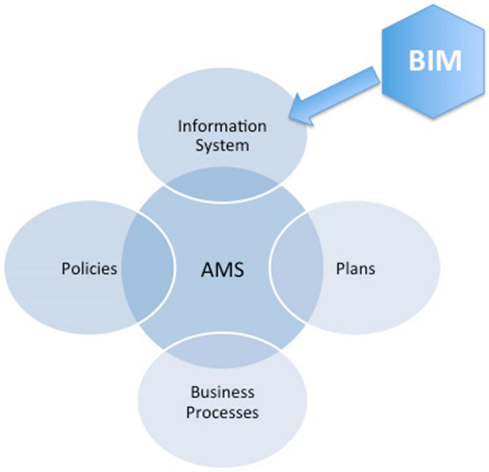


Figure 2.13. AMS (Assets Management System) elements (Guillen et al., 2016)

The Industry Foundation Classes (IFC) is “a standardized non-proprietary data format for sharing and accessing construction and facility management data, enabling interoperability between heterogeneous software applications”. This format is described by the ISO 16739:2013 “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries”. It is an open international standard for BIM data that is exchanged and shared among software applications used by the various participants in a building construction or facility management project. The Construction Operations Building Information Exchange (COBie) is "a data exchange model for the publication of building information subsets focused on delivering nongeometric information and asset data, rather than geometric information" (Guillen et al., 2016).

As a subset of the IFC, initially, the US Army Corps of Engineers developed COBie as a delivering O&Ms specific data method in a standardized format, in a spreadsheet format. For operations, maintenance and asset management, COBie assists by capturing and providing information essential to support. All data from consultants, the contractor, sub-contractors, suppliers, and even the client could be combined and stored in the COBie file. It is because COBie consists of multiple sheets documenting attributes of the facility, its systems and assets and details of their product types, placement, warranties, maintenance requirements etc. Specific items could be used and linked with the main file if there are additional attributes, issues, and documentation while the project is developing. UK government has introduced de COBie format as principal part of Level 2 BIM requirement that will be mandatory for all centrally procured Government contracts from 2016. Level 2 BIM includes 3D BIM models and project and asset information available in COBie format.

Complementary documents of the ISO 16739:2013 to support BIM level 2 above are PAS 1192-2:2013 “Specification for information management for the capital/delivery phase of construction projects using BIM” and PAS 1192-3:2014 “Specification for information management for the operational phase of assets using BIM”. In which, PAS 1192-2 specify an information management process of project information model (PIM) in the capital/delivery phase of projects to; in the O&M phase, PAS 1192-3 is use for Asset Information Model (AIM) (Fig 2.14). In particular, PAS 1192-2 and PAS 1192-3 are closely related to the ISO 55000 series of standards due to its provision of one overarching framework for adopting and implementing focus on the operational phase of assets.

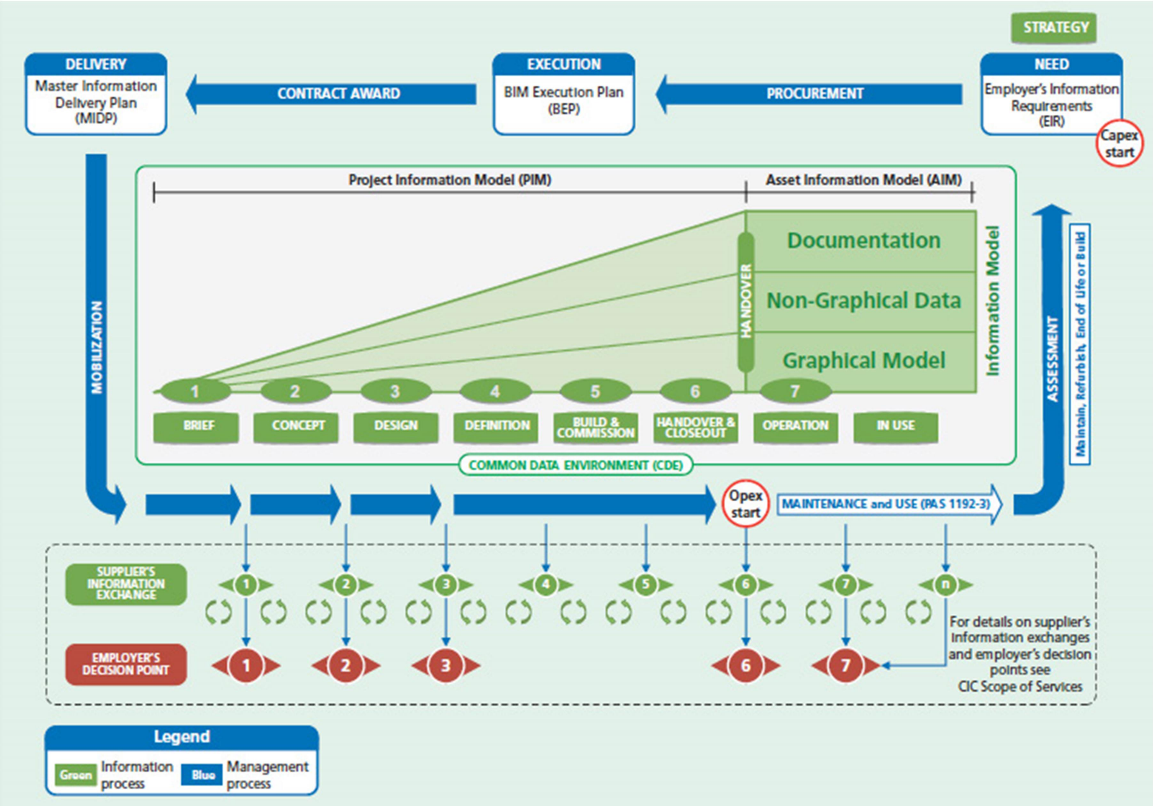
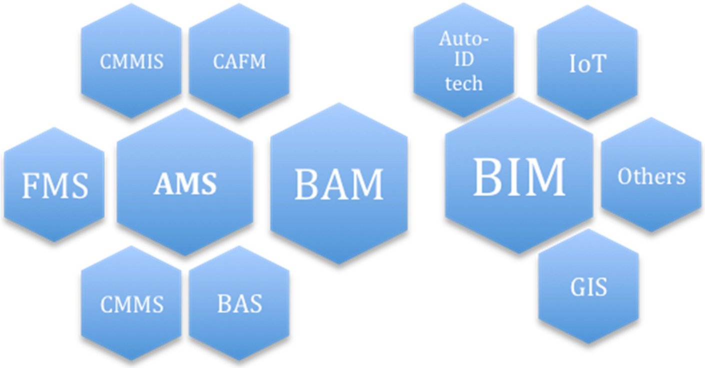


Figure 2.14. The AM information delivery cycle (Guillen et al., 2016)

Particular technologies, such as the use of cloud computing, passive RFID tags and 3D scanning, have facilitated added value to BIM in a AM/BAM or O&M context. Vice versa, the BIM potential aids in the introduction and effective use of these technologies and others as condition monitoring and predictive maintenance, energy consumption control, etc. Actually, these technologies can be seen as information sources that are integrated and used in the building management through the BIM implementation and its interoperability with rest of software packages, which are linked to the operation and maintenance of the building (Figure 2.15) (Guillen *et al.*, 2016).



Other software
- 3D scanning
- Condition monitoring
- Energy consumption

Figure 2.15. BAM and BIM in interoperability software environment

Interoperability software of BAM as a part of AM includes: Facility Management Systems (FMS) are software packages supported the maintenance and management of a facility. It aids managers to take care of work orders, asset inventory, and safety. Computerized Maintenance Management Systems (CMMS), Computer-Aided Facility Management (CAFM), and Computerized Maintenance Management Information System (CMMIS) are others AM software classified under FMS, can be used for handling building assets. In case interoperability software of BAM has been used in a building management organization, its ability to support the BIM Data and Uses should be calculated and defined as in the previous steps. If this software has not existed in this organization, it is essential that a proper one must be chosen.

According to the interoperability requirements of the BAM approach, the BAM system should support to import and/or export building asset database to other systems such as the integration and acceptance of BIM Data. Therefore, It is particularly significant to consider that the BAM system should have the ability importing and/or exporting building asset data directly from the BIM Model. Aimed at this purpose, the BAM system has to support open standards for data transfer which had been used in BIM like COBie.

Finally, BAM system should be capable of handling other graphical data (photographs and plans for example) and interacting with different technologies such as Building Automation Systems BAS, Condition Monitoring, etc.

Comparing with the application of CAFM or CMMS software, the use of BIM models aids in two aspects that still simple before:

- ➢ Allowing to present AM/BAM since the very commencement of the building lifecycle (like designing and constructions period)
- ➢ As an interface, BIM software represents physical and functional characteristics intelligently and detail

In new intelligent buildings, Building Automation Systems (BAS) have the main role in conforming the control system of the building. It includes facilities control and the interaction with users. These systems are going to produce relevant information and will be one of the main sources for BAM. Once again, the interoperability of BAS hardware/software with BAM system and BIM is the problem to be able to use these data.

2.3.2.2.4 BIM as BAM's tool and applying process

Before, the use of BIM concentrated on earlier lifecycle stages of building such as pre-planning, design, construction and integrated project delivery of buildings and infrastructure. However, since recently, the BIM research focus has gradually shifted to other issues like maintenance, refurbishment, deconstruction and end-of-life considerations, especially of complex structures. As buildings and structures have differing framework conditions by dissimilar in types of use (e.g. residential, commercial, municipal, infrastructural), in age (e.g. new, existing, heritage) and in ownership (e.g. private owner, housing association, authorities, universities), which cause influencing the application of BIM, BIM level of detail and its supporting functionalities regarding design, construction, maintenance and deconstruction processes due to stakeholders' requirements (Volk, Stengel and Schultmann, 2014).

Nowadays, with the development of the BIM model shown in figure 2.12, it is not difficult to realize that BIM had big changes that make BAM system change also. From BIM 5D with Cost estimating function; to 6D models - BIM has the ability to control the construction and operation impact; shift to 7D models BIM can manage not only planning both of operation and maintenance, but also consider all execution till the rest of building life-cycle. Thus, all phases of BAM's strategy are covered and modelled by BIM (Fig 2.16).

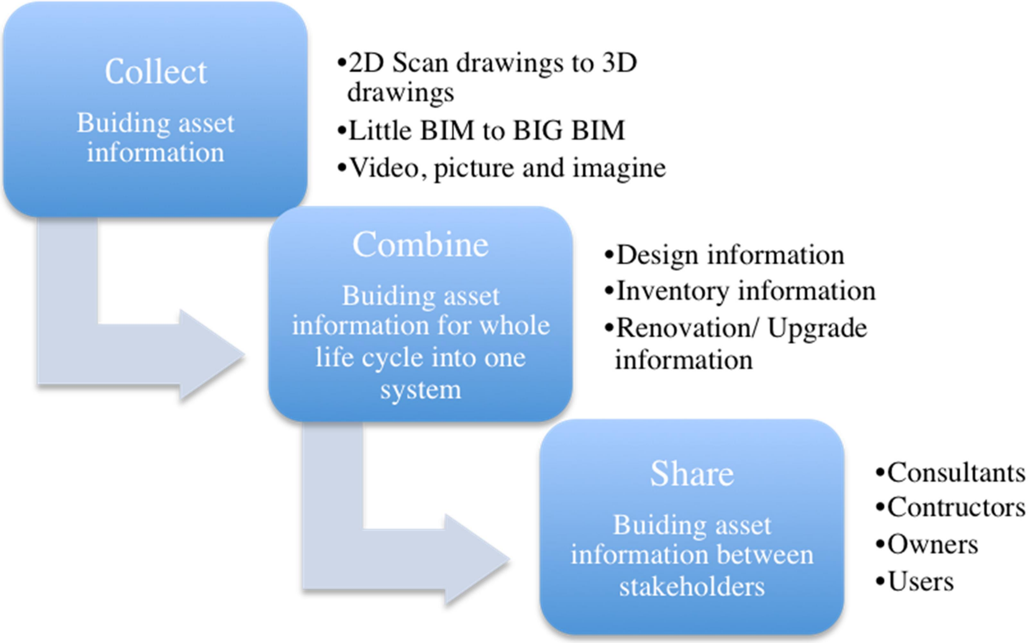


Figure 2.16. BIM as Building asset life cycle management's tool revise from (Guillen *et al.*, 2016) *research*

Nevertheless, BIM implementation in existing buildings compared with the new ones, faces more capabilities and challenges to manage successfully building assets. Different BIM creation processes for new and existing buildings are depicted in (Fig. 2.17). For new buildings, BIM is created in a process over several life-cycle stages, starting from inception, brief, design to production (case I) and part of the project delivery. With the fact that sometimes BIM has not been used in the building life cycle yet, some create isolated BIM solely for a designated, single purpose. In existing buildings - depending on the availability of pre-existing BIM - BIM can be either updated (case II) or created a new (case III).

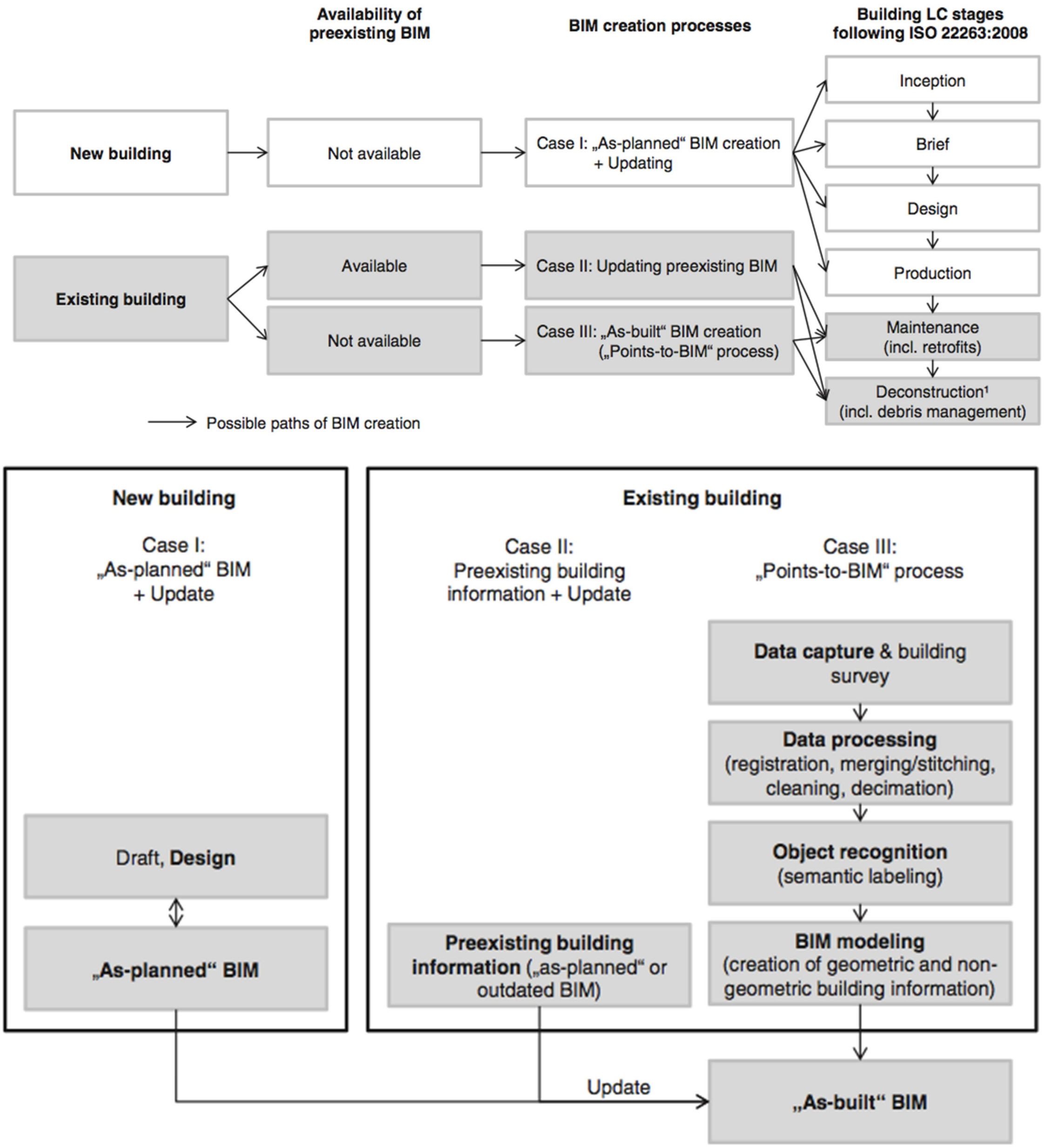


Figure 2.17. BIM model creation processes for new or existing buildings, depending on the available/pre-existing BIM model and Building lifecycle stages and their related requirements (Volk, Stengel and Schultmann, 2014)

In Europe, more than 80% of residential buildings are built before 1990 and mainly do not have building documentation in BIM format. Therefore, if implemented in practice, costly and mainly manual reverse engineering processes (‘points-to-BIM’, ‘scan-to-BIM’) (case III) help recapturing building information more easily and less costly. In this case, the first point of process start with "Data capture & building survey" performed with the object recognition approaches in Fig 2.18.

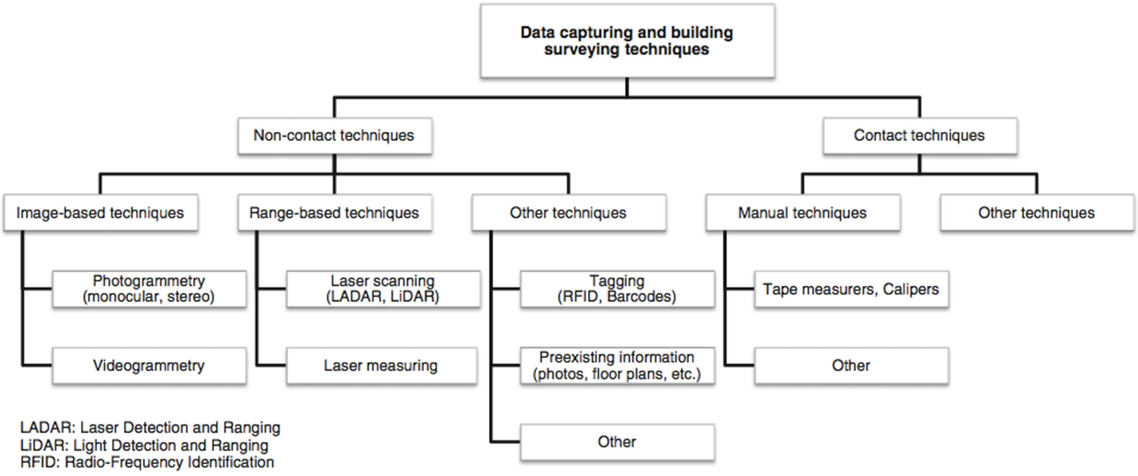


Figure 2.18. Systematic review of object recognition approaches applied in existing buildings (Volk, Stengel and Schultmann, 2014).

2.3.2.2.5 Benefits of applying BIM to BAM

While the benefits of implementing BIM during the design and construction process have been readily observed in practice, particularly in terms of its use by contractors to control and manage projects cost and schedule, the number of reports about the profit bring from applying BIM to BAM is still trivial. The first reason is such benefits are evaluated with the duration of asset's life cycle is considered, so researchers need to have a long-term performance to make accessions needed. The second reason is, as others technologies, BIM has both direct and indirect effects on BAM, and normally for indirect effects, they need time for showing off.

However, there are more and more study about potential benefits of using BIM in BAM, and they seem to be significant, e.g. as valuable ‘as-built’ (heritage) documentation, maintenance of warranty and service information, quality control, assessment and monitoring, energy and space management, emergency management or retrofit planning. Decontamination or deconstruction processes could also benefit from structured up-to-date building information to reduce errors and financial risk, e.g. through deconstruction scheduling and sequencing, cost calculation, rubble management, optimization of deconstruction progress tracking or data management (Volk, Stengel and Schultmann, 2014).

In other research of (Love et al., 2014), the conclusion about several direct benefits of BIM model to BAM performance is a long list, included:

- Saving AM labour utilization (e.g. by shorter work order time);

- Reducing utility costs (e.g. through simulation of options in relation to energy efficiency, more informed choices could be made);
- Savings of fuel and material (e.g. through less travel and waste are facilitated);
- Building comfort management (e.g. by promoting improved productivity);
- Accurate database (e.g. there is no need to re-survey for 'As-Built');
- Compliance regulations (e.g. auto-checking building and safety codes);
- Optimize space usage (e.g. smart algorithms);
- Improving inventory management (e.g. spare parts and material); and
- Configuration management (e.g. impact/functional conflicts)

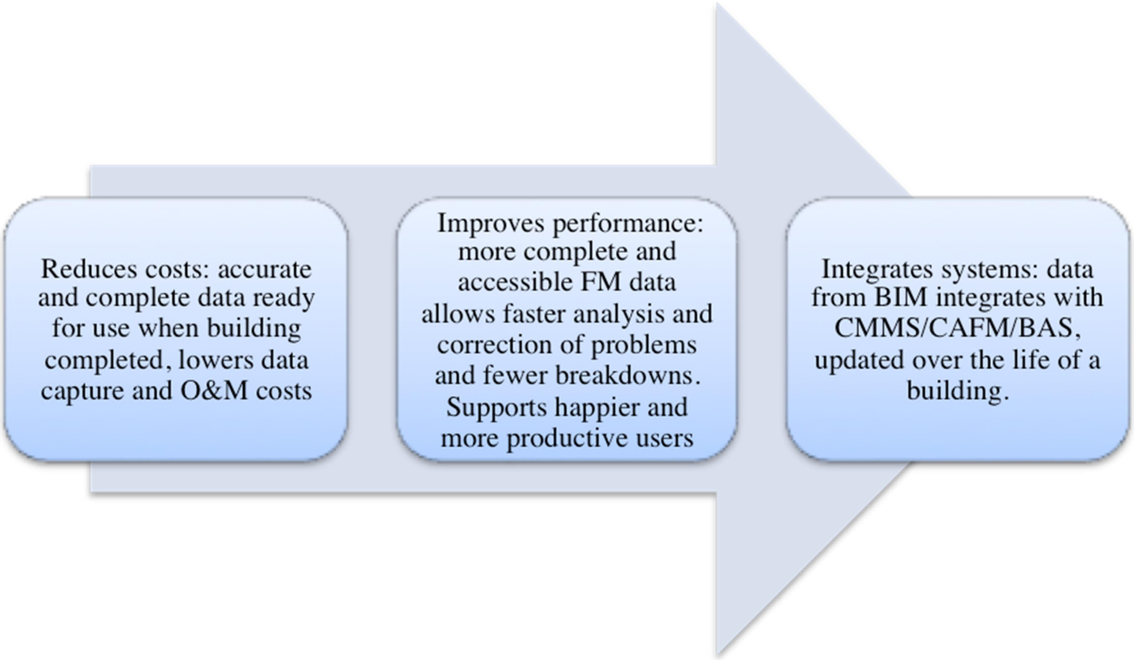


Figure 2.19. The main benefits achieved when integrating BIM (Ashworth, Carbonari and Stravoravdis, 2015)

Besides, as BAM system is a set of interrelated and interacting elements of an organization, whose function is to establish the asset management policy and asset management objectives, as well as the processes needed to achieve those objectives. From the upon reviews of the BIM model and its supported software show the total benefits of implementing BIM processes and technologies for BAM functions. They include: a reduction in all the costs for investment - maintenance and operation of building assets by improving BAM performance (Fig 2.20). With BIM, the quality of asset information was lifted due to BIM has the integrability of multi-sources information, update propensity of changes. BIM also improved interoperability between stakeholders, and whole life-cycle asset management (Fig 2.21). Thus, right decisions of

BAM could have been driven by right information, then help in optimizing the expense and reduce risk.

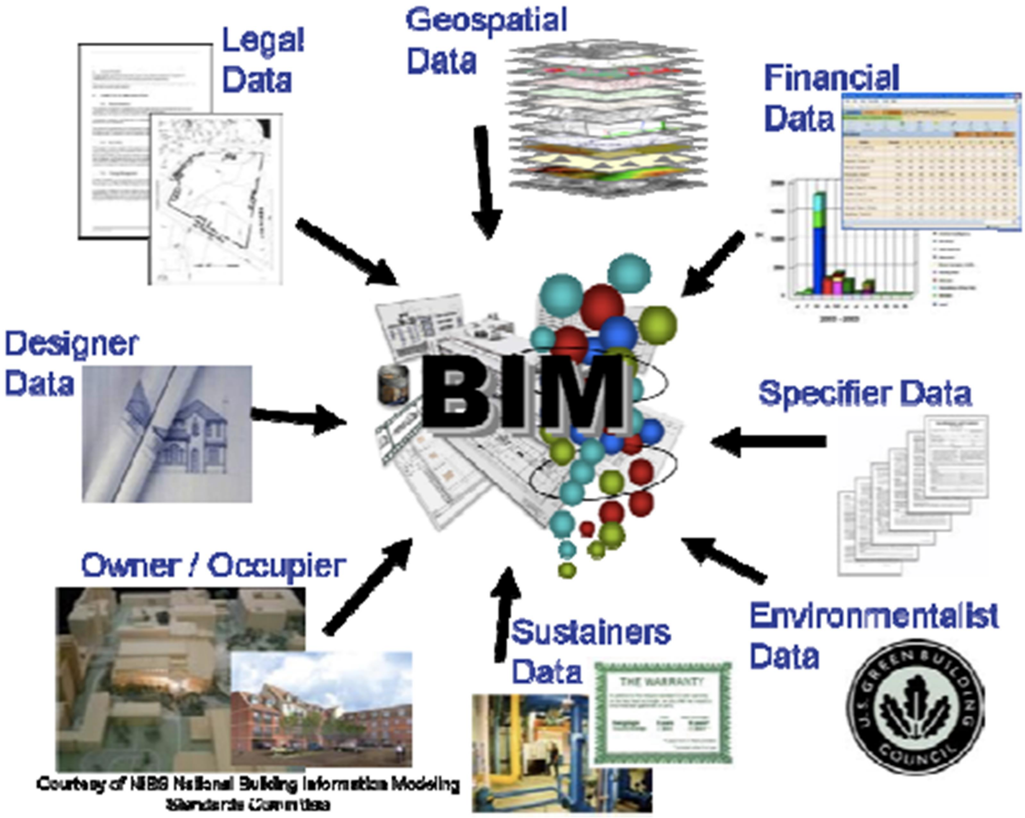


Figure 2.20. Communication, collaboration and Visualization with BIM model (NIBS) (Arayici and Aouad, 2011)

Albeit more and more reasearches assure that the benefits as the result of applying technology could be acquired during assets' operation and maintenance rather than those that can be acquired during design and construction process , has been the impetus for BIM adoption. Nevertheless, many asset owners are still skeptical about the value of adopting and integrating BIM technologies and processes into their existing BAM system and organizational operations. As there is significantly growing evidence linking BIM benefits to BAM, this scenario is vitally critical. Such view deserves exploring as it is the asset owner who is ultimately best positioned to realize the benefits that can be derived by implementing a "BIM for BAM" strategy.

2.4 Smart building asset management systems model

2.4.1 Some recent smart building asset management

2.4.1.1 The BAI Approach to Building Asset Management - a result of Building asset insight LLC

The *Building Asset Interdependency Model (BAI Model)* (Building asset Insight, 2016) is a framework for implementing world-class *Building Asset Management.* The BAI Model helps building owners and operators transform themselves from strict functional alignment to a matrix structure in which *a small, central Asset Management organization* plays the lead role. From the review of Building asset insight LLC, their researchers realize that constructing, operating, maintaining, and refurbishing buildings consume more human and natural resources than any other human activity. Up to 30% of global annual greenhouse gas emissions are contributed by the building sector in general. This sector also consumes up to 40% of all energy. The global construction market is expected to exceed $12 trillion in 2020, two-thirds of total current US GDP and about 13% of projected Global World Product (GWP). Each dollar of building construction cost will be matched by between two and eight dollars of other costs over a building's life cycle. Given the massive growth in new construction in economies in transition, and the existing building stock inefficiencies worldwide, if nothing is done to improve how we manage buildings, greenhouse gas emissions from buildings will more than double in the next 20 years.

Whether one wants to improve the financial performance of their own organization or help save the planet, the need for a value-centric approach to FM is apparent. Building asset insight LLC researchers have seen how most FM organizations destroy value in the way they organize, the incentives and metrics they put in place, their financial approaches, and the design of their building management programs and processes. When looks deeper into value destruction one finds that the enemy is themselves; their building management paradigms constrain their ability to extract maximum value from their building assets.

Building asset insight LLC has built a comprehensive framework, which needed to help define the problem. The framework considers how people working within the right environment (organizational structure, incentives, metrics, program design, business improvement initiatives) equipped with the right information (about building and asset cost, performance, risk) can perform activities (managing maintenance, capital investment, energy, and risk) to make optimum asset- based decisions – decisions that maximize value. The framework delivered value in today's building management world and be able to accommodate standards, business improvement initiatives, existing and future technologies. Finally, the framework shows how thinking differently can unlock new value opportunities from managing building assets. Building Asset Insight has developed the BAI Model (Fig 2.21) to meet this need.

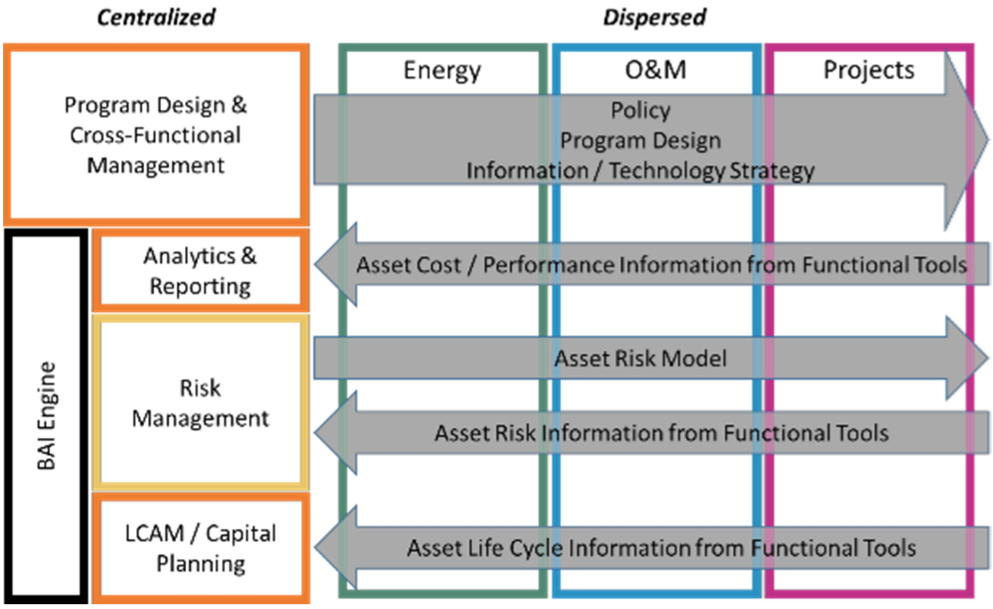


Figure 2.21. Asset Management Organization in BAI model (Building asset Insight, 2016)

A typical arrangement is shown here. The Asset management organization – the leftmost column - sets the strategies, develops policy, designs the cross- functional programs in the overlaps, establishes performance metrics, performs analytics and provides reporting. It also performs the Risk Management function. All this gives the traditional functional organizations a consistent strategic direction. The Asset Management organization is the policy link between a building management organization and senior management. Culturally, pursuing Asset Management helps an organization to adopt *the Asset Management Paradigm.* This is explained in table 2.3 below.

Table 2.3. BAI's framework (Building asset Insight, 2016)

Attribute	**Functional Paradigm**	**Asset Management Paradigm**
Scope	A set of discrete activities delivered to functional best practices.	Cross-functional management of assets to achieve optimum outcomes (maximum value contribution to the business).
Technology	Technology supports activities within a functional silo.	Technology helps manage functional activities and captures a comprehensive set of information about assets.
Information	Information is used to manage processes, budgets and performance metrics within a functional silo.	Cross-functional information enables the analytics needed to optimize asset decision-making and to create value in the overlap activities.
Analytics	Analytics consist of reporting functional information or using it to improve a functional process.	Analytics derive insight from cross-functional information that enables better asset decision-making.
Value	Cost savings (e.g. accounting expense reduction) aligned to functional budgets.	The optimum combination of asset cost, reliability and performance, consistent with budget constraints and risk tolerance.

Information & Technology

Develop an information map: what will the asset management program do, what information is needed to do it, and where will the information come from? The information map identifies how existing technology tools need to be reconfigured to provide the needed information.

Provide an information consolidation and analytics tool is needed to make sense of the information.

Balancing the short-term and the long-term

The focus of the organization in the short term is to optimize operation of existing assets; the focus in the long term is to optimize investment in new assets (replacement) or existing assets (refurbishment). The designations for the program overlaps have been changed in this figure to better represent the tradeoff.

Repair or Replace

Conceptualize the decision: The repositioned Project and O&M circles are connected by the black line. A "slider" is positioned along the connector based on information taken from the functional tools and run through the asset analytics. Eventually, the slider reaches the replacement trigger point ("R"). The reconfigured functional tools capture the "right" information per the information map, the BAI Engine applies the "right" cross-functional analytics, in order to make the "right" decisions - decisions that maximize value to the organization

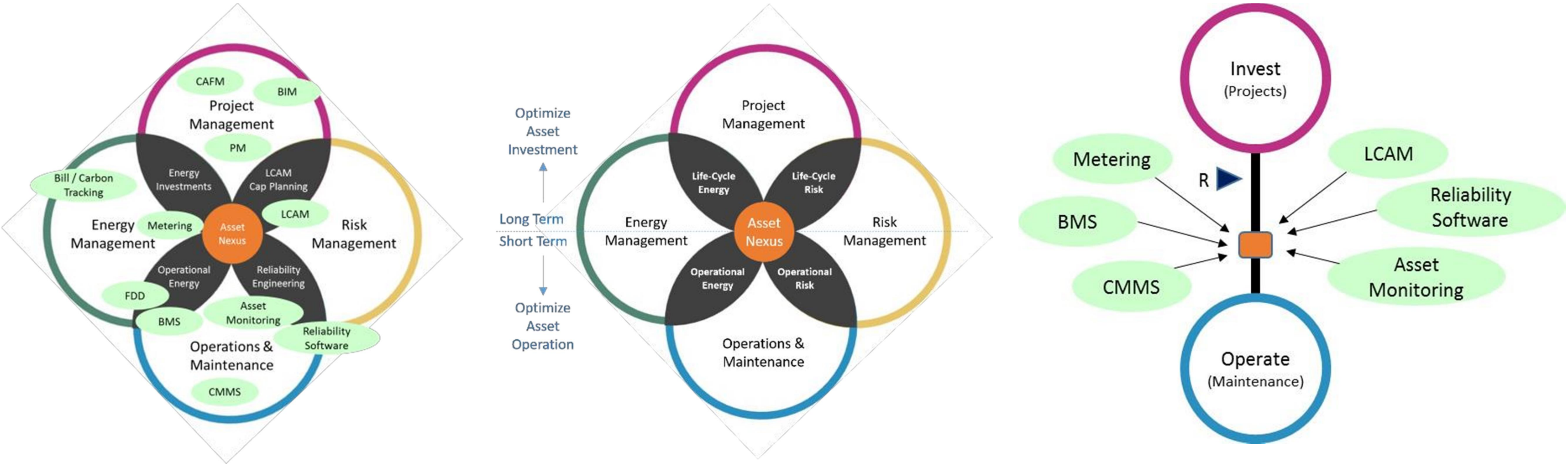


Figure 2.22. BAI model into BAM (Building asset Insight, 2016)

With the BAI Model as the backdrop, Assessment Tool from Building Asset Insight aims to identify gaps and barriers to success for individual organizations considering implementing BAM (Fig 2.22). It shows how to address the organizational challenges associated with BAM. The BAI Engine provides the analytics and decision-making tools to support the framework. It addresses the technological aspects of BAM. Taken together, the BAI Model, the Readiness Assessment Tool and the BAI Engine provide a coherent, mutually reinforcing solution to the problem of extracting the most value from building assets.

2.4.1.2 The Internet of Things: smart property management at Two Castles Housing Association

Capita's ground-breaking project with Two Castles Housing Association tackles fuel poverty using smart home technology. Two Castles Housing Association, which manages properties across the North of England, has formed an innovative partnership with Capita to install smart sensor monitoring equipment to capture and analyse household data such as air quality, temperature and humidity. The project is the first of its kind for the sector and help tackle overheating and fuel poverty, plus the health issues and property damage caused by damp, as well as helping to provide services to vulnerable residents (Fig 2.23).

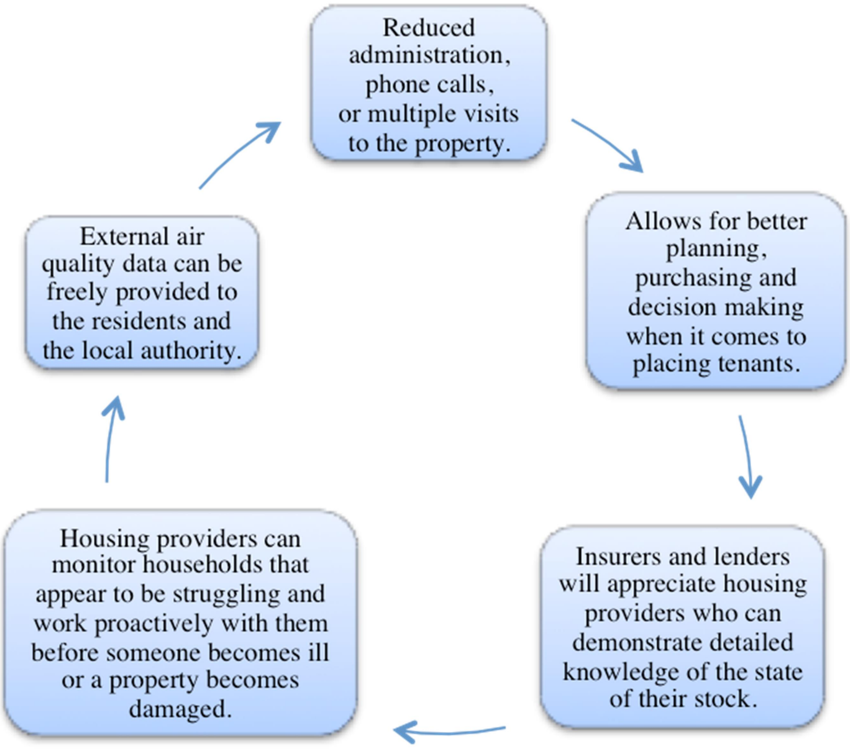


Figure 2.23. Benefits of smart sensors in property management in Two Castles Housing Association

2.4.1.3 Smart Building Management Systems and Internet of Things - Building Management Internet of Things (BMIoT) solution

(Astier, Zhukov and Murashov, 2017) presented their smart building management system, which used the technological evolutions like IoT, so it could face the new challenges regarding modern building technical management systems (BTMS). Their management system - Building Management Internet of Things (BMIoT) (Fig 2.24) allow them to address the new issues with the renovation of both software and hardware architectures. The hardware architecture for a BMIoT system is deployed on a site called Solaris in Clamart, France (www.solaris-energie-positive.com). Specifications: 30,000 m² surface area; 116 geothermal probes 100m under-ground; 126 km of heating coil in the floor; A 1,000 m² in-door garden; 5,000 lights paired to a high-performance BTMS; A new generation BTMS; 10 levels - 100 controllers – 24,000 controller points; 1,700 presence sensors - 450 energy meters; 1,000 real-time alarms; 6 heat pumps – 11 central compressed air supplies. On the optical fibers are 100 WAGO controllers, an HP Proliant server, two HP-Z1 PCs (operator workstations), 50 TV screens, and an ADSL Internet access. The Software Architecture The fixed workstations are two Windows HP-Z1 PCs; the only software they need is a Web browser. The BTM server runs CentOS; it rusts the Apache Web Server, PHP, and the MySQL relational DBMS. The remote workstations are Windows computers, tablets, or smartphones, the only required software being a web browser. The WAGO controllers use the MODBUS/TCP protocol as well as a MySQL client, which lets them directly use the MySQL DBMS. The software for the controllers is written using an automation language by the WAGO Company.

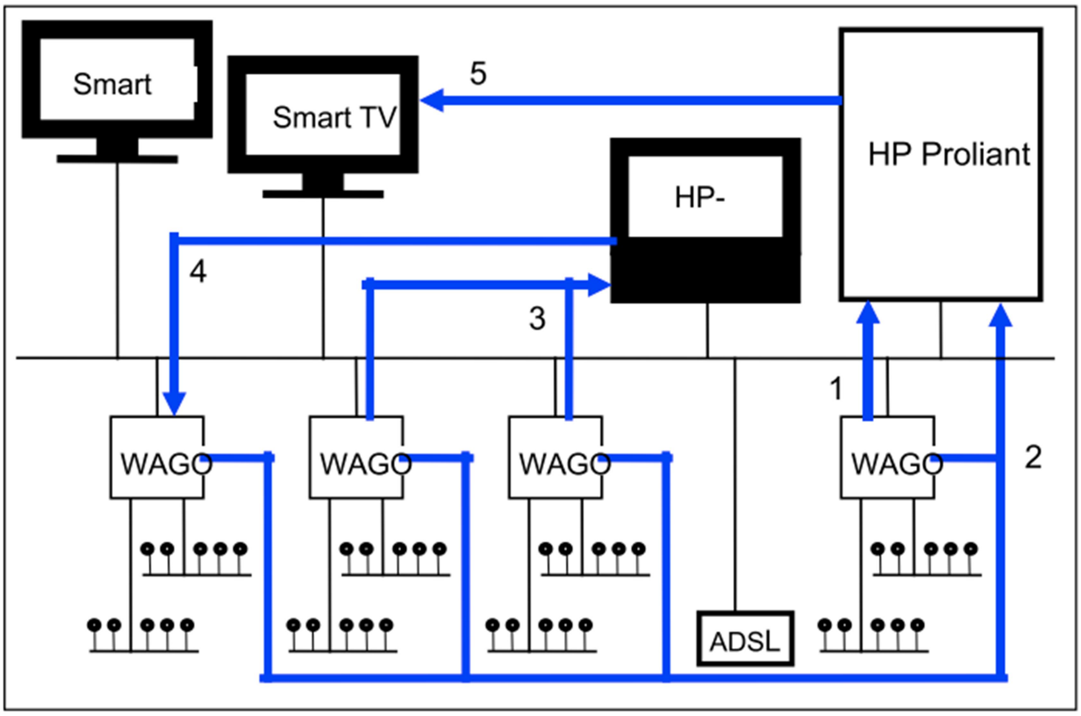
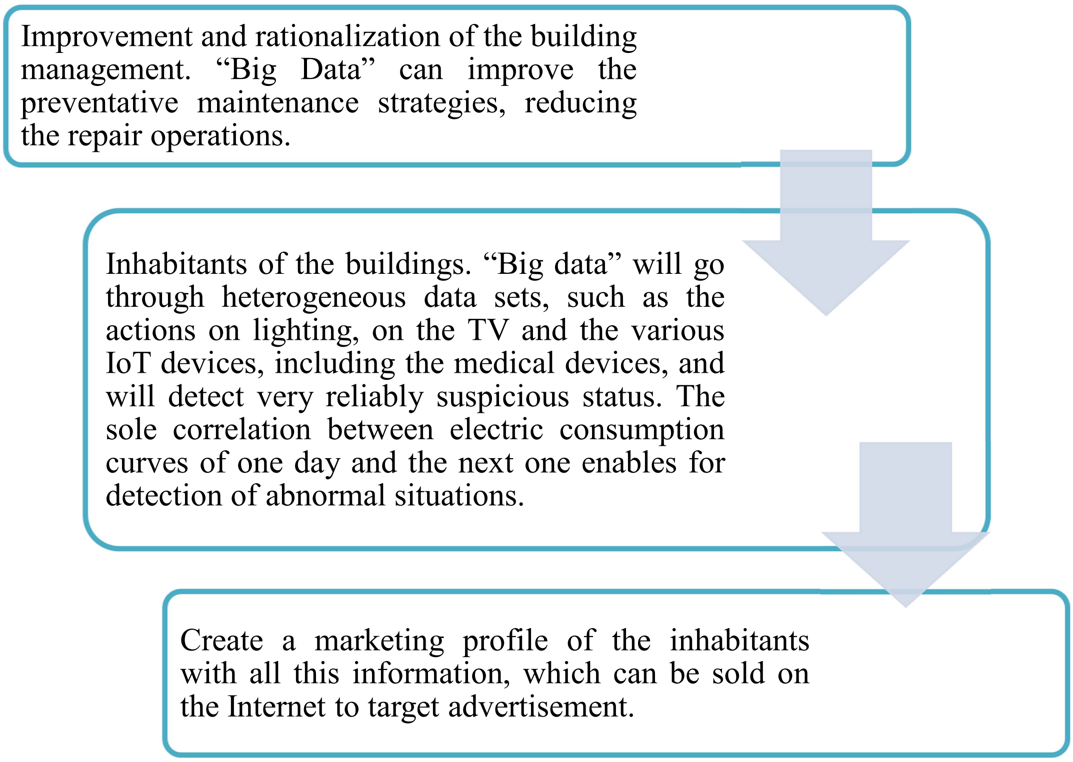


Figure 2.24. Overall working of BMIoT (Astier, Zhukov and Murashov, 2017)

The software solution provides uniform supervision of both “typical” building equipment such as heating, lighting and energy consumption, as well as end-user IoT devices with new use-cases such as media consumption meters or health-related devices. Its goal is to facilitate the transition of companies for maintenance in good operation conditions of buildings or facility management to a business model of Internet Player. The main point of this transition lies in going from “small data” of traditional BTMS to the “big data” which is the foundation of new and additional economic activities.

The data are no longer isolated individual values, it is aggregated contextual data: a place, a temperature, and weather conditions at this point in time. Once this “big data” is available and set up, it becomes possible to provide new services to both the managers of the buildings and the inhabitants on the other (Fig 2.25). These new services will be built using “big data” technologies, especially “deep learning”, artificial intelligence or automatic analysis of large volumes of data.



Improvement and rationalization of the building management. “Big Data” can improve the preventative maintenance strategies, reducing the repair operations.

Inhabitants of the buildings. “Big data” will go through heterogeneous data sets, such as the actions on lighting, on the TV and the various IoT devices, including the medical devices, and will detect very reliably suspicious status. The sole correlation between electric consumption curves of one day and the next one enables for detection of abnormal situations.

Create a marketing profile of the inhabitants with all this information, which can be sold on the Internet to target advertisement.

Figure 2.25. New services provide to both the managers of the buildings and the inhabitants (Astier, Zhukov and Murashov, 2017)

2.4.2 Challenges of applying smart technologies into building asset management

The analysis of various cases studies at various scales allowed identifying the main benefits and challenges of building asset management innovation. The benefits that smart technologies brought to building asset management or engineering asset management are proved by the study about smart technologies in these parts above. For the barriers, the highlight studies could be namely are (Parlikad *et al.*, 2013), (Ashworth, Carbonari and Stravoravdis, 2015), (Coburn, 2016), and (Parlikad *et al.*, 2017). Some old barriers have been solved in lately years; some still are challenges to management innovations. The main barriers about smart technologies adoption can put into 5 groups as follows (Fig 2.26):

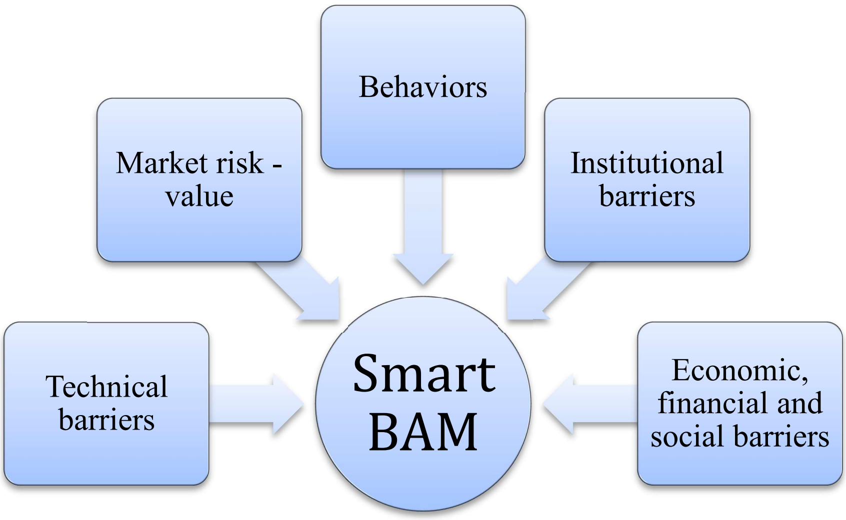


Figure 2.26. Five groups of main barriers for applying smart technologies into building asset management

In which, ***the technical barriers*** include of two types of lack: learning and knowledge sharing about some new technologies adapted to the recent building asset management system. Once all needed technologies are available, how to combine all in one for the most effective collecting – sharing database system. From the reports recently, it could not be denied that they are still wondering about issues relating to the effective use of data that need addressing:

1) The "right" data (Data capture should be driven from a "what are you trying to achieve" rather than from a "what can be measure" perspective);

2) Data quantity (how much data should be captured? collecting as much data as possible or just set of data is required to monitor the condition of an asset? With the data may not be immediately apparent, is it able to predict what data might become useful in the future?);

3) Data quality (How good does the data need to be to give you adequate information? Because perfect data is elusive and expensive, the risk of having imperfect data is also increased by sharing and outsourced collecting information. So it may be possible to set a quality/quantity threshold, which is more affordable than trying to capture data of quality, which is not actually required. Hence, organisations may be able to make good decisions with less than perfect information);

4) Data sharing and cost (Caring about costs associated with both the capture and use of data, stakeholders are paying more and more attention to share their data. One effective way of reducing costs is by having other organisation in the value creation network can gather information on the assets. However, data sharing standards should be enforced sharing of that data because the information is exchanged with various other software, from and to several stakeholders. Besides, the shared data needs to be tagged by users with a confidence rating to avoid duplicating or losing data during the processes. This means that users are aware of the quality of the data shared, and that information source is able to trace and update that information with more confidence and less cost.)

For **market risk-value barrier**, there is a requirement of a structure that "maximum or optimal value to all the stakeholders". Nevertheless, stakeholders' value perspectives sometimes are not the same, like owners and users. Hence, broader perspectives are needed to avoid blindness of decision makes: If the aim is for individuals and organisations to be able to make decisions which are in the interest of the whole of the stakeholder network, they need to understand the perspectives of the other participants in the network. Incentives should be in place so that they make decisions that are optimal for the whole system, and have the necessary shared information to form those decisions , then have win – win systems.

About ***behaviours barrier***, the need for changing behaviours of many actors (such as the lack of routines and workflows for management of building assets for their whole life cycle; collaboration and communication between all building assets' stakeholders - specially the users; and in general, the need of transparency against the fear of a potential transparency (linked to the difficulty of any implementation of real sustainable development approaches)… are mainly named.

Institutional barriers are distinguished by zone level, national level and local level. Indeed, even though building asset management is more and more globalized, its policy, guidance and standard are not global yet. These barriers then effect on the difference between the lower management level and the upper ones of international organizations or collaboration.

The final about ***Economic, financial and social barriers*** is against the life cycle cost/ or life cycle value approach of using smart technology. Due to the type of experts involved in smart technologies application who are in the great majority technical experts without any abilities in socio-economic issues: on the one hand, the performance of renovation asset management projects, which focused on new buildings, are assessed easier than the one of the retrofitting of existing buildings because of the one way process (applying smart technologies from beginning, no need revising the recent system) and on the other hand the solutions are often non-transferable because of the lack of any socio-economic analysis together with the technical analysis. There is a need of sustainable development approaches dealing with technical, environmental, social and economic issues together, a real need of life cycle cost/life cycle value analysis.

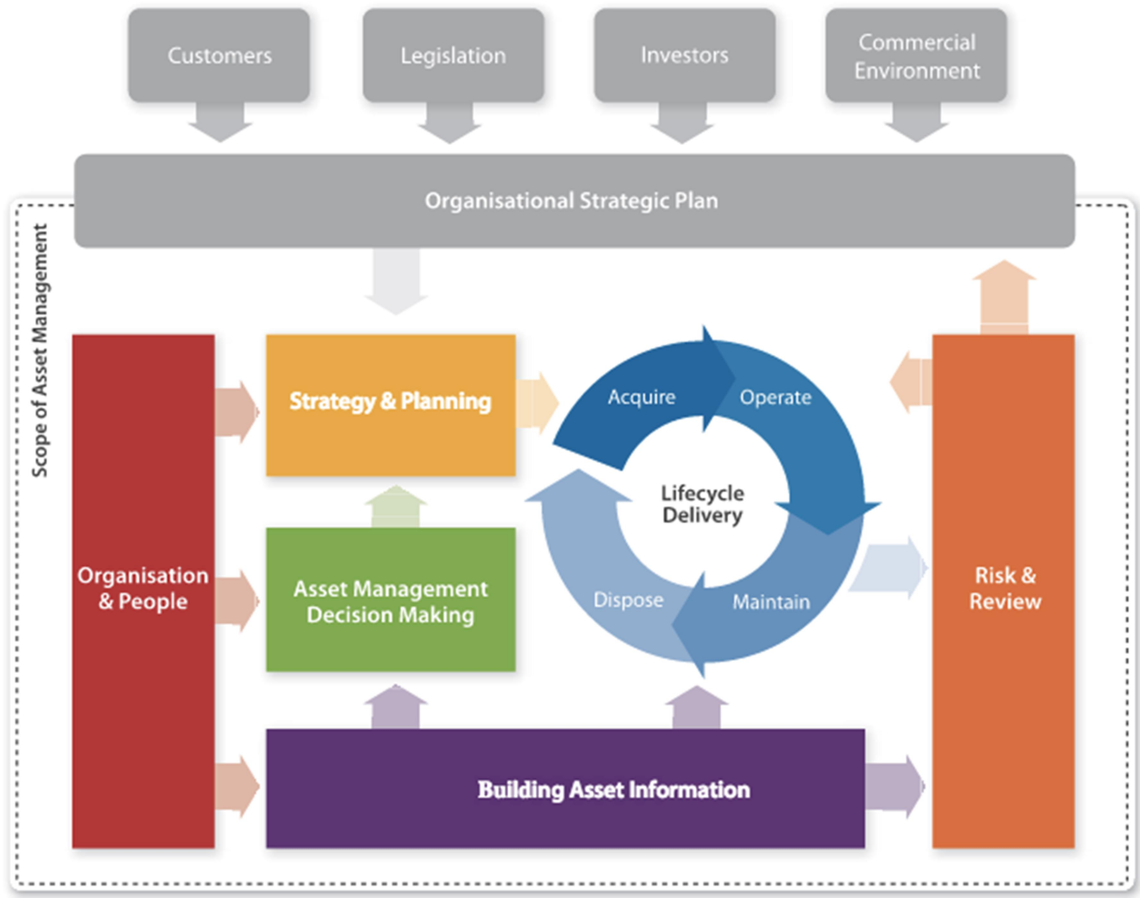
2.4.3 Smart building asset management system design

The benefits of Smart building asset management (Smart BAM) created by applying smart technologies into BAM are proven in many researches, improving the performance and the contribution to safety, health along the building asset lifecycle and protection of the environment by reducing buildings' expenditure and trash. Together with the organizational commitment to quality, performance or safety, it helps to mitigate the legal, social and environmental risks associated to building assets. Smart BAM, as a discipline, allows organizations to optimize the whole life value of managing building assets portfolios. For a single building management organization, the list of assets or portfolio may contain diverse assets in types, distributors, and subjected to differing demand/utilization requirements.

In the 21st Century, Smart Technologies are introduced to several building asset management stakeholders, namely owners, contractors and users, aim to improve performance, quality, and to upsurge satisfaction. Smart technologies have transformed understanding and perspective of stakeholders towards performing business, collaboration cooperation, communication and connection. Stakeholders are using smart technologies for accessing, exploiting and managing assets. These smart technologies adopt in such sectors creates a giant challenge in training and implementation. Nevertheless, using such technologies will improve several areas performance and productivity; reduce costs, improve sustainability, increase users’ satisfaction, retention, and loyalty in the long run. Nonetheless, new threats will be presented such as, security, privacy, legal conflicts and risky reputation, if it is used inappropriately. From the state of using smart technologies for building asset management, it could not be denied that up to now there is no smart management system that combines all the technologies been able to full support for BAM. This following part of research aims to build a smart building asset management system, which formed by smart technologies and strategies after investigate and assess some of the effects and influences of smart technologies.

2.4.3.1 Smart building asset management conceptual model

In the 3rd version of Asset management – an anatomy (IAM- The Institute of Asset Management, 2015), IAM emphasize that "it is vital to remember that people do asset management and therefore people, and their knowledge, competence, motivation and teamwork" have a huge influence on the asset management outcomes. Tools and technologies are important: "but engagement of the workforce, clarity of leadership, and collaboration between different departments and functions are the real differentiators of a leading asset management organisation". So, what and how people do asset management with knowledge, competence, motivation and teamwork have a huge influence on asset management outcomes. From this point of view, in this part, author will dig into building asset management conceptual model (Fig 2.27), to figure out how smart technologies can connect all the subjects of building asset management concept, and build a smart building asset management model.



Group 1 - Strategy & Planning

1. Asset Management Policy
2. Asset Management Strategy & Objectives
3. Demand Analysis
4. Strategic Planning
5. Asset Management Planning

Group 2 - Asset Management Decision-Making

6. Capital Investment Decision-Making
7. Operations & Maintenance Decision-Making
8. Lifecycle Value Realisation
9. Resourcing Strategy
10. Shutdowns & Outage Strategy

Group 3 - Life Cycle Delivery

11. Technical Standards & Legislation
12. Asset Creation & Acquisition
13. Systems Engineering
14. Configuration Management
15. Maintenance Delivery
16. Reliability Engineering
17. Asset Operations
18. Resource Management
19. Shutdown & Outage Management
20. Fault & Incident Response
21. Asset Decommissioning & Disposal

Group 4 - Asset Information

22. Asset Information Strategy
23. Asset Information Standards
24. Asset Information Systems
25. Data & Information Management

Group 5 - Organisation & People

26. Procurement & Supply Chain Management
27. Asset Management Leadership
28. Organisational Structure
29. Organisational Culture
30. Competence Management

Group 6 - Risk & Review

31. Risk Assessment & Management
32. Contingency Planning & Resilience Analysis
33. Sustainable Development
34. Management of Change
35. Asset Performance & Health Monitoring
36. Asset Management System Monitoring
37. Management Review, Audit & Assurance
38. Asset Costing & Valuation
39. Stakeholder Engagement

Figure 2.27. Building asset management conceptual model with its detail subjects - revise from (IAM- The Institute of Asset Management, 2015)

However, there is a big question is should a smart management system fit for all building asset system? Does it worth to invest with all its challenges? Could smart building asset management system maximize all 39 subjects, which IAM presented at the same time? How do building managers know which values are core goals of their organization? What should we do to measure its performance? These questions will be solved in the following part.

2.4.3.2 Smart building asset management processes

From all the designs of conceptual model and measurement BAM performance tracking model above, the Smart Building Asset Management processes with building asset information needed are built, detail in table 2.4.

Table 2.4. Smart Building asset management processes and the building asset information needed

Building asset management processes

	BAM Proccesses	**Identifying assets**	**Real-time tracking assets**	**Trammiss/ communicatting**	**Analysis database**	**Decision making**	**Performance mensurement**
Smart technologies applied Stakeholders		RFID tags Barcode BIM 3D	RFID tags (Active) Sensor system Camera system 3D scan	CAMF IoT BIM 4D/5D	Cost –Benefit analysis method Global cost method Life cycle cost method BIM 5D/6D	Risk base methods Value base methods BIM 7D	KPIs system for access asset value and BAM system value
Constructors	Design	**(A)**=(1)+(2)+(3)+(4) +(5)+(6) in designing step		**(A)=> (A*)**			
	Construction	**(B)**=(1)+(2)+(3)+(4) +(5) +(6) in construction step		**(B)=>(B*)**			
	Maintenance		**(C)**=(1)+(2)+(3)+(4) +(5) +(6) in real-time	**(C)=>(C*)**	(A*)+ (B*)+ (C*)		
	Renewal/renovation		**(D)**=(1)+(2)+(3)+(4) +(5) +(6) after renovation	**(D)=>(D*)**	(A*)+(B*)+(C*)+ (D*)		

	BAM Proccesses	**Identifying assets**	**Real-time tracking assets**	**Trammiss/ communicatting**	**Analysis database**	**Decision making**	**Performance mensurement**
Owners	Technical department		**(A')**=(1)+(2)+(3)+(4) in designing step **(B')**=(1)+(2)+(3)+(4) +(5) +(6) in construction step **(C')**=(1)+(2)+(3)+(4) +(5) in real-time **(D')**=(1)+(2)+(3)+(4) +(5) after renovation ***Note 1**: In case BAI is already in common language, switch to the next step*	(A')=> (A'*) (B')=> (B'*) (C')=> (C'*) (D')=> (D'*)	(I)=(A'*)+(B'*)+ (C'*)+(D'*)	Analysis (I)	Result analysis (I) in KPIs (8)
	Financial/accoutant department		(6A) in designing step, (6B) construction step, (6C) real-time and (6D) after renovation ***Note 1***	(6)=>(6*)	(II)=(6A*)+(6B*) +(6C*)+(6D*)	Analysis (II)	Result analysis (II) in KPIs system (8)

	BAM Proccesses	**Identifying assets**	**Real-time tracking assets**	**Trammiss/ communicatting**	**Analysis database**	**Decision making**	**Performance mensurement**
	Human resources		(7A) in designing step, (7B) construction step, (7C) real-time and (7D) after renovation ***Note 1***	(7)=>(7*)	(III)=(7A*)+(7B*) +(7C*)+(7D*)	Analysis (III)	Result analysis (III) in KPIs system (8)
	Other (External suplier)						
Users	Technology	(5)					
	Finance	(6)					
Legal	Technical Standards	(9)					
	Law Doccuments	(10)					
	Sustantable development						
	Resources: Energy (electricity, gas), Water	(11)					
	Waste, CO2 emission	(12)					

Note	(1) Technical Asset info: – Asset type – Manufacture – Supplier – Model name – Serial number – Color – Insulation class – Energy info – Spare parts info – Life cycle phase	(2) Installation info: – Installed place – Date installation – Install guide – Test reports – Certificate description – Purchase order No – Purchase document	(3) Warranty info: – Start date – Warranty duration – Warranty description	(4) Maintenance info: – Related documents – Scope of maintenance – Asset status – Mantenance history – Frequency – Instruction – Accessibility	(5) Identify asset info: – Asset ID – RFID/Barcode ID – Control panel ID – Purchase order No – Purchase document	(6) Cost info (material, labor, machine): – Investment cost – Annual cost for maintenance – Allocation cost (management, operation) – Annual expenditure cost	(7) Labor and machine(s) expended - Labor and machine(s) expend for install asset - Labor and machine(s) expend for maintenance - Labor and machine(s) expend for renovation
	(8) KPIs system: – Asset performance – Building asset management performance ***Note 2:* *See KPIs table 1.4***	(_) BAI in original languages of diffirent software	(_*) BAI in common language				

Sources of Building Asset Information (Farghaly *et al.*, 2018)

2.5 Conclusion

Smart BAM offers opportunities for improving the performance of asset management in both individual building level and organization one. It also contributes to improving safety and health of building assets along with their lifecycle. With Smart BAM, sustainable development could be achieved by reducing buildings' expenditure, Co2 emission, and waste. Together with the organizational commitment to quality, performance or safety, it helps to mitigate the legal, social and environmental risks associated to building assets.

Smart BAM allows organizations to optimize the whole life value of managing building assets portfolios such as finance, performance, and risk.

However, for each building management organization in different sectors, the list of assets or portfolio may contain dissimilar assets in types, distributors; subjected to differing demand/utilization requirements. These organizations generally have diverse management strategy or various core value goals as well. Therefore, the new issue for building managers before using Smart BAM should focus on smart management system fitting to their BAM system and organization. Do managers create their own “Smart BAM” to optimize the organization values? What should we do to make it? These questions will be answer in the next chapter.

CHAPTER III. SMART ASSET MANAGEMENT OF SOCIAL HOUSING

French social housing sector is submitted to increasing challenges: aging, poor quality, degraded life environment, high running expenses, tenants' low income, reduction of public funding and increase in sustainability requirements to reduce consumption of energy and greenhouse gas emission. To meet these challenges, this sector needs to innovate in both management methods and operations' procedure. Due to the multi-stakeholder of this sector, these two issues need to be implemented simultaneously to improve the sector performances.

This chapter presents the design of a Smart BAM for the lifecycle management right for French social housing asset management organizations, which bases on their characteristics. This system sets up the role and responsibility of French social housing stakeholders (local authorities, government, investors, contractors and tenants) as well as the collective work organization and cooperation. This smart management system aims at establishing a balance between economic and social goals of social housing management organization in France. An application of this system on the asset management of a social housing stock in the North of France will be presented in this chapter.

3.1 Literature review of France social housing

The social housing in France was initiated in the 19th century but was significantly developed after the Second World War (1948). The creation of Habitation à Loyer Modéré (HLM) 'low-rent housing' aimed at helping moderate-income people (Habitat, 2003). The government adopted policies to develop the social housing sector. It adopted specific programs: FNAH (Fonds Nationaux pour l'Amélioration de l'Habitat), LOV (Loi d'Orientation pour la Ville) and SRU (Solidarité et Renouvellement Urbain). These programs resulted in an important development of this sector (***Figure 3.1***).

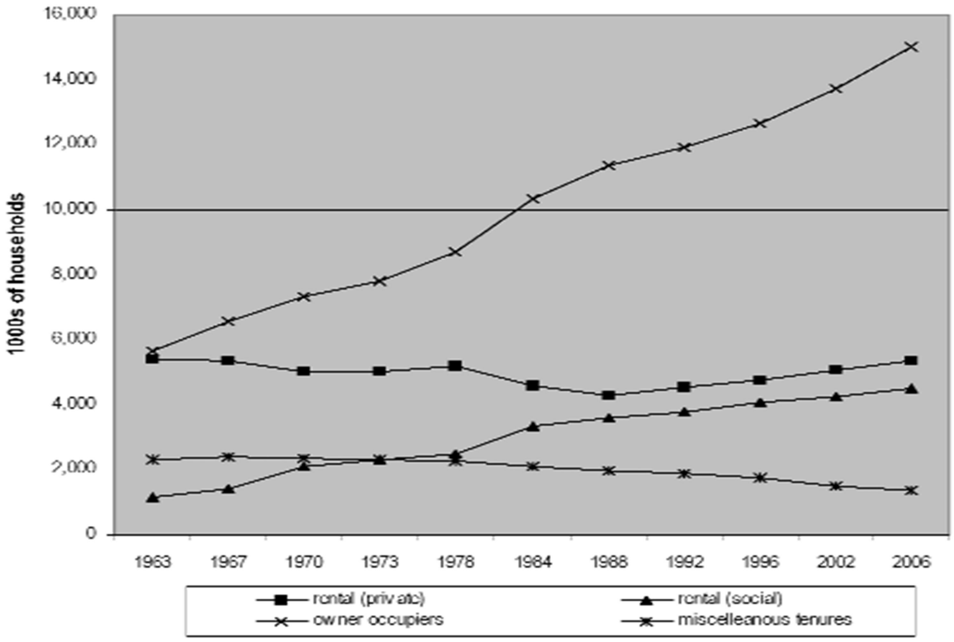


Figure 3.1. Housing tenure in France (Schaefer, 2008)

In recent years, we observed a stabilization of the social housing stock in France. It accounted for 19.1% in 2000 and 18.7% in 2013 of the housing sector in France. It is on top of the social housing stocks in OECD (Organization for Economic Co-operation and Development) group. In 2015, this sector included 5.4 million units, which present around 18% of the housing sector (Figure 3.2) (OECD Affordable Housing Database, 2017), (Rochard, Shanthirablan and Brejon, 2015). Figure 3.3 shows that the majority of this stock is old (more than 20 years).

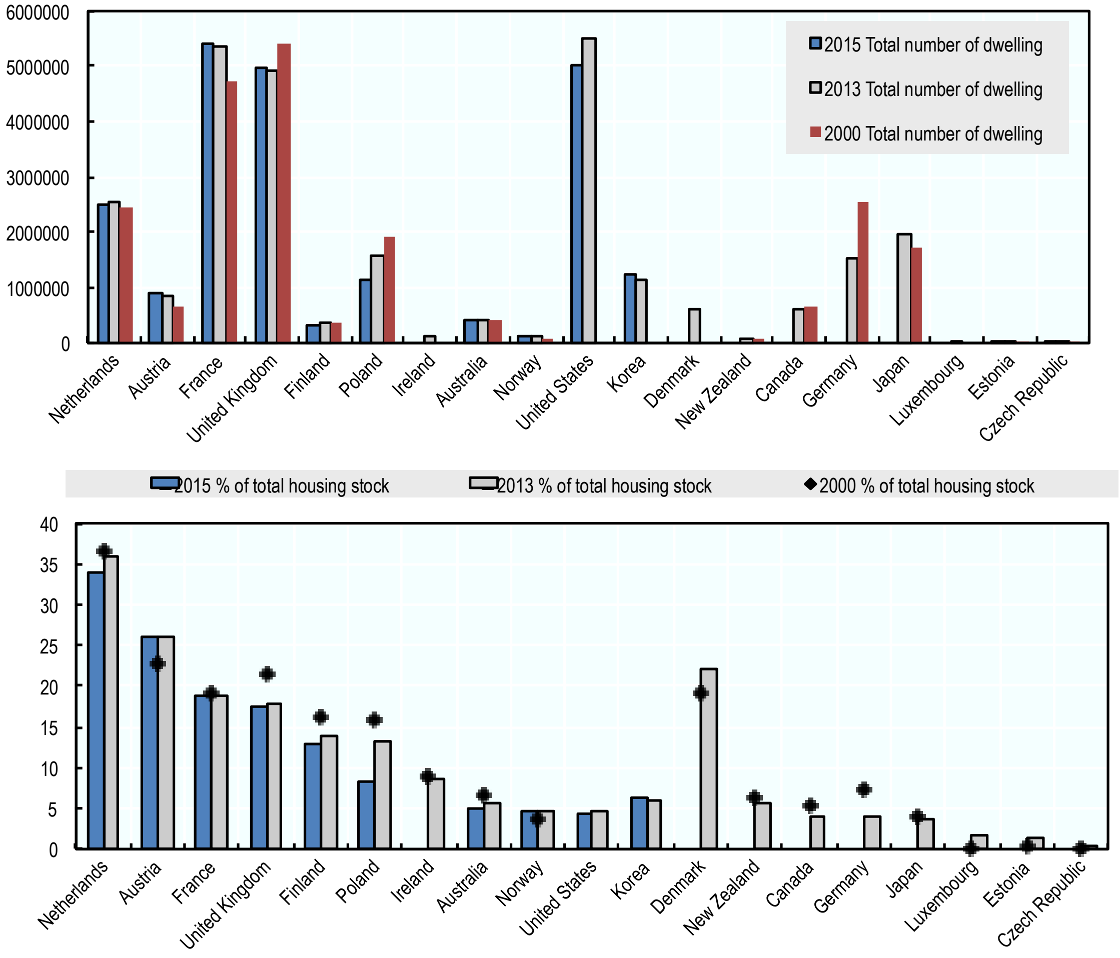


Figure 3.2. Social housing in the OECD (OECD Affordable Housing Database, 2017)

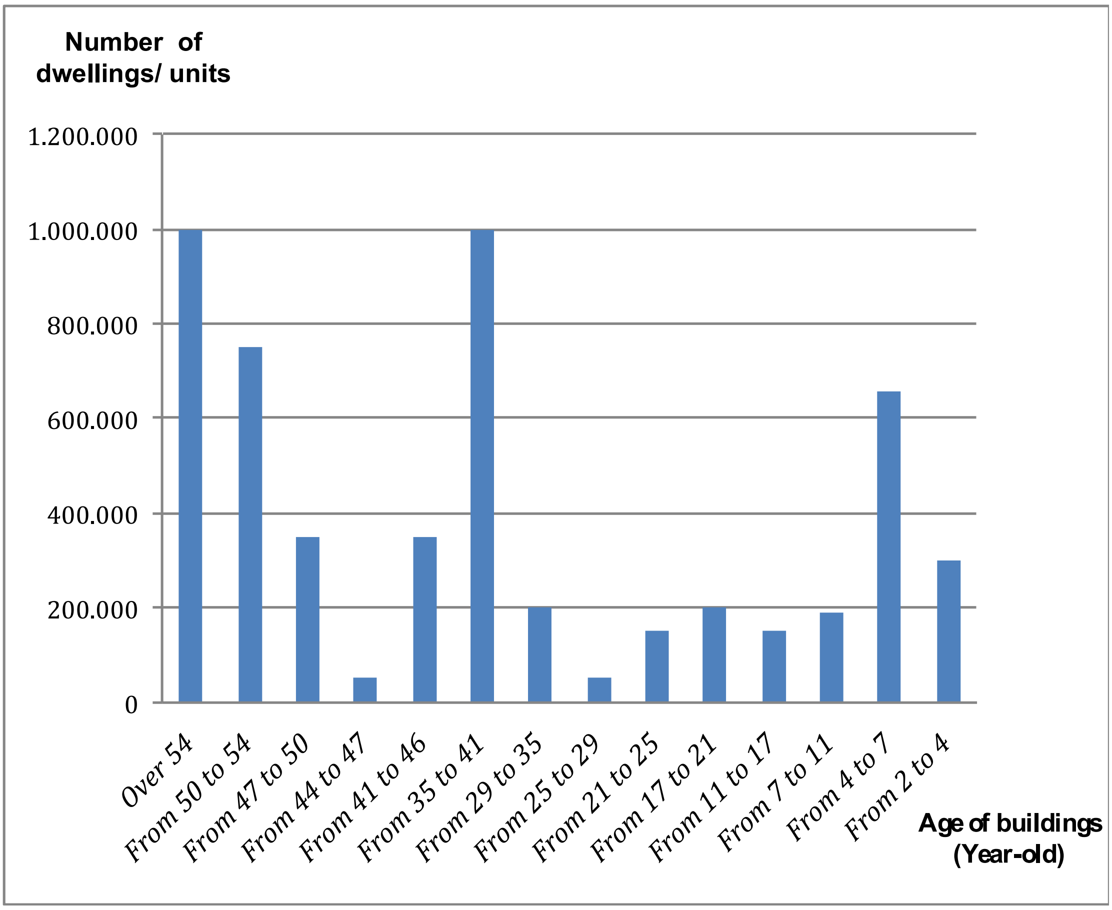
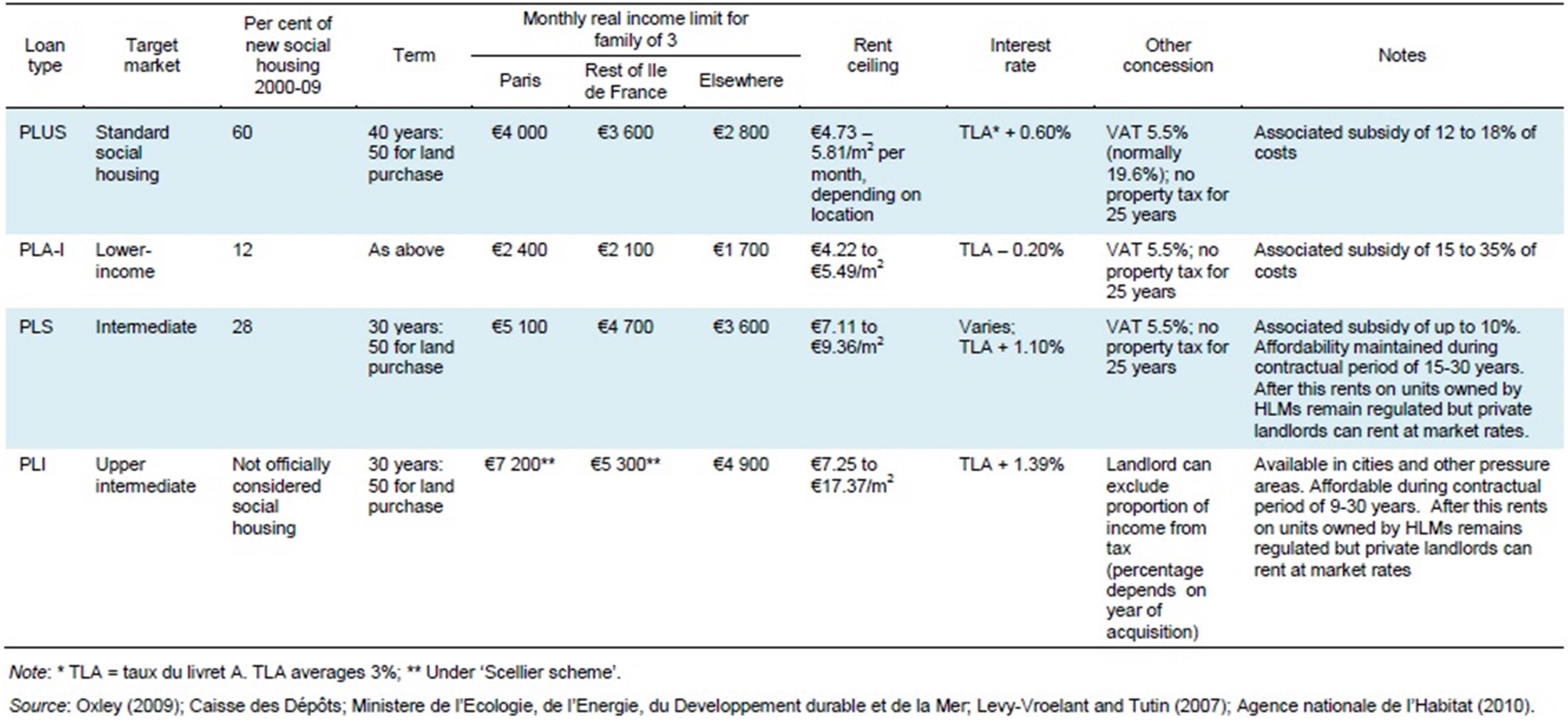


Figure 3.3. Distribution of the social housing in France according to the age (Rochard, Shanthirablan and Brejon, 2015)

The social housing stock mostly belongs to social landlord. Only 5% of this stock is owned by SEM (Sociétés d'économie mixte - Semi-public companies) or the private sector (Peppercorn and Taffin, 2009). This sector is beneficiated from public aids. Non-social landlords do not access to the same aid, but they have lower social obligations (***Table 3.1***) (OECD Affordable Housing Database, 2017), (Schaefer, 2003), (Peppercorn and Taffin, 2009), (Schaefer, 2008).

Table 3.1. *Off-market loans for social and intermediate housing in France (Scanlon and Whitehead, 2011)*



Loan type	Target market	Per cent of new social housing 2000-09	Term	Monthly real income limit for family of 3			Rent ceiling	Interest rate	Other concession	Notes
				Paris	Rest of Ile de France	Elsewhere				
PLUS	Standard social housing	60	40 years: 50 for land purchase	€4 000	€3 600	€2 800	€4.73 – 5.81/m^2 per month, depending on location	TLA* + 0.60%	VAT 5.5% (normally 19.6%); no property tax for 25 years	Associated subsidy of 12 to 18% of costs
PLA-I	Lower-income	12	As above	€2 400	€2 100	€1 700	€4.22 to €5.49/m^2	TLA – 0.20%	VAT 5.5%; no property tax for 25 years	Associated subsidy of 15 to 35% of costs
PLS	Intermediate	28	30 years: 50 for land purchase	€5 100	€4 700	€3 600	€7.11 to €9.36/m^2	Varies; TLA + 1.10%	VAT 5.5%; no property tax for 25 years	Associated subsidy of up to 10%. Affordability maintained during contractual period of 15-30 years. After this rents on units owned by HLMs remain regulated but private landlords can rent at market rates.
PLI	Upper intermediate	Not officially considered social housing	30 years: 50 for land purchase	€7 200**	€5 300**	€4 900	€7.25 to €17.37/m^2	TLA + 1.39%	Landlord can exclude proportion of income from tax (percentage depends on year of acquisition)	Available in cities and other pressure areas. Affordable during contractual period of 9-30 years. After this rents on units owned by HLMs remains regulated but private landlords can rent at market rates

Note: * TLA = taux du livret A. TLA averages 3%; ** Under 'Scellier scheme'.

Source: Oxley (2009); Caisse des Dépôts; Ministere de l'Ecologie, de l'Energie, du Developpement durable et de la Mer; Levy-Vroelant and Tutin (2007); Agence nationale de l'Habitat (2010).

In addition, low-income tenants beneficiate from housing aids, such as AL ("Allocation Logement") and APL ("Allocation Personalisée Logement) (Habitat, 2003), (Schaefer, 2003). The French government determines also the rent ceilings. The housing's rental price in this sector is about 60% lower than that in the private sector. Tenants in both social or private sectors beneficiate of direct social aid (***Table 3.2***) (Schaefer, 2003), (Le Blanc and Laferrère, 2001), (OECD Affordable Housing Database, 2017).

Table 3.2. *Ceiling of rent per month per square meter (Schaefer, 2003)*

Category	***Land-lord***	***Tenure***		***Agglo PARIS***	***Paris***	***Main cities***	***Other areas***
Very social	Social	Rental	PLA I	4,4 €/m2	4,6 €/m2	3,8 €/m2	3,5 €/m2
Social	Social	Rental	PLUS	4,9 €/m2	5,2 €/m2	4,3 €/m2	4,0 €/m2
Social	Social & private	Rental	PLS= 1,5 PLUS	7,4 €/m2	7,8 €/m2	6,5 €/m2	6,0 €/m2
Intermediate	Social & private	Rental	PLI = 1,9 PLUS	9,3 €/m2		7,7 €/m2	7,2 €/m2
Tax relief	Private investor	Rental		11,4 €/m2	12,9 €/m2	8,8 €/m2	8,3 €/m2
Average market rent for new tenants per month per square meter							
Free market	Private	Rental		11,8 €/m2	14,9 €/m2	7,0 €/m2	

3.2 Social housing asset management

3.2.1 Technical approach

According to CHOA, the complex building asset like social housing can be divided into seven fundamental systems: Structure, enclosure, electrical, mechanical, fire safety, interior finishes& amenities and site work. However, things will be much more complicated while accessing into inventory. Each asset has separate operation, maintenance and renewal planning. From seven basic systems, managers have to separate “hundreds of items: roofs, windows, doors, boilers, light fixtures, pumps, fans, floor finishes, fire extinguishers, emergency exit signs, elevators, smoker detectors… and the list goes on” (CHOA’s, 2013b)

“Building asset management is a process and decision support framework that covers the full service life of the physical asset from cradle to grave” (CHOA’s, 2013c). The strategy of the life cycle building asset includes 3 phases: maintenance, repairing and long-term renewal. The input information for the asset management includes the asset inventory, condition assessment, deferred maintenance, capital renewal cost, work prioritization and planning, preventive maintenance and repair costs, effective reporting module (Gerbasi, 2005),(CHOA’s, 2013c)(CHOA’s, 2013a)(CHOA’s, 2013b)(CHOA’s, 2013d)]. The asset inventory combines the biggest volume of information. On one hand, from initiating, it includes location, type, and place in service date, warranty expiration date, quantity and purchase cost. On the other hand, over time, it should add more information: asset identification numbers, service contractors, manufacturer’s product literature, photos of the assets, maintenance logs for each asset and even capacity or energy consumption. Moreover, data come from several sources: construction drawings, service contracts, equipment lists, operation & maintenance documents (O&Ms) and construction specifications (CHOA’s, 2013b).

The amount of information required for management decision-making is extremely large. For each component, managers must choose the type of maintenance (corrective or preventative or predictive maintenance) and the time to be renewed.

3.2.2 Change requirements

Since 2002, social housing companies have been strongly encouraged by the French government to establish their approach of strategic management to optimize the scarce resources. Without this strategic approach, they could not beneficiate from public aid. The competition with the private sector constitutes also an important driver for establishing the strategic management approach (Gruis and Nieboer, 2004).

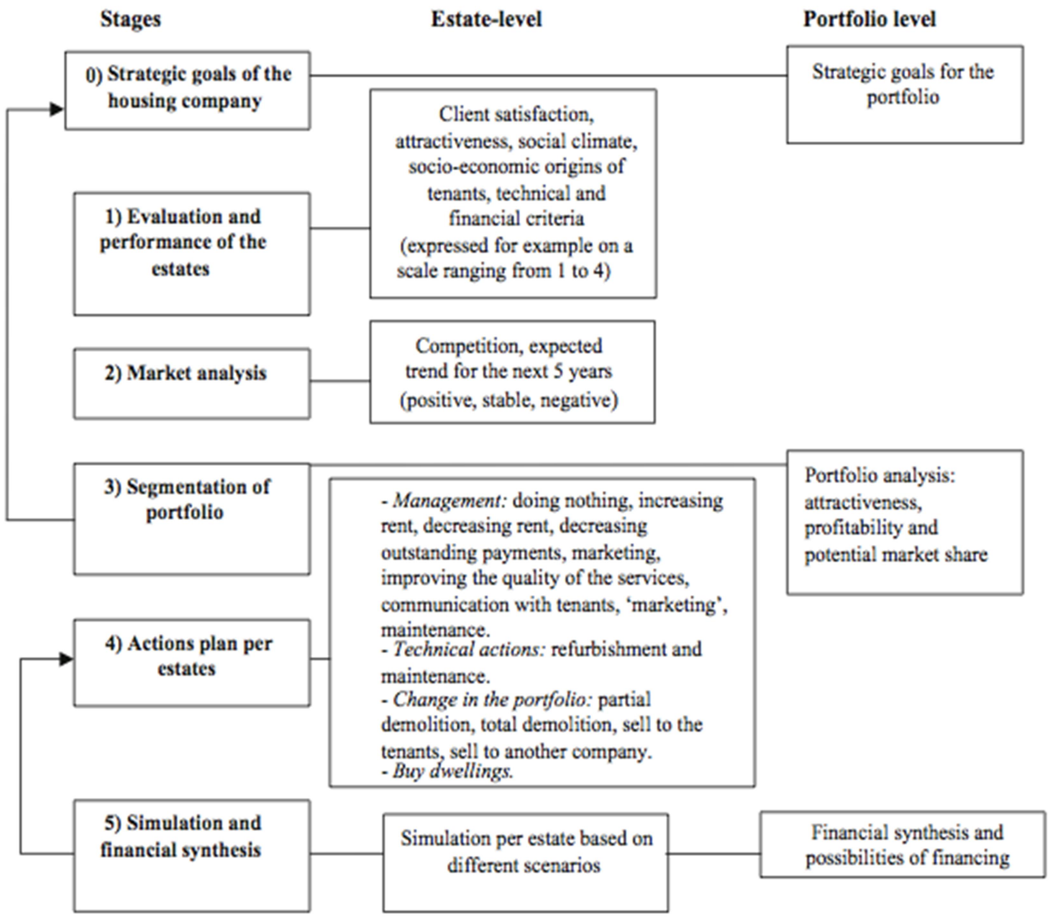


Figure 3.4. Strategic asset management process (Gruis and Nieboer, 2004)

Requirements for the social housing asset management in France changed deeply. Before, "The building and housing code states the minimum maintenance requirements. Maintenance is required to ensure safety standards for elevators, heating systems, gas appliances, collective gas-controlled mechanical ventilation systems, garage doors, detection systems, fire protection, etc." (Gruis and Nieboer, 2004). Tenants have to pay for on-going maintenance depending on characteristics of their dwelling through services charges. They expect improved housing quality. The private sector has more attract of social housing tenants by providing better services at the same cost (Gruis and Nieboer, 2004).

The social housing sector faces major difficulties to cope with the today's requirements. About 25% of the French social housing stock was built 30 - 40 years ago and more than 20% of this stock is over 50 years – old. 35% of this stock could be considered recent or renovated (Schaefer, 2008). In the building's lifecycle point of view, the majority of this stock is in the "Adulthood" and "Old Age" stages. With poor management, "Many of these dwellings have mediocre technical quality and a poor market position" (Gruis and Nieboer, 2004).

Social landlords must focus on asset renewals and upgrade or even rebuild. However, the social housing sector suffers from the high number of stakeholders with different strategies and interests. Managing a complex stock, submitted to specific policies, with high number of stakeholders together with ensuring economic and social balance is not straightforward. Innovation is required to solve this complex equation.

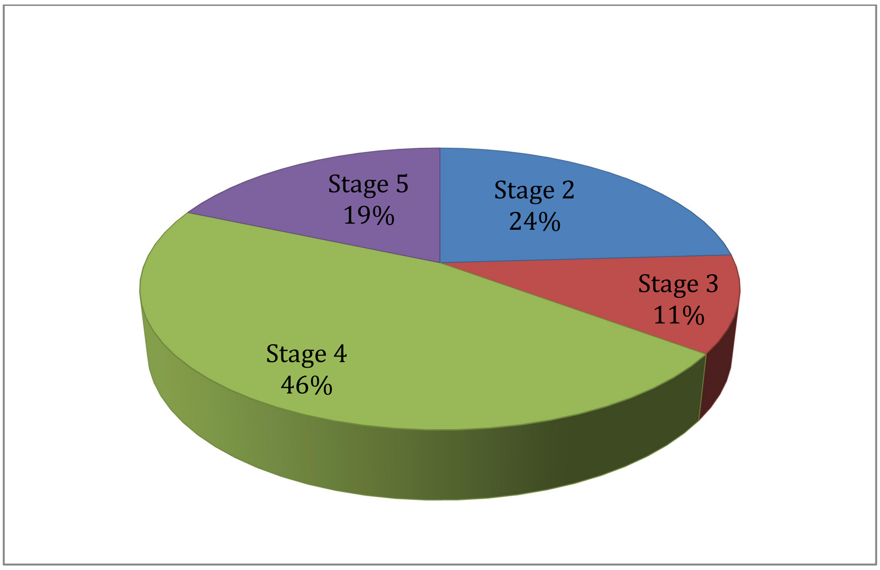


Figure 3.5. Breakdown of French social building stock by stage of the buildings -Number of dwellings/ units - Source of data (Schaefer, 2008)

3.2.3 Use of smart technologies

Use of new technologies for sustainable development has become a global trend in our society. Smart technology like BIM or PMS (Project Management System) is already used in the construction activity (Jupp, 2014). Use of BIM in buildings construction and management shows that it could reduce the managers workload and optimize buildings efficiency (Jupp, 2014), (Love *et al.*, 2014), (Volk, Stengel and Schultmann, 2014), (Barry, 2013).

Other studies focused on modernizing asset management decision processes. Dino Gerbsic worked on asset management system (AMS) in Canada (Gerbasi, 2005), Ashish Shah analyzed Australian practices on Building Asset Management (BAM) system types (Shah, Tan and Kumar, 2004), Dewich and Miozzo worked on the latest technology to collect data in social housing sector (Dewick and Miozzo, 2004). Kitshoff and Ronald explored how to increase productivity and performances of social housing asset management by innovation (Kitshoff, Gleaves and Ronald, 2012).

Good examples could be cited in the modernization of buildings asset management using the digital technology:

- The use of sustainable technology in Scottish social housing (Dewick and Miozzo, 2004).
- The use of BIM and FIM in Hong Kong's public rental housing (BIM forum, 2013).
- The energy monitoring program of a social housing in Ireland (Sinnott and Dyer, 2012).
- Analysis of the return on investment of BIM in HLM management in France (Caisse de deposts, 2015).

The Smart Technology is used in buildings asset management to improve buildings performances, life quality and to tenants' satisfaction. The Smart Technology enhances stakeholders understanding and perspectives in performing business, cooperation and communication. The use of this technology in buildings improves buildings performances and productivity, reduces costs, improves sustainability, increases users' satisfaction, retention, and loyalty in the long run. However, its implementation faces major challenges related to the physical, social and governance complexity of this sector as well as the other issues related to the privacy and security.

3.3 Smart building asset management of HLM organization

Reviews about the intelligent asset management process with the applying of smart technologies into asset management were presented in the section 2.4 of chapter 2. However, we needed to adapt the presented process for the management of social housing assets. Fig 3.6 presents the organization of a smart asset management of HLM stock.

It includes 5 steps. Each step defines the list of stakeholders as well as their contribution to building asset management process. Step 1 to step 3 are used for managing individual building assets level, while 4th and 5th step can apply for both building and organization management level.

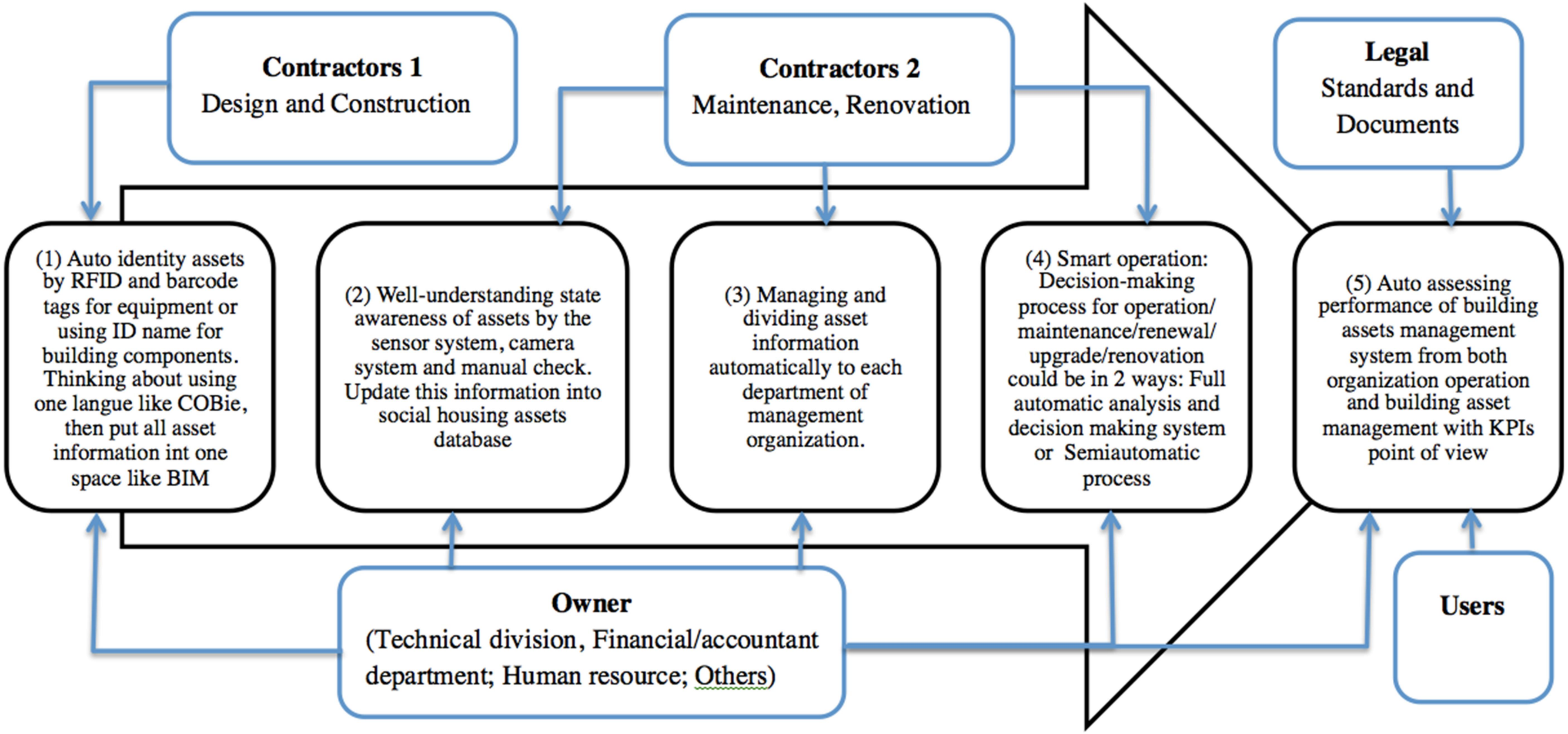


Figure 3.6. Smart asset management system for LHM organization in 5 steps with the stakeholders(Modified parttern from Parlikad et al., 2017)

3.3.1 Step 1: Identification of social housing assets and building performances

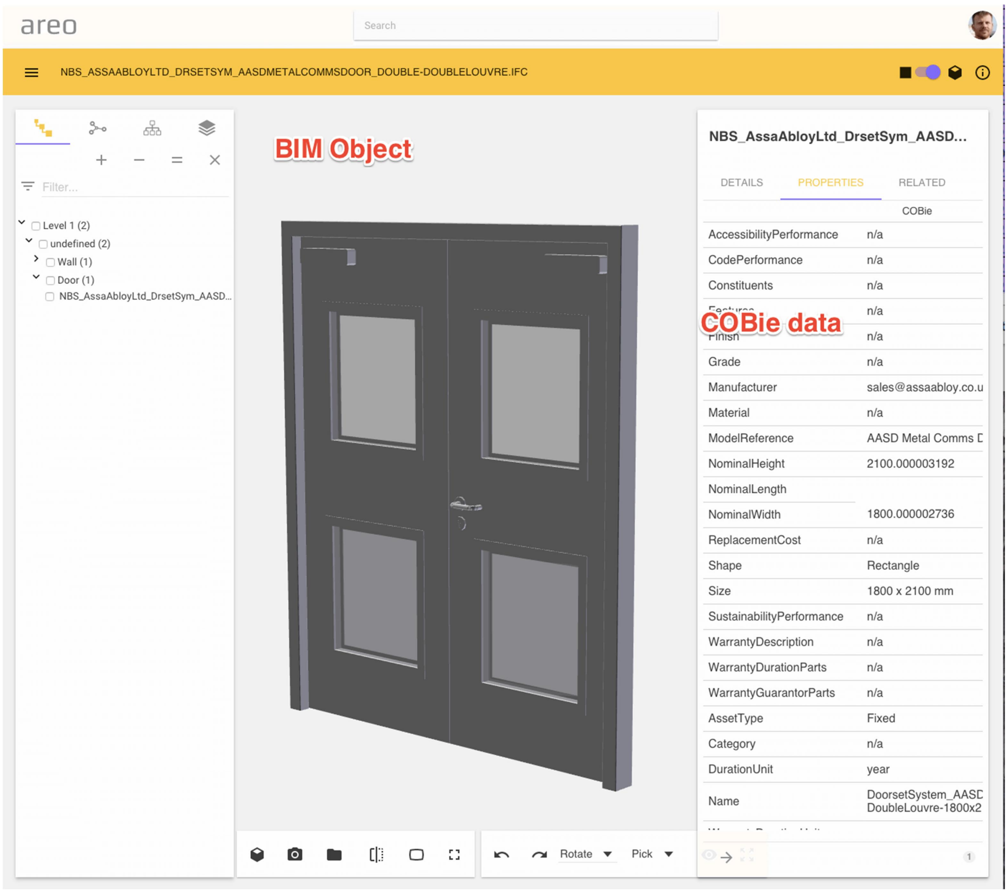
Two-dimensional barcodes and Radio Frequency Identification (RFID) tags can be used for identifying housing's equipment like MEP's equipment and interior stuffs. Architectural, structural and MEP's components can be named by ID codes (related to their place or types), which is also popular in BIM environment (Table 3.3).

Table 3.3. *Auto identification tools for each asset types*

Asset types	**Two-dimensional barcode and ID code**	**RFID tags (Active) and ID codes**	**ID codes**
Architectural assets (Enclosure and, interior finishes & amenities	Doors, windows		Wall cladding, roof's cover
Structural assets			Foundation, Columns, Beams, Floors, roofs, stairs
Mechanical assets	Hot water heaters, Heat exchanger	Booster pumps, air make-up unit, elevator machines	Pipes, wires
Electrical assets	Switches, power receptacles, light fixtures, enter phone control panel, fire control panel	Distribution equipment, power transformer equipment, security cameras, door access control, emergency generator	Power distribution panel boards, wires
Fire safety assets		Emergency lighting, exit signs, fire detection equipment, heat and smoke detectors	Guidance broads
Site work			Soft landscaping (plants, laws) Hard landscaping (roadways, pathways, retaining walls, outdoor parking, stair, fences, sewage water)

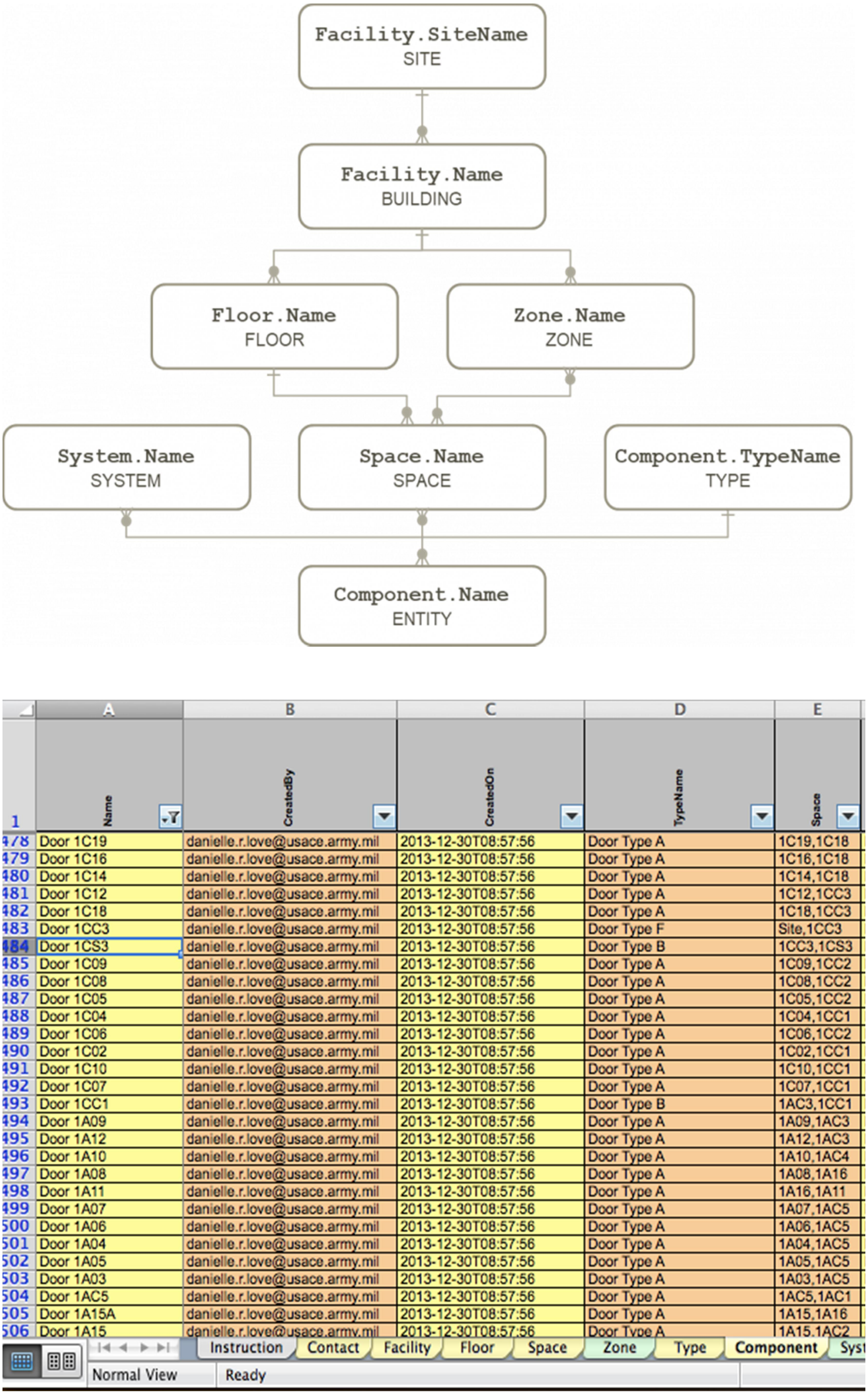
RFID tags and barcodes could store important amount of information: required information for management process could be stored in barcodes and RFID tags. The ID codes help managers to access to assets' information in BIM environment or in COBie spread sheets. Fig 3.9 and 3.10 show an example of how information stored and shared by this system. Information is provided by all the contractors related to building assets, from design to construction and operation (maintenance and renovation if has).

However, building assets are named normally in a technical way in BIM. Components and equipment have the same technical name (Fig 3.7). Therefore, we need an identification system for building assets management in the operation and maintenance stages to distinguish the components or equipment with the same technical name. The simplest way consists in adding their localization such as realized by COBie (Door 1CS3 – Row 484 of Fig 3.8 is door type B in zone 1CC3, 1CS3). This problem could also be solved easily with the different barcode for each asset.



	COBie
AccessibilityPerformance	n/a
CodePerformance	n/a
Constituents	n/a
Features	n/a
Finish	n/a
Grade	n/a
Manufacturer	sales@assaabloy.co.u
Material	n/a
ModelReference	AASD Metal Comms D
NominalHeight	2100.000003192
NominalLength	
NominalWidth	1800.000002736
ReplacementCost	n/a
Shape	Rectangle
Size	1800 x 2100 mm
SustainabilityPerformance	n/a
WarrantyDescription	n/a
WarrantyDurationParts	n/a
WarrantyGuarantorParts	n/a
AssetType	Fixed
Category	n/a
DurationUnit	year
Name	DoorsetSystem_AASD DoubleLouvre-1800x2

Figure 3.7. Statistic data of a door in BIM and COBie interfaces (Soure: https://blog.areo.io/what-is-cobie/)



	A	B	C	D	E
1	Name	CreatedBy	CreatedOn	TypeName	Space
478	Door 1C19	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C19,1C18
479	Door 1C16	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C16,1C18
480	Door 1C14	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C14,1C18
481	Door 1C12	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C12,1CC3
482	Door 1C18	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C18,1CC3
483	Door 1CC3	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type F	Site,1CC3
484	Door 1CS3	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type B	1CC3,1CS3
485	Door 1C09	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C09,1CC2
486	Door 1C08	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C08,1CC2
487	Door 1C05	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C05,1CC2
488	Door 1C04	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C04,1CC1
489	Door 1C06	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C06,1CC2
490	Door 1C02	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C02,1CC1
491	Door 1C10	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C10,1CC1
492	Door 1C07	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1C07,1CC1
493	Door 1CC1	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type B	1AC3,1CC1
494	Door 1A09	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A09,1AC3
495	Door 1A12	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A12,1AC3
496	Door 1A10	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A10,1AC4
497	Door 1A08	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A08,1A16
498	Door 1A11	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A16,1A11
499	Door 1A07	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A07,1AC5
500	Door 1A06	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A06,1AC5
501	Door 1A04	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A04,1AC5
502	Door 1A05	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A05,1AC5
503	Door 1A03	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A03,1AC5
504	Door 1AC5	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1AC5,1AC1
505	Door 1A15A	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A15,1A16
506	Door 1A15	danielle.r.love@usace.army.mil	2013-12-30T08:57:56	Door Type A	1A15,1AC2

Figure 3.8. Building components in COBie environment (COBie example)

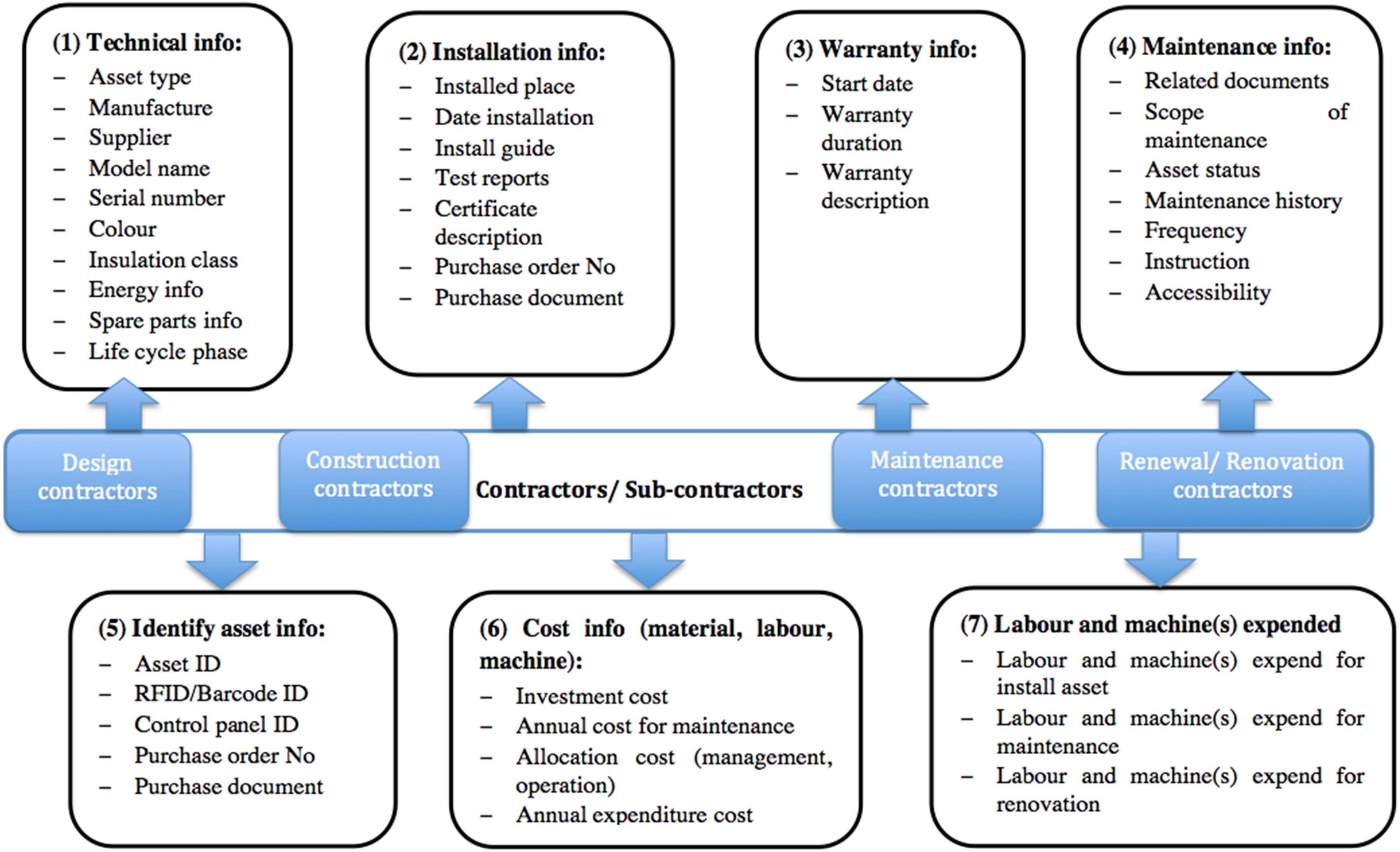


Figure 3.9. Statistic data - identification information of building assets

Beside the statistical data of social housing assets, the social information related to the legal field needs to store in the building asset information database. This information is extremely important when the social landlords do the maintenance, renewal, upgrade or renovation for their building (Fig 3.10). This information has strong relationship with KPIs of building performance (Table 2.5 – Chapter 2) and will be the core concerning of 4th and 5th steps of smart asset management process (Fig 3.6).

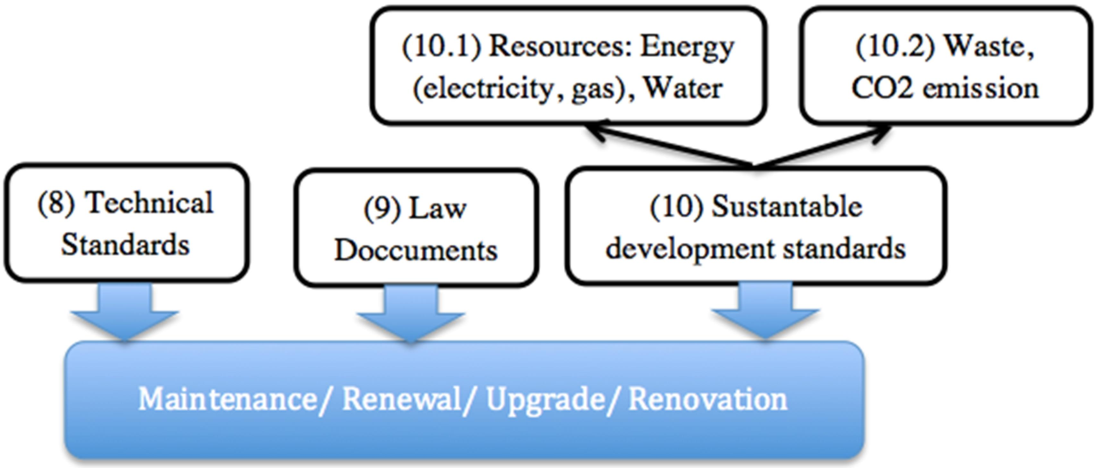


Figure 3.10. Social information of social housing assets

Nevertheless, social housing assets' managers are not always able to collect needed data, due to the long lifecycle of buildings' assets. Most of these buildings were built long time ago. Information missing could result from data transfer from one contractor to the other, or from lack of update during maintenances. This situation will be solved during the next step - the second process of management – tracking the real-time state of assets.

3.3.2 Step 2: Tracking the state or condition of social housing's assets – update asset dynamic data

Sensing technology and IoT facilitate transfer and update of information as well as the track of building assets' status. They track critical parameters that provide indication of the rate of progression or the likelihood of development of different failure modes of an element, an asset or the system. Mechanical, electrical, fire safety assets with RFID tags (Table 3.3) have favorable conditions to connect automatically with the monitoring system through IoT. Data captured by sensors will be sent to managers, or update to PI server by connecting sensors using wired or wireless networks. New engineering datasets (not available in previous systems) provided by new sensors, are interpreted and translated into same language with the old one. The core data could be updated manually or automatically to building asset information database in BIM environment.

In addition to dynamic auto tracking, manual check and reports are used for assets tagged by barcode and ID name. Manual works could be done by owners' managers, contractors or even users. Indeed, users can report problems using on-line BIM online version. Users could also report assets operating using light BIM.

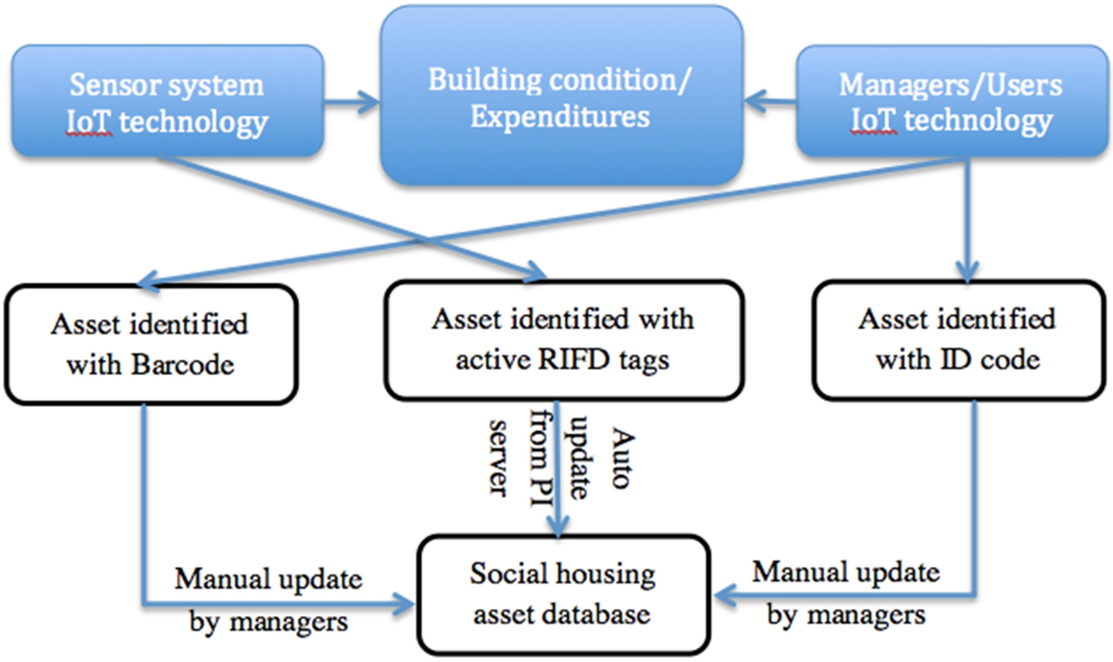


Figure 3.11. Tracking real-time data and updating to building asset database

3.3.3 Step 3: Managing and dividing asset information automatically

The intelligent asset model aims at providing single query mechanism to access to available data, without requiring searches across multiple databases and storage locations in different organizations. The ideal is to access to 7 information categories as illustrated in Fig 3.9. However, the amount of information needed for each asset types is not the same (architectural assets – doors in Fig 3.7 and mechanical assets – boiler Fig 3.29 are examples). In addition, managers from different departments of social landlords' organizations or sub-contractor for maintenance/ renovation demand the distinct and particular asset information, like the technical managers, take the asset information of the numbers (1)-(2)-(3)-(4)-(5) in Fig 3.9 and (8) in Fig 3.10 into consideration. While the financial or accountant officers concern only the number (6) info (Fig 3.9) and (9), (10) (Fig 3.10), and the human resource manager has the responsibility about labor or machine - (7) Fig 3.9 and (9) Fig 3.10 if needed.

The amount of information captured day by day makes the asset management database huge and leads to increasing expanses. An important question concerns the minimum volume of data which provides an effective management. Thus, dynamic BIM model and PI server were developed to combine tools to help manager to access to priority information and classify it (Fig 3.12).

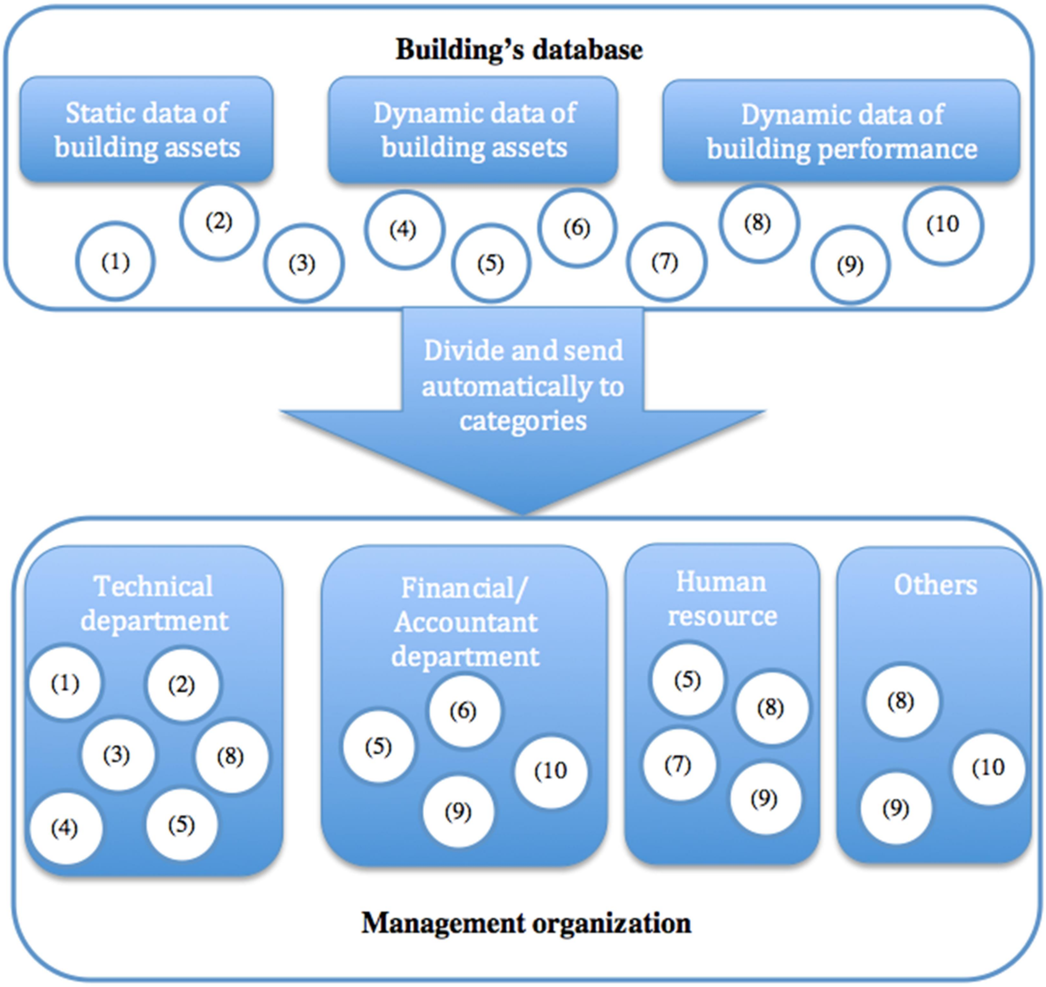


Figure 3.12. Architecture of the proposed classifying information model

3.3.4 Step 4: Smart decision making

Smart decision-making is the main concern for asset managers. New developments in the area of BIM software enable an effective use of the smart asset management in the social housing sector. For example, the creation of the BIM dynamic model aims to help the managers and users to make effective decisions regarding comfort and energy consumption. Each asset is represented by a software program that continuously seeks data from various sources (including sensors) and takes decisions without a need for human intervention (Fig 3.13). This model is used to auto - modify the temperature, humidity and brightness parameters in the BIM interface (Alileche, 2018). Besides controlling the comfort functions, the BIM dynamic model enables users to track consumption and waste. Access to daily expanses could impact users' behavior, push them into saving energy and water.

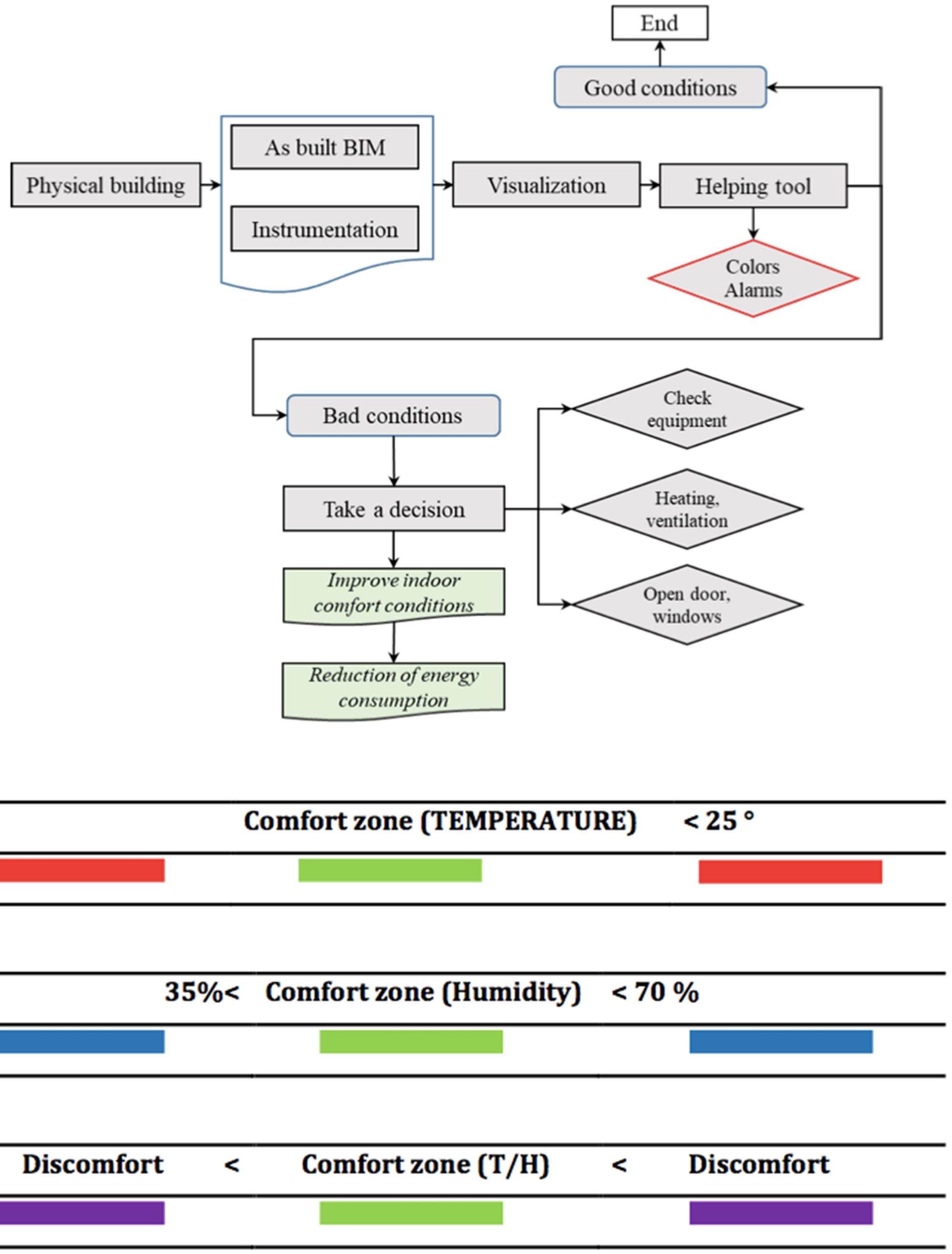


Figure 3.13. Auto decision-making process with the method that regarding to comfort zone (T/H) and energy consumption of the building (Alileche, 2018)

Advances in the area of predictive maintenance using dynamic BIM model enable asset managers to understand the state of their assets, to predict impending failure and create the opportunity to take optimized preventative actions (Fig 3.14).

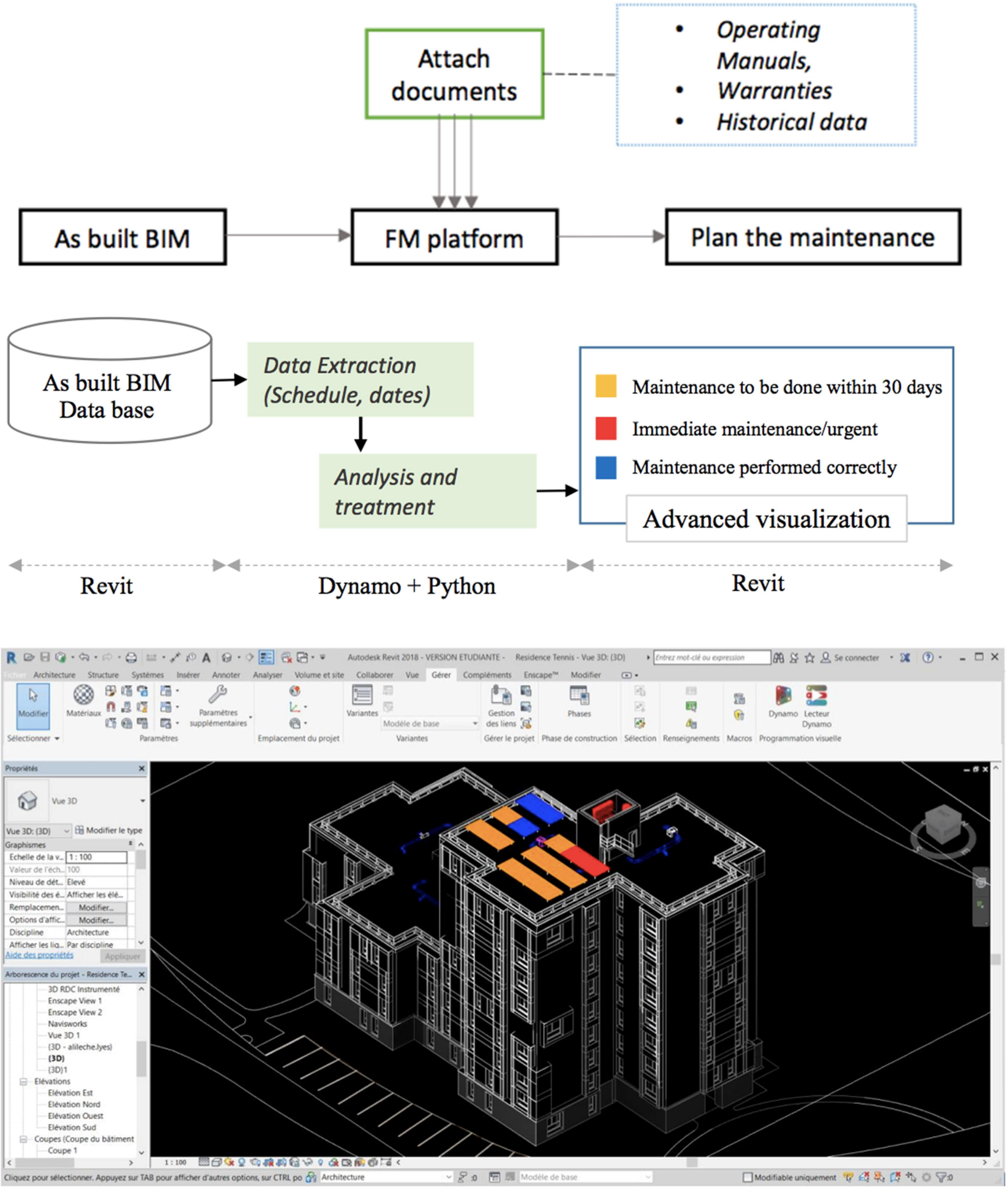


Figure 3.14. Maintenance plan and the predict maintenance of Triolo building (Alileche, 2018)

Sensors and IoT make building asset management easier with auto-decision making tools. Along with automatic decision-making process, semi-automatic tools are also important.

They can be used for activities in operation (Fig 3.15), maintenance (Fig 3.16 -3.17), renewal, upgrade and renovation (Fig 3.17).

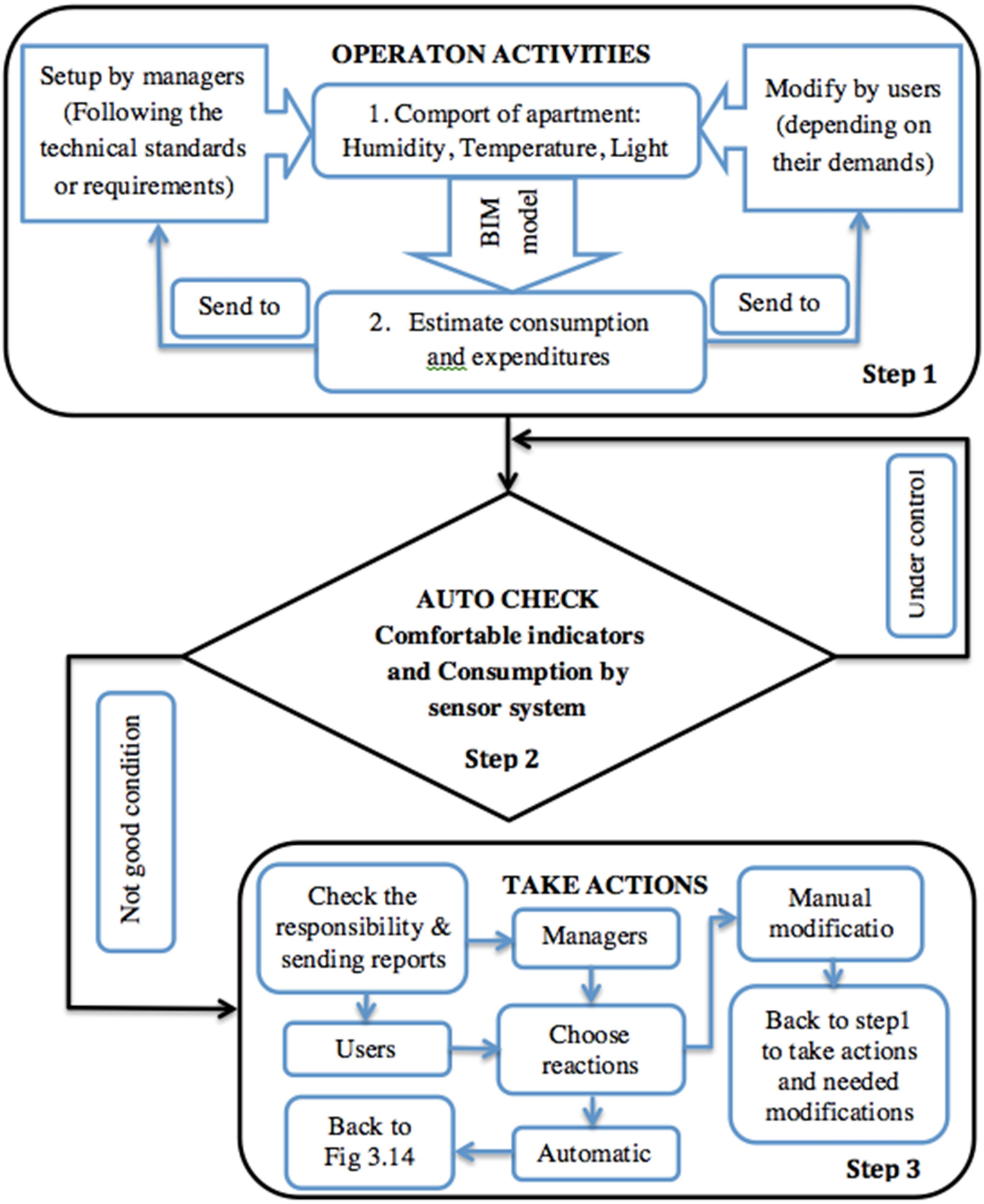


Figure 3.15. Semiautomatic decision-making model of operation activities

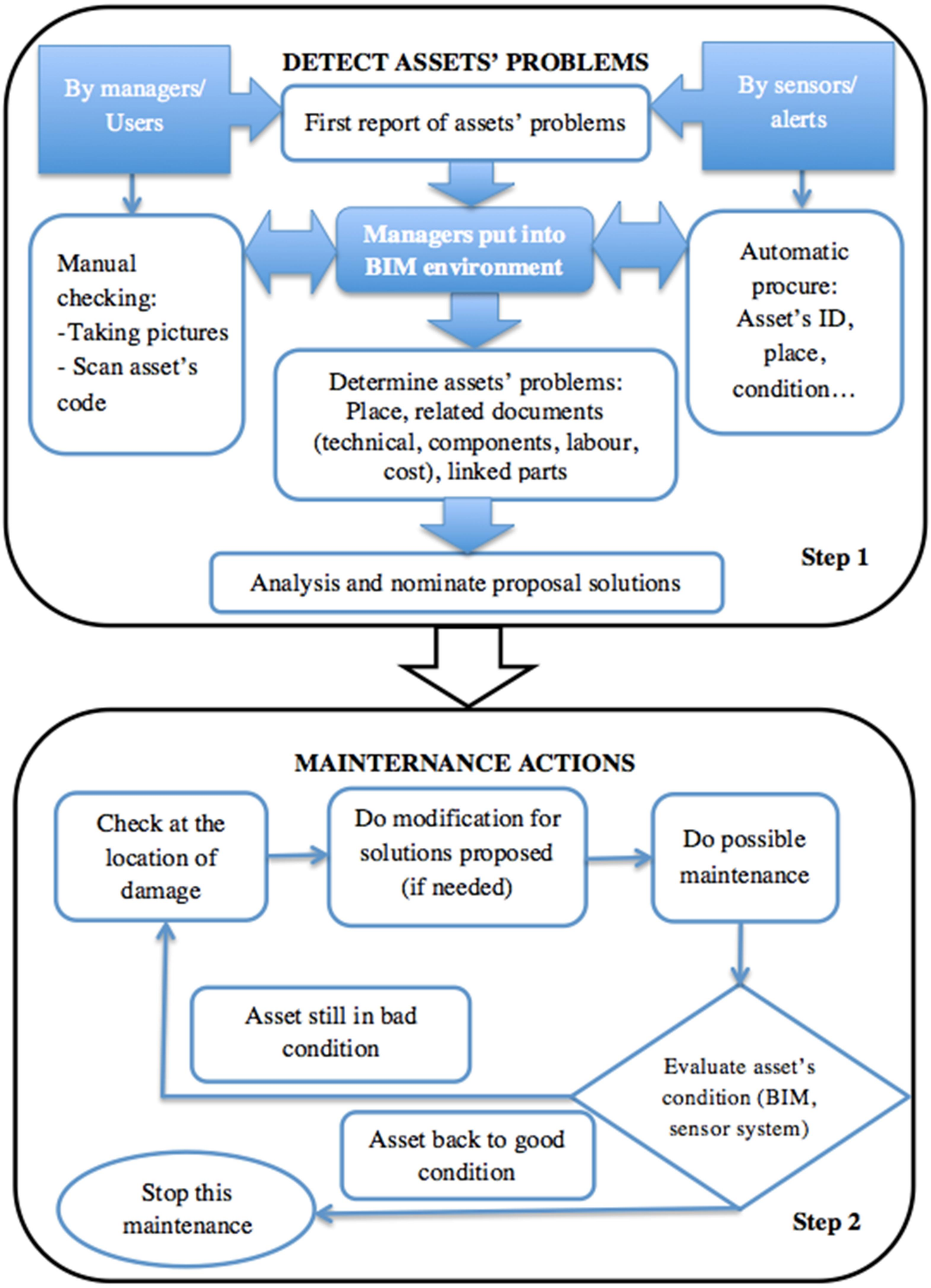


Figure 3.16. Semiautomatic decision-making process for correct maintenance activities

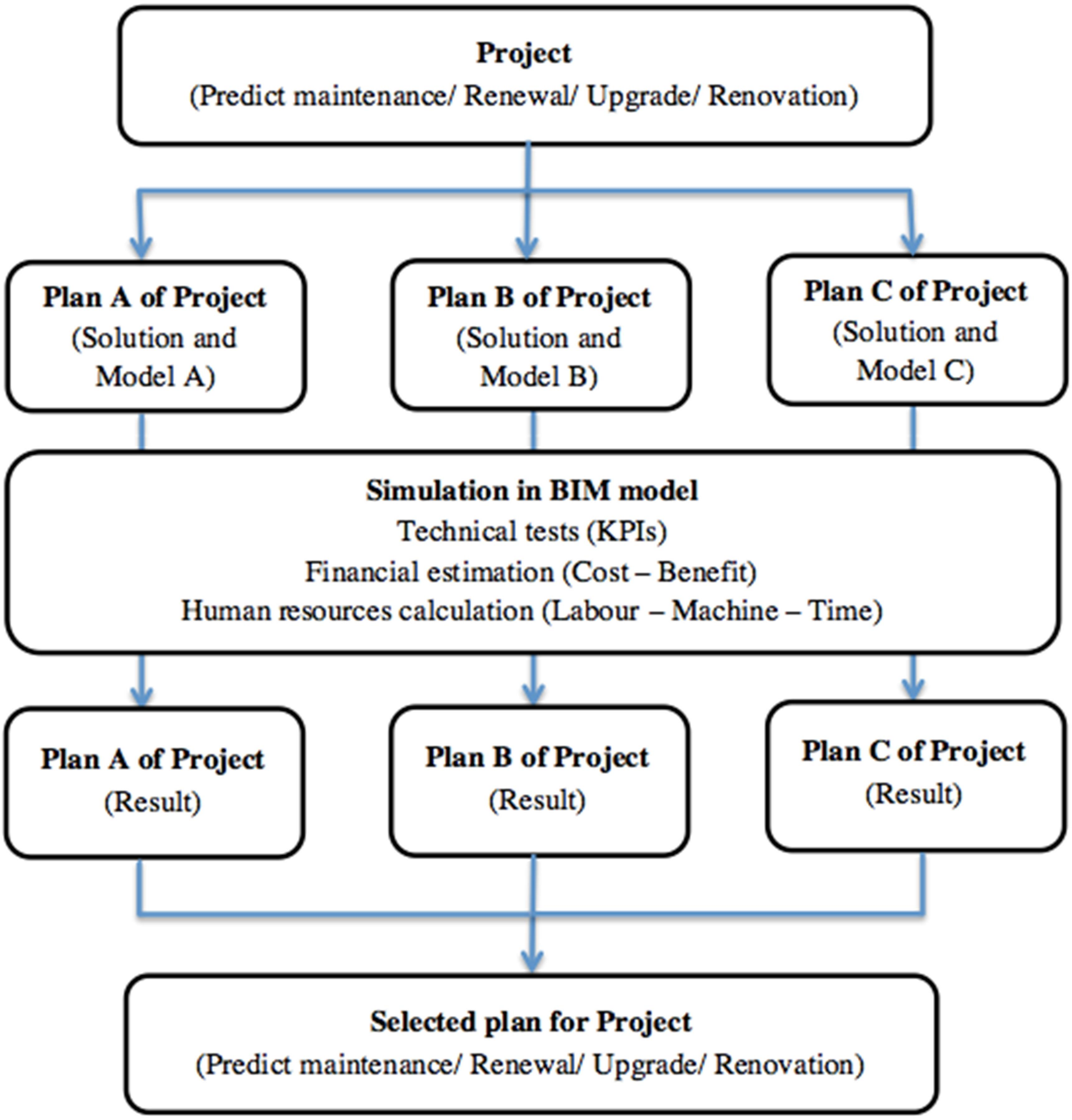


Figure 3.17. Select the most feasible plan of projects by using semiautomatic decision-making tool

The asset management trend is shifting from minimizing costs realizing value (ISO 55000 family of standards and PAS -55 before it). Model proposed in 3.15-3.16-3.17 provide the following assets' value:

- Benefits arising from the asset to the stakeholders through effective performance of the system (Step 2 in Fig 3.15; Step 2 in Fig 3.16, Simulation step in Fig 3.17)
- Risks caused by the asset to the system and stakeholders (Step 3 in Fig 3.15; Evaluate asset condition Step 2 in Fig 3.16, Make several plans in Fig 3.17).
- The expenditures incurred on the asset (Step 1 in Fig 3.15; Simulation all plans in Fig 3.17).

This section shows that BIM dynamic (with COBie extension) plays a key element in smart social housing asset management. It helps managers to get estimated results of simulated solutions or plans before making decision. Therefore, smart decision-making for social housing asset process has not been only based on the cost but also on risk and performance. The BIM model removes the difficulty of quantitative assessment in social housing asset management.

3.3.5 Step 5: Measuring performances of assets management

It is difficult to evaluate the management performances of complex building stocks such as the social housing and the impact of innovation on this management. The efficiency of the management of the social housing asset should be established according to specific criteria considering their social role. The key performance indicator system (KPIs) for this sector should consider both qualitative and quantitative performances. KPIs will be used to measure the impact of the use smart technologies on the improvement of the social housing performances.

Assessment of performance of building assets management includes 3 levels: asset, individual building and all organization. It is conducted with KPIs presented in section 1.1.3 (chapter 1) and summarized in Table 3.4. Hence, to continue the 5th step of smart asset management in social housing sector, another analyzing system for managing value of social housing asset management at organization level must be done.

Table 3.4. *KPIs for smart building asset management system device to performance measurement perspectives and value-based method*

1. Financial	**2. Functional**	**3. Sustainable**	**4. User satisfaction**
1.1. Operating costs (per sq.) (S); (B) – (O) 1.2. Building maintenance cost (per sq.) (S); (B) – (O) 1.3 Life cycle cost (L) – (B), (O) 1.4. Maintenance efficiency indicators (MEI) – (S)-(L); (A), (B), (O)	2.1. Indoor environmental quality (IEQ) (S); (B) – (O) 2.2. Resource consumption – energy; water; materials (S); (B) – (O) 2.3. Building performance index (BPI) (S), (B)	3.1 CO2 emission (S); (B) – (O) 3.2. Property and real estate (S); (B) – (O) 3.3 Waste (S); (B) – (O)	4.1. User satisfaction with the quality of apartment (S)-(L); (B) – (O) 4.2 User satisfaction with the services (S)-(L); (B) – (O)

Note:

(S) Short-term indicators –(L) Long-term indicators

(A) – (B) – (O) - Indicators to evaluate performance of: A- Assets, B- Buildings, O - Organizations

3.4 Application on Lille Métropole Habitat (LMH)

3.4.1 Presentation of LMH

LMH is the Public Housing Office (OPH) of Lille Metropolis. LMH ensures the management of a stock composed of 31,986 units, which accounts for around 10% of the region's public housing stock and more than 26% of the HLM metropolitan stock. Around 52% of LMH stock is located in sensitive urban zones.

LMH is organized in 8 agencies and 2 antennas, with the objective to ensure high quality service close to tenants (Fig 3.18).

LMH is engaged in social responsibility (LMH, 2014) with a focus on social and environmental impact, transparency, and partners respect. LMH focused also on innovation and use of Smart Technology in social housing through a partnership with Lille University. Within this partnership, a smart monitoring system was designed for social housing apartments; this system was used to monitor around 15 apartments. The partnership included also a pilot project for the application of BIM to a social housing residence (Triolo).

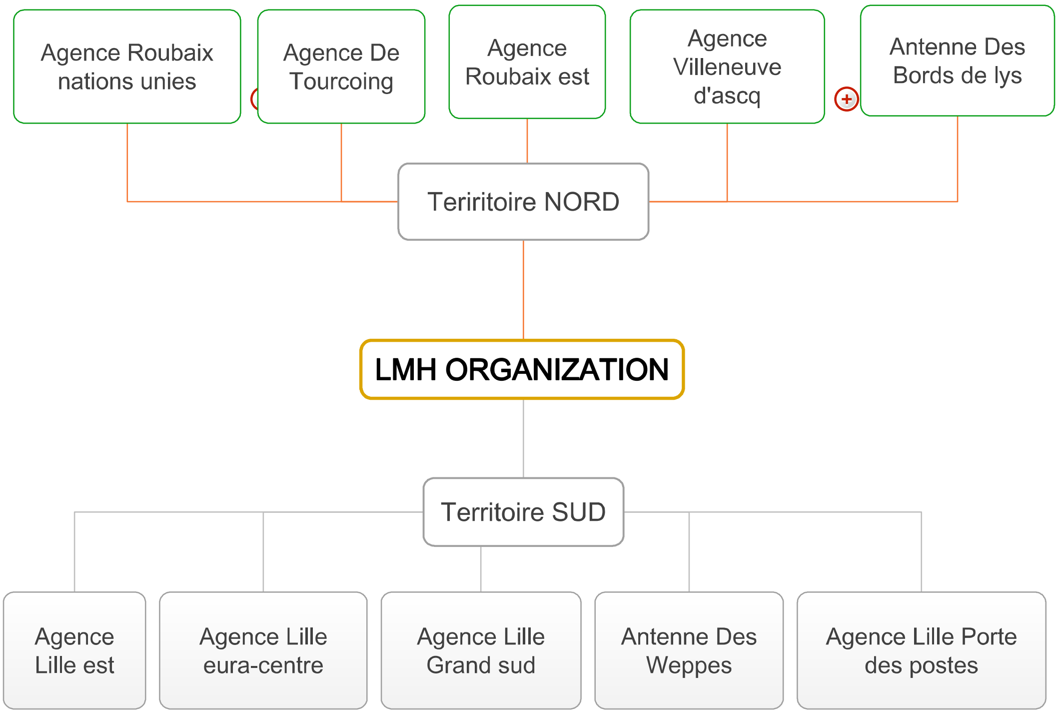


Figure 3.18. LMH organization

3.4.2 Presentation of LMH stock

LMH is in charge of nearly 330 residences (31 986 housing units in 47 towns) including 209 collective residences. Collectives residences can be classified into 4 categories according to their lifecycle stage (Stage 2 to 5; stage 5 designates old buildings). Table 3.5 provides details about this classification. About 23% of the buildings are in stage 2 (age between 1 and 16 years), but they represent only 8% of the total number of apartments and 8% of the total surface, which means that recent buildings have smaller surfaces. 58% of the buildings are in stages 4 and 5 (more than 30 years), but they represent 85% of the total number of apartments and 85% of the total surface, which means that the majority of the stock of collective buildings is old.

Table 3.5. *Stats about the lifecycle stage of LMH collective stock (LMH Data, 2015).*

STAGES	**STAGE 2**	**STAGE 3**	**STAGE 4**	**STAGE 5**	**TOTAL**
Number of building	49	38	92	30	209
Number of building (%)	23,44%	18,18%	44,02%	14,35%	100,00%
Total surface	107.172	91.997	769.247	341.531	1.309.947
Total surface (%)	8,18%	7,02%	58,72%	26,07%	100,00%
Number of apartment	1.616	1.440	11.807	6.054	20.917
Number of apartment (%)	7,73%	6,88%	56,45%	28,94%	100,00%

Table 3.6 provides the details of expenses per square meter for the 4 categories of buildings. The average expenses per square meter for buildings in stage 2 is equal to 16,69 €, while that in stage 5 is equal to 24,14 (44% higher than that in stage 2). This high difference results from the water and energy for heating expenses: 5 €/(m^2) for buildings in stage 2 to be compared to 12,5 €/(m^2) for buildings in stage 5. The maintenance expenses are close for all the buildings categories, which means that these expenses concern mainly vital maintenance, which do not take into consideration the assets degradation.

Table 3.6. *Influence of the lifecycle stage on buildings expenses (€/m^2) in collective buildings (LMH Data 2015)*

Expenditure (€ /m2)	**STAGE 2**	**STAGE 3**	**STAGE 4**	**STAGE 5**
Water	2,21	4,49	4,69	5,39
Energy for heater and hot water	2,81	3,64	6,14	7,14
Maintenance for elevator	0,37	0,32	0,34	0,26
Maintenance for building	6,16	6,41	6,06	7,49
Electricity	1,80	1,67	1,49	1,28
Financial cost	3,33	2,91	2,63	2,58
Total	16,69	19,44	21,35	24,14

3.4.3 Application of smart social housing asset management to Triolo residence's assets

3.4.3.1 BIM Model

The smart technologies were used in the residence Triolo (Shahrour *et al.*, 2017). A BIM model was created for this residence (Figure 3.19 to 3.23). It includes layers related to the architectures, water system, ventilation, maintenance and monitoring (Alileche and Shahrour, 2018). The BIM model provides a powerful tool for the residence management with ease access to information concerning the building, equipment, maintenance and comfort conditions. It could be enhanced with additional information concerning property and security as well as predictive maintenance.

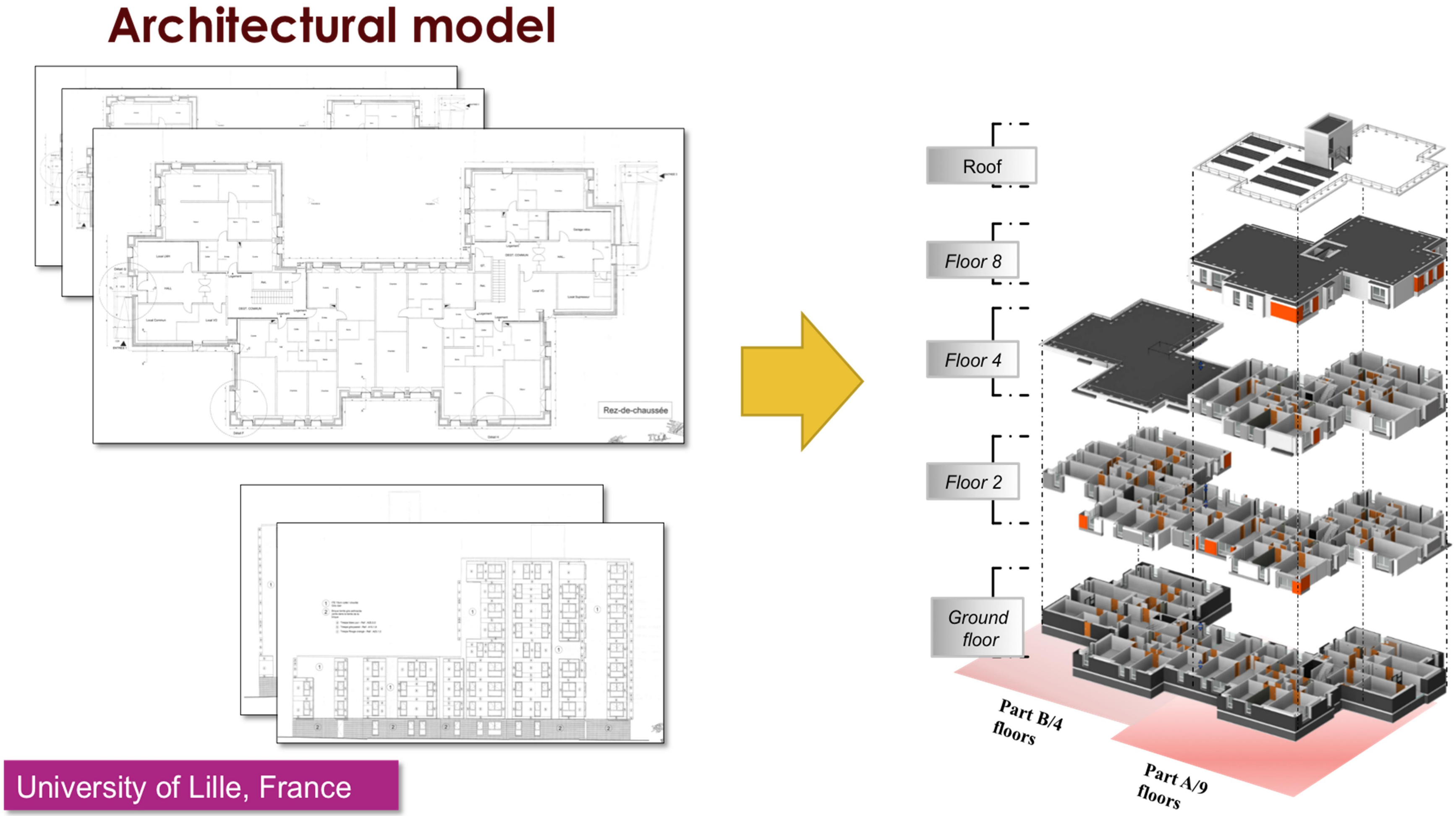


Figure 3.19. The architectural model of Triolo building (Alileche and Shahrour, 2018)

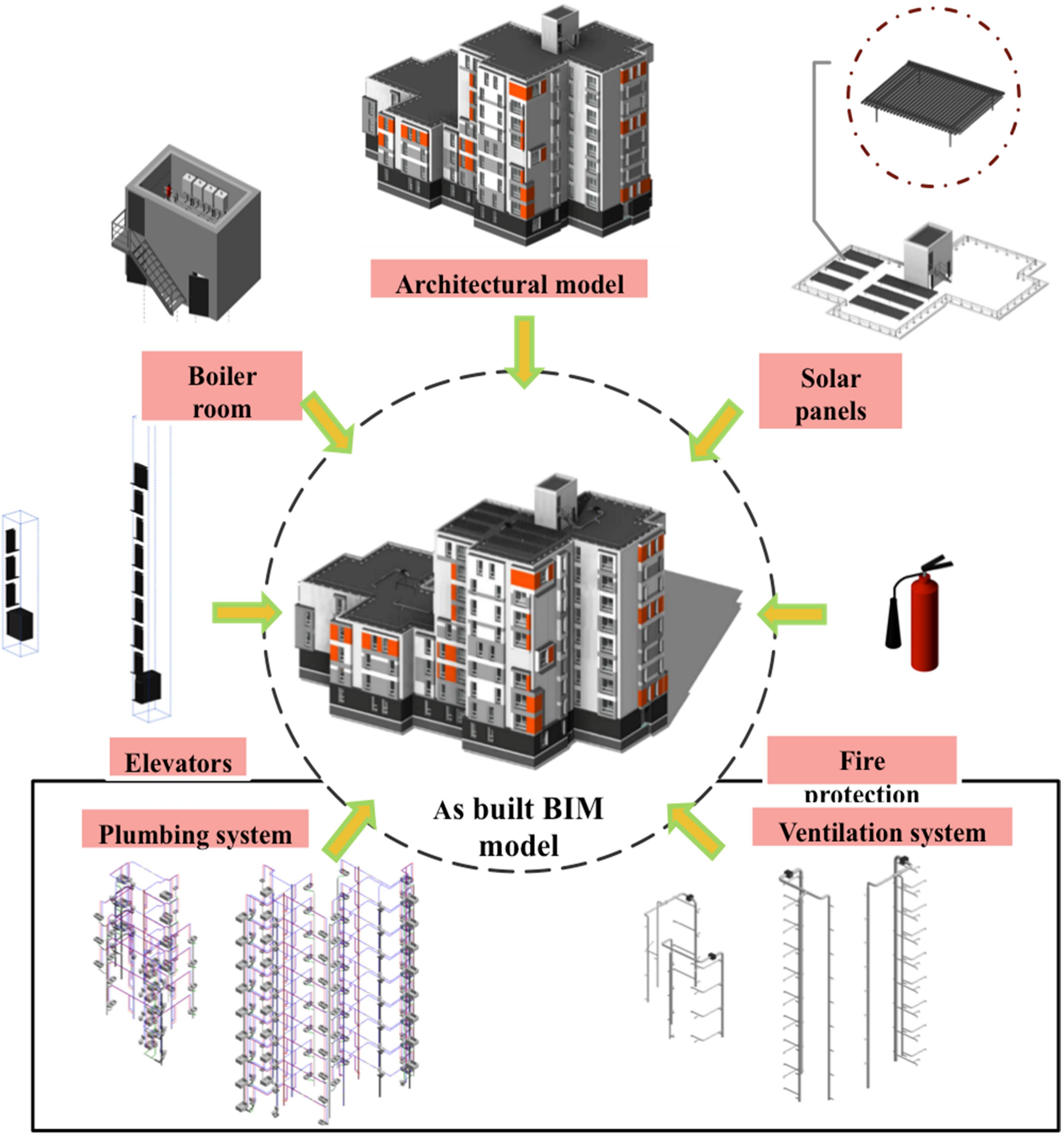


Figure 3.20. Full concept in BIM model of Triolo building (Alileche and Shahrour, 2018)

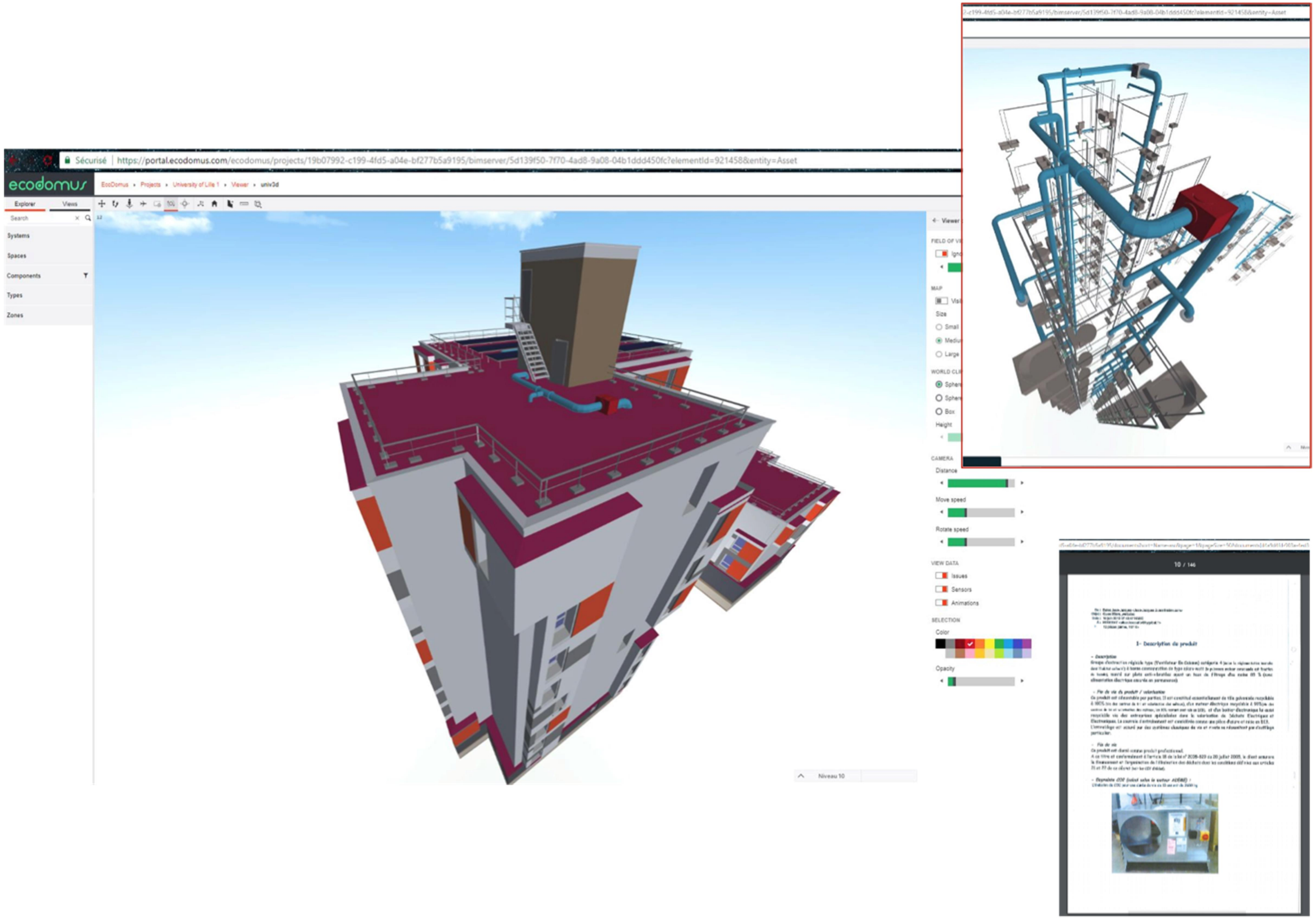


Figure 3.21. BIM model of Triolo building with maintermance doccuments added (Alileche and Shahrour, 2018)

Propriétés

Installations él

Modifier le type

Panneau

Numéro de ci...

Données d'identification

Image

Commentaires: Capteur de te...

Identifiant: 10

Visible dans le...: ☑

Phase de construction

Phase de créa...: Nouvelle const...

Phase de dém...: Aucun(e)

Analyse d'énergie

Capteur de te...: http://www....

Electricité - Circuit

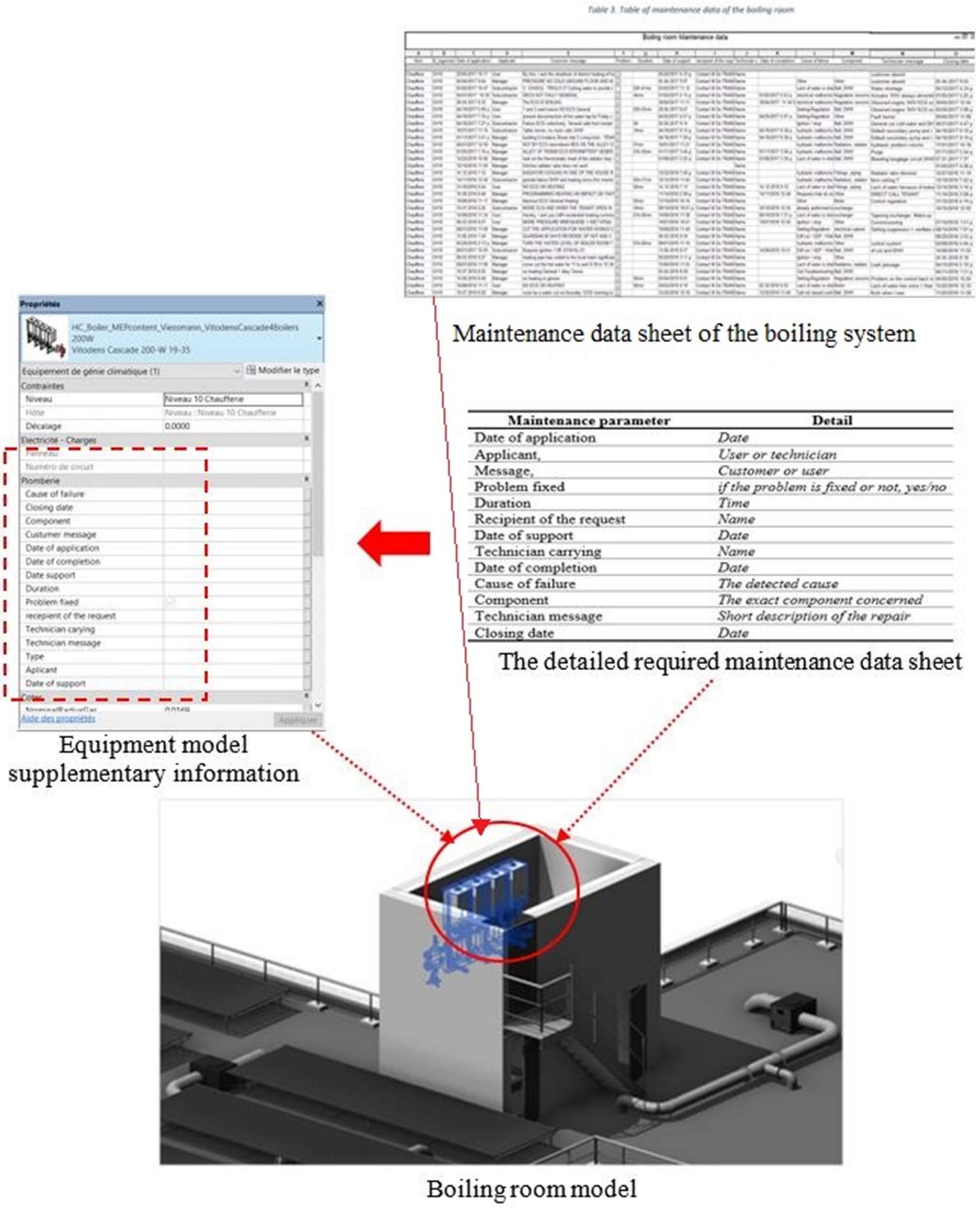
Données é

Capteur de température

Aide des propriétés

Appliquer

Figure 3.22. Sensor system's results was presented in Triolo building's BIM model (Alileche and Shahrour, 2018)



HC_Boiler_MEPcontent_Viessmann_VitodensCascade4Boilers 200W
Vitodens Cascade 200-W 19-35

Equipement de génie climatique (1)

Contraintes

Niveau: Niveau 10 Chaufferie
Hôte: Niveau : Niveau 10 Chaufferie
Décalage: 0.0000

Electricité - Charges

Panneau
Numéro de circuit

Plomberie

Cause of failure
Closing date
Component
Custumer message
Date of application
Date of completion
Date support
Duration
Problem fixed
recepient of the request
Technician carying
Technician message
Type
Aplicant
Date of support

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*

Figure 3.23. Building asset maintenance with BIM model (Alileche and Shahrour, 2018)

3.4.3.2 Smart Monitoring

(Aljer, Loriot and Shahrour, 2017) has presented a design, fabrication and use of an innovative system for social housing monitoring. The specifications of the system were determined through concentration with social housing tenants as well as technical and administrative staffs. The system is based on the use of a central unit (Raspberry Pi), which tracks and controls the indoor environment (temperature, humidity, air quality, lighting, noise…), the water and energy consumption as well as the state of doors and windows (open/closed). The system uses a friendly interface, which allows users to follow real-time data and to access to historical data enhanced by information concerning the quality of the indoor environment and the expenses (Fig 3.24).

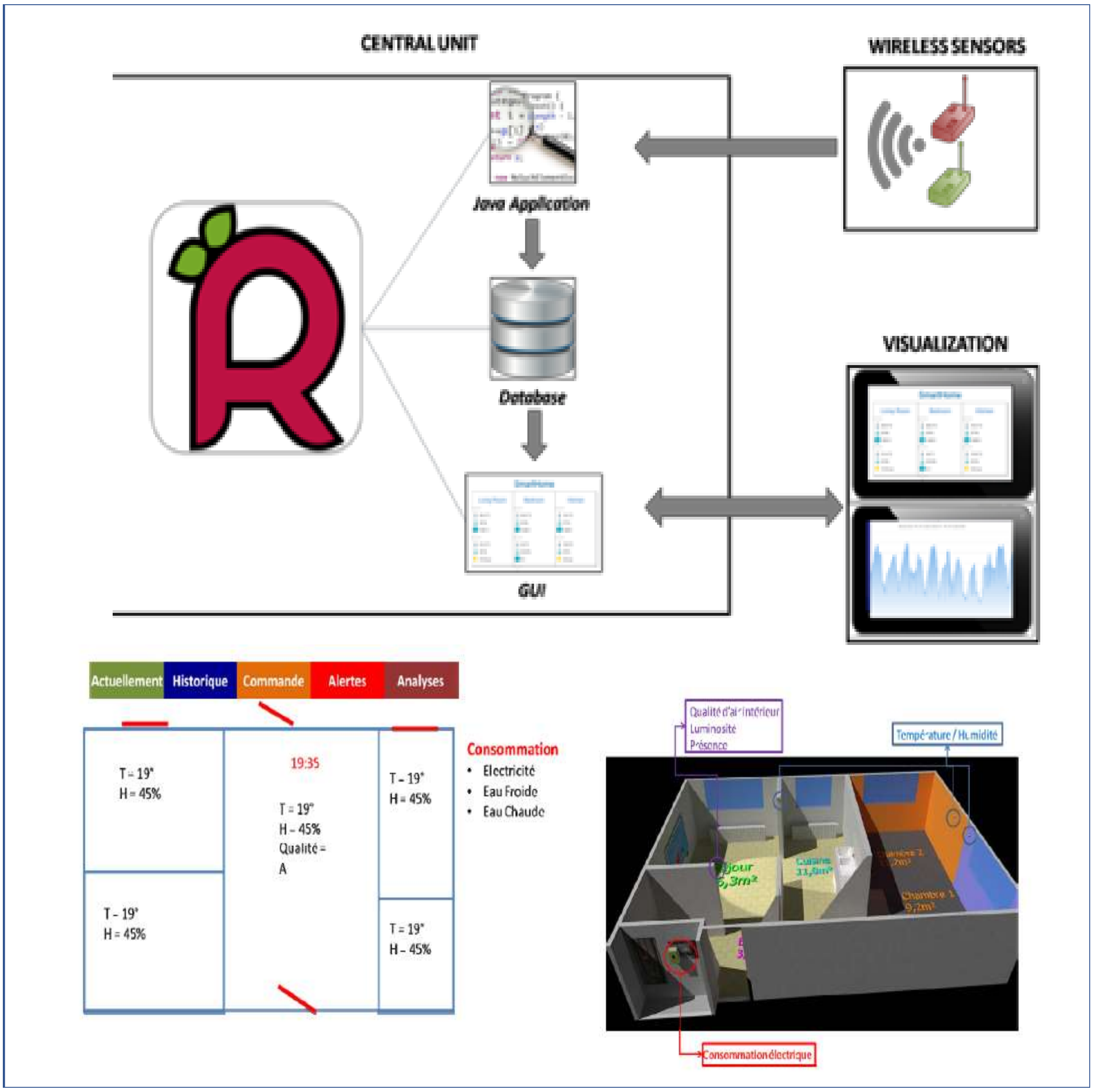


Figure 3.24. Smart monitoring system for social housing (LGCgE)

The smart monitoring system was used to follow the indoor comfort conditions (temperature and humidity) in some apartments of the residence (Fig 3.25) ((Shahrour and Jnat, 2017), (Jnat, 2018). It showed that the comfort conditions were almost respected, but with excess in the heating temperature. The reduction of the indoor temperature to standards condition could result in important savings (around 30%).

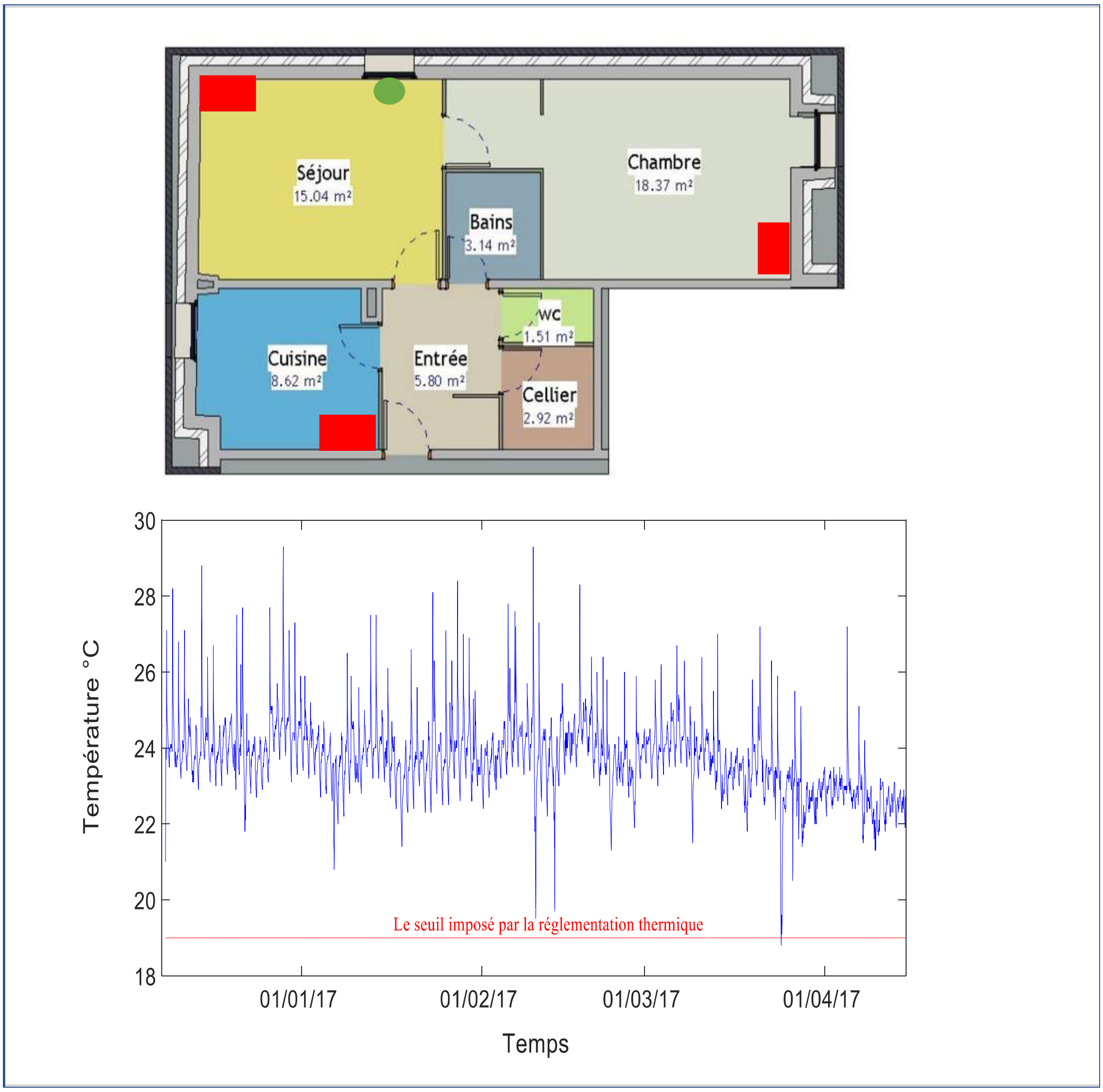


Figure 3.25. Use of the smart monitoring system in Triolo residence (Jnat, 2018)

3.4.3.3 Smart asset management application

Step 1: Identification of social housing assets and building performances

Triolo residence's assets are been able to identify only by ID codes (related to their place or types), in BIM environment (Alileche, 2018) . The RIFD tag and barcode are not ready to use for this work.

Step 2: Tracking the state or condition of social housing's assets – update asset dynamic data

Even though sensing system and IoT facilitate installed could transfer and update of information as well as the track of building assets' status automatically, the data captured by sensors still asked for update manually due to the large amount of data processing need to reduce. The online BIM version and light BIM are not ready yet; the users could only report assets operating by describing in emails or phones. So, to achieve the smart tracking asset state, in the next period, LMH managers should share the friendly interface of BIM with users.

Step 3: Managing and dividing asset information automatically

Unfortunately, tools are not yet available for automatic management of asset information. These tools have to be implemented.

Step 4: Smart decision making

Smart decision-making regarding comfort and energy consumption to auto - modify the temperature, humidity and brightness parameters; or predictive maintenance using dynamic BIM model in the Triolo's BIM interface was presented (Alileche, 2018). Others processes of smart decision making which proposed for operation (Fig 3.15), maintenance ((Fig 3.14, Fig 3.16, Fig3.17), renewal, upgrade and renovation (Fig 3.17) could be facilitated by the BIM model.

Step 5: Measuring performances of assets management

Unfortunately, tools are not yet available for automatic management of asset information. These tools have to be implemented.

3.5 Conclusion

This chapter presented the application of the smart asset management on social housing. This sector is submitted to increasing challenges related to aging, degraded life environment, high running expenses, tenants' low income and increase in sustainability requirements to reduce not only consumption of energy and water but also greenhouse gas emission. To meet these challenges, this sector needs to innovate in management and operations' procedure. Due to the multi-stakeholder of this sector, these two issues need to be implemented simultaneously to improve the sector performances.

A smart building asset management is proposed for social housing. It includes the following steps:

1. Identification of social housing assets and building performances
2. Tracking the state or condition of social housing's assets – update asset dynamic data
3. Managing and dividing asset information automatically

4. Smart decision making
5. Measuring performances of assets management

Step 1 concerns the design and construction, steps 2 to 4 concern the maintenance and renovation, while step 5 concerns the crucial phase of performances assessment.

The implementation of this system requires the construction of a BIM model and smart monitoring of indoor conditions and equipment. It requires stakeholders' involvement, particularly users.

The application of the smart building asset management to LMH asset showed major difficulties, because of the absence of basic tools such as the BIM model, smart monitoring and facilitated stakeholders' involvement. However, LMH started an interesting pilot project at Triolo residence. This pilot project provided preliminary interesting results, in particular possibility to reduce the heating expenses and to establish preventive maintenance

General conclusion

This work concerned the use of smart technologies in Building Asset Management (BAM) to improve management performances at both individual building level and organization one. The literature review about building assets management showed the necessity of developing an innovative BAM model for different building asset systems and its management organization. This model aims at optimizing operating performance, reducing risk and improving quality of life for users.

This research proposed a smart BAM that combines latest technologies in building management such as RIFD tags, barcodes, IoT, BIM, and BAM. Analysis of recent application of these technologies to building asset management, showed the capacity of these tools to improve the management process: support to asset identification, track and update building asset database, management and share of asset information, creation of smart decision-making processes and measuring performances of assets management with building asset management strategy throughout building assets lifecycle. In smart BAM model, the role of each stakeholder, the conjunction between different parts of building management organization and the BAM's strategy are clarified and optimized. The division of work, coordination, and decision-making of all building asset stakeholders is based on the fundamental principles and standards of the asset management process, according to ISO 55000 family of standards (and PAS -55 before it).

The second major contribution of this work concerns the use of the smart BAM in French social housing sector. This sector faces major challenges such as aging, degraded life environment, high running expenses, tenants' low income and increase in sustainability requirements to reduce energy consumption and greenhouse gas emission. To meet these challenges, this research presented a methodology for the adaptation of the smart BAM to this sector.

Smart BAM for social housing was applied for LMH organization. The application showed major difficulties, because of the absence of basic tools such as the BIM model, smart monitoring and facilitated stakeholders' involvement. However, LMH started an interesting pilot project at Triolo residence. This pilot project provided preliminary interesting results, in particular, the possibility of reducing heating expenses and establishing preventive maintenance.

The BAM for the social housing is established. We hope that we will have some opportunities in the future for its implementation at large-scale to test its efficiency and continue the work of its improvement.

References

Alileche, L. (2018) *Use of BIM for the optimal management of existing building*. Lille University.

Alileche, L. and Shahrour, I. (2018) 'Use of BIM for Social Housing Management Use of BIM for Social Housing Management', in *17th International Conference on Computing in Civil and Building EngineeringAt: Tampere, Finland*, p. 8.

Aljer, A., Loriot, M. and Shahrour, I. (2017) 'Smart System for Social Housing Monitoring', in *2017 Sensors Networks Smart and Emerging Technologies (SENSET)*, pp. 1–4. doi: 10.1109/SENSET.2017.8125057.

Amadi-Echendu, J. E. *et al.* (2010) 'What Is Engineering Asset Management?', in *Definitions, Concepts and Scope of Engineering Asset Management*, pp. 3–16. doi: 10.1007/978-1-84996-178-3.

Arayici, Y. and Aouad, G. (2011) 'Building information modelling (BIM) for construction lifecycle management', in *Construction and Building: Design, Materials, and Techniques*, pp. 99–117.

Ashworth, S., Carbonari, G. and Stravoravdis, S. (2015) 'How Facility Management can use Building Information Modelling (BIM) to improve the decision making process', *Journal fur Facility Management: Wissenschaft trifft Praxis*, 10(June), pp. 56–67.

Astier, J. Y., Zhukov, I. Y. and Murashov, O. N. (2017) 'Smart Building Management Systems and Internet of Things', *IT Security, [S.l.]*, 3(2074–7136), pp. 18–29. doi: http://dx.doi.org/10.26583/bit.2017.3.02.

Barry, D. (2013) *Asset Management Point of View Management Capacity in Rural Communities*.

BIM forum (2013) *BIM & FM in Hong Kong Public Rental Housing Projects*.

Le Blanc, D. and Laferrère, A. (2001) 'The effect of public social housing on households' consumption in France', *Journal of Housing Economics*, 10(4), pp. 429–455. doi: 10.1006/jhec.2001.0300.

Boller, C. (2004) 'Integrating Smart Technologies into Engineering , Using Biology , Cost Management and Music as the Vehicle', in *12th Internat. Symposium on Materials and Civilization*, pp. 159–161.

British Standards Institute (2008) *PAS 55: Asset Management*.

British Standards Institute (2014) 'ISO 55000:2014(E) - Asset management'.

Building asset Insight (2016) *The BAI Approach to Building Asset Management*. Available at: http://buildingassetinsight.com/wp-content/uploads/2016/09/Organizational-Readiness-Assessments.pdf.

Caglar, M. F. and Yavuz, M. (2016) 'Use of Radio Frequency Identification Systems on Animal Monitoring', *SDU International Journal of Technological Science*, 8(2), pp. 38–53.

Caisse de deposts (2015) *Maquette numérique bim premiere retours d'experience d'organismes HLM*.

CHOA's (2013a) *What are the different types of assets that we own ?*

CHOA's (2013b) *What is an Asset Inventory ..?*

CHOA's (2013c) *What is Building Asset Management ..?*

CHOA's (2013d) *What is Maintenance ?*

Coburn, J. (2016) *The Case for Building Asset Management*, *Building Asset Insight*. Available at: http://buildingassetinsight.com/downloads/.

Dewick, P. and Miozzo, M. (2004) 'Networks and innovation : sustainable technologies in Scottish social housing', *R&D Management*, 34(3), pp. 323–333.

Farghaly, K. *et al.* (2018) 'Taxonomy for BIM and Asset Management Semantic Interoperability', *American Society of Civil Engineers*, 34(2014), pp. 1–13. doi: 10.1061/(ASCE)ME.1943-5479.0000610.

Gerbasi, D. (2005) *An Asset Management System for School Buildings in Quebec*.

Gruis, V. and Nieboer, N. (2004) *Asset Management in the Social Rented Sector: Policy and Practice in Europe and Australia*. Available at: http://books.google.co.uk/books?id=DvVfynlX8_0C.

Grussing, M. N. (2014) 'Life Cycle Asset Management Methodologies for Buildings', *Journal of Infrastructure Systems*, 20(1), p. 4013007. doi: 10.1061/(ASCE)IS.1943-555X.0000157.

Guillen, A. J. *et al.* (2016) 'Building information modeling as asset management tool', *IFAC-PapersOnLine*. Elsevier B.V., 49(28), pp. 191–196. doi: 10.1016/j.ifacol.2016.11.033.

Habitat, I. C. (2003) *INTA CC Habitat – small introduction of social housing in France*. Available at: https://inta-aivn.org/images/cc/Habitat/background documents/CCHabitat_Housing social France.pdf.

IAM- The Institute of Asset Management (2015) *Asset Management – an anatomy*.

Isam SHAHROUR *et al.* (2017) *Approche inclusive de l'innovation dans le logement social - 3ème colloque LMH – Lille 1*.

Jnat, K. (2018) *Smart Bâtiment : Analyse et optimisation des dépenses d'énergie dans le logement social*. Lille University.

Jupp, J. (2014) 'Technology Adoption and Management Innovation in Construction', in *International Conference on Computing in Civil and Building Engineering ASCE*, pp. 753–760.

Kitshoff, J., Gleaves, R. and Ronald, G. (2012) 'Social Housing Asset Management: An Innovative Approach to Increase Productivity and Performance', in *Case Studies in Service Innovation*, pp. 107–109.

Law, K. H., Smarsly, K. and Wang, Y. (2014) 'Sensor data management technologies for infrastructure asset management', *Sensor technologies for civil infrastructures*, 2, pp. 3–32. doi: https://doi.org/10.1533/9781782422433.1.3.

Lin, Y. C., Cheung, W. F. and Siao, F. C. (2014) 'Developing mobile 2D barcode/RFID-based maintenance management system', *Automation in Construction*. Elsevier B.V., 37, pp. 110–121. doi: 10.1016/j.autcon.2013.10.004.

LMH (2014) *ISO 26000 LMH, 2014*. Available at: http://www.lmh.fr/accueil-general/accueil-lmh/responsabilite-sociale-d-entreprise/le-developpement-durable-a-lmh/323-la-norme-iso-26000 (Accessed: 1 January 2019).

López, A. J. G. *et al.* (2017) 'Asset Management for Buildings within the Framework of Building Information Modeling Development', in *Decision Management: Concepts, Methodologies, Tools, and Applications*, pp. 133–150. doi: 10.4018/978-1-5225-0651-5.ch006.

Love, P. E. D. *et al.* (2014) 'A benefits realization management building information modeling framework for asset owners', *Automation in Construction*. Elsevier B.V., 37, pp. 1–10. doi: 10.1016/j.autcon.2013.09.007.

Mathew, J. *et al.* (2018) 'Smart Asset Management for Electric Utilities: Big Data and Future', in *Asset Intelligence through Integration and Interoperability and Contemporary Vibration Engineering Technologies*, pp. 311–322.

Neuhofer, B., Buhalis, D. and Ladkin, A. (2015) 'Smart technologies for personalized experiences : a case study in the hospitality domain', *Electron Markets*, 25(3), pp. 243–254. doi: 10.1007/s12525-015-0182-1.

OECD Affordable Housing Database (2017) *OECD Affordable Housing Database (2016-2017) - Public policies towards affordable housing (PH): 'Social rental housing' and 'Affordable housing programmes', Public policies towards affordable housing*. Available at: http://www.oecd.org/social/affordable-housing-database.htm (Accessed: 1 September 2018).

Parlikad, A. *et al.* (2014) 'Measuring the performance of asset management systems', *Asset Management Conference 2014*, (October), p. 3.04 (6 .)-3.04 (6 .). doi: 10.1049/cp.2014.1046.

Parlikad, A. K. *et al.* (2013) *Engineering asset management: Issues and challenges*. Available at: https://www.researchgate.net/publication/260059412_ENGINEERING_ASSET_MANAGEMENT_ISSUES_AND_CHALLENGES.

Parlikad, A. K. *et al.* (2017) *Intelligent Assets for Tomorrow ' s Infrastructure : Guiding Principles*. doi: 10.13140/RG.2.2.16125.26085.

Peppercorn, I. and Taffin, C. (2009) 'Social housing in the USA and France: Lessons from convergences and divergences', *Urban Planning International*, 3, pp. 25–30.

Pietrabissa, A. *et al.* (2013) 'Optimal planning of sensor networks for asset tracking in hospital environments', *Decision Support Systems*. Elsevier B.V., 55(1), pp. 304–313. doi: 10.1016/j.dss.2013.01.031.

Plant, C. and Veletanlic, E. (2017) *Physical Technologies Challenges in Obtaining Government Support for Commercialization*. Available at: https://www.impactcentre.ca/research/physical-technologies/.

Re Cecconi, F. *et al.* (2016) 'Asset management in a BIM environment', in *16th*

International Conference on Computing in Civil and Building Engineering, pp. 750–757.

Rochard, U., Shanthirablan, S. and Brejon, C. (2015) *Bâtiments résidentiels: Typologie du parc existant et solutions exemplaires pour la rénovation énergétique en France*.

Scanlon, A. and Whitehead, C. (2011) *French Social housing in an international context*. doi: http://dx.doi.org/10.1787/5kgcd9s0q8f8-en.

Schaefer, J. (2003) 'Financing Social Housing in France', *Housing Finance International*, 17(6), pp. 27–34.

Schaefer, J.-P. (2008) 'Social rental housing and housing markets in France', in *Social Housing in Europe II: A review of policies and outcomeson*, pp. 95–104. doi: 10.1080/14616710903357268.

Shah, A., Tan, T. and Kumar, A. (2004) 'Building Infrastructure Asset Management : Australian Practices', in *CIB World Building Congress 2004, May 2-7, 2004, Toronto, Canada*, pp. 1–8.

Shahrour, I. and Jnat, K. (2017) 'Smart Technology for a comprehensive approach of comfort in social housing', in *2017 Sensors Networks Smart and Emerging Technologies (SENSET)*, p. 4. doi: 10.1109/SENSET.2017.8125059.

Sinnott, D. and Dyer, M. (2012) *Energy Monitoring Programme for Social Housing in Ireland : Pre- and Post- Retrofitting*.

Srinivasan, R. and Parlikad, A. K. (2017) 'An approach to value-based infrastructure asset management', *Infrastructure Asset Management*, 4(3), pp. 87–95.

Volk, R., Stengel, J. and Schultmann, F. (2014) 'Building Information Modeling (BIM) for existing buildings - Literature review and future needs', *Automation in Construction*. Elsevier B.V., 38, pp. 109–127. doi: 10.1016/j.autcon.2013.10.023.

Wang, N. *et al.* (2014) 'Implementation of Asset Management System Based on Wireless Sensor Technology', *Sensors & Transducers*, 164(2), pp. 136–144.

Willson, G. H. (2013) 'The Right Technology for Asset Management Programs', in *Pipelines 2013*, pp. 84–89. doi: https://doi.org/10.1061/9780784413012.007.